NATURAL ENVIRONMENT RESEARCH COUNCIL

PEATLAND FORESTRY

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A REVIEW OF AFFORESTATION ON PEAT IN GREAT BRITAIN

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This review is intended as an introduction to the specialised Forestry Commission papers to be presented later in the symposium.

Location, Extent and Characteristics of British Peatlands

Throughout this paper the term peat is used to mean acid peat of sufficient depth to isolate the tree crop from the underlying mineral material despite modern drainage and ploughing treatments. This generally implies peat of 2 ft or more in depth.

In Britain, the occurrence of peats of this depth - mainly in the north and west of Scotland - is clearly connected with rainfall, temperature, geology and terrain. Zehetmayr (1954) has used rainfall broadly to distinguish areas where deep peats develop extensively from those where development is more dependent on local impeded drainage. He has noted that extensive peats occur under rainfalls over 30 ins. in north Scotland and over 40 ins. in south Scotland and northern England where average temperatures are higher.

The most extensive peat areas are on the older acid rocks, especially those north of the Highland boundary fault, which are usually poor in plant nutrients and generally slow to weather. Where rainfall and geology are conducive to peat development the effect of terrain, though less distinct than elsewhere, affects the proportion of deep to shallow peat and the size of individual deep peat areas. In the extreme north and east and in parts of south Scotland extensive deep peats are common, whereas in west Scotland and Wales deep peat areas tend to be smaller and more intermixed with shallow peats and mineral soils.

In afforestation the north, west and south Scottish Conservancies already have extensive, recent plantings on peat and these Conservancies, especially north Scotland, contain the bulk of potential plantable peat areas. The total extent of peatlands in Britain is not known but has been estimated by Lines and Neustein (1966) as exceeding 5 million acres. The Scottish Peat Committee (Appleton 1962) considered that of 1.7 million acres of peat deeper than 2 ft in Scotland about 1 million acres were capable of being improved and used for agriculture or afforestation. The potential for afforestation is therefore great and the existing commitment substantial, and this Symposium is particularly opportune in view of the 50,000 acre planting programme now planned for the Scottish Conservancies where deep peats are most extensive.

No satisfactory or complete classification of peats fo forestry has yet been devised. Fraser (1933) whose classification is often quoted has isolated the commoner peats by structure and vegetation in his three major classes -

1. *Trichophorum* dominated areas with pseudo-fibrous peats - characteristic of the west Highlands.

2. *Calluna/Eriophorum* dominated fibrous peats - characteristic of north and central Scotland.

3. *Molinia* dominated amorphous peats occurring most extensively in the Borders.

These have long formed a valuable broad framework but there are innumerable intermediates with varying proportions and vigour of the characteristic and associated species. Classification is further complicated by the rapid and extensive changes in surface vegetation caused by interference especially by burning. But if no generally acceptable standard classification has been evolved there has been a recognised scale from the unplantable peats at one end to the relatively fertile peats at the other; the presence and proportion of individual species in the surface vegetation being the main means of placing a particular site on the scale. *Trichophorum* and *Sphagna* dominate at the unplantable end with *Eriophorum* and *Molinia* and finally *Juncus* increasing towards the more fertile acid peats. The span of *Calluna* across this scale is great and its vigour is a better indicator than its mere presence. *Erica tetralix* has been more an indicator of water-logged conditions than a guide to fertility. This vegetational range is roughly parallelled by that from raised bog to richly flushed blanket or basin peat. Though estimates of fertility based on surface vegetation have been the central feature in assessing plantability, exposure and the difficulty of drainage and ploughing have also been important local criteria.

AFFORESTATION TECHNIQUES

Physical Treatment

The development of hand turfing and plough turfing has been completely reviewed by Zehetmayr (1954) and a review of developments since that time is the main concern of a later paper in this Symposium by Neustein and Rowan.

In outline the hand turfing method used by Stirling Maxwell at Corrour and based originally on Belgian practice is generally accepted as the origin of turf planting in Britain. Since that time the general developments which can clearly be traced are:-

(1) The combining of hand turfing and draining to provide local drainage at the planting spot with general drainage of the site.

(2) The adoption of ploughing and the development of two allied but distinct operations of turf ploughing and deeper ploughing to provide cross-drains. This is the common practice today.

In turf ploughing a single mould-board Cuthbertson has always had a prominent place but double mould-board ploughing gained ground until very recently - encouraged because of its lower cost. There are now doubts about the efficacy of the shallow turf from double mould-board ploughing both from experiments and in the field. The early performance of crops on single mould-board ploughing is often better and work by Binns (1962) suggests that faster early growth is correlated with the better nitrogen mineralisation under the larger turf from single mould-board ploughing. Thus although both single and double mould-board ploughs are in common use at present, the single mould-board plough is likely to be increasingly favoured.

In addition to drainage and the release of nitrogen the covering of ground vegetation and the delay of its regrowth close to the tree have been factors of importance and are especially so now, when it is desired to use Sitka spruce as widely as possible. The rapid regrowth of dense heather after drainage on the acid deep peats remains an important problem under the present techniques of ploughing and draining. The use of nurse species or herbicides to control it are expensive and not always effective in practice. The present profiles of ploughed deep drains leave something to be desired. They are steep sided and subject to shrinkage especially on the deeper, wetter peats which are plastic below the surface skin. Rapid loss in drain depth and capacity is a common feature of present deep cross-draining.

Because of these problems research attention is turning towards treatments of the rigg and furr kind in which wider, shallower, and more stable drains would be excavated by rotary plough and the ground between drains completely covered by a mound of peat clods sufficiently deep to smother ground vegetation. The same machine would be used again after establishment to increase drain size and throw more clods of peat onto the planted mound. In theory such a treatment should maximise the amount of aerated and rootable peat, nitrogen release, and vegetation suppression and would have the advantage of stable drains and low maintenance cost. It is also possible that crop stability would be improved.

The problem of stability on deep peats has not yet become important, as most crops are too young. Basin peats tend to be sheltered, but there are extensive deep blanket peats already planted where wind velocities will be high. However Frazer and Gardiner (1967) in their studies of the rooting and stability of Sitka spruce have shown that deep peats are substantially more stable sites than peaty and surface water gleys. Their findings put deep peats in an intermediate position between peaty gleys and brown earths in regard to the stability of Sitka spruce and show a tree height of 60 ft against the critical wind velocity of 40 knots. There is some hope, therefore, that windthrow will not be a crippling feature of forestry on deep peat although there is bound to be a future feed-back from windthrow to drainage and turfing at planting.

Nutrition

The development of the use of fertilizers on tree crops on peat up to 1954 has been clearly set out by Zehetmayr (1954). As in the case of turfing, the value of phosphate was originally appreciated by Stirling Maxwell and later confirmed by Forestry Commission experiments, especially those laid down by M. L. Anderson in the 1920's. Early experimental work tested other major nutrients but yielded little of immediate application to general practice and the use of potassium, which we now know to be necessary on the infertile peats, is a relatively recent development.

The nutrition of crops on deep peat is to be dealt with by specialised papers later in the Symposium but certain main trends are worth mentioning to provide a broad background. Until the late 1950's the most infertile peats, i.e. those towards the Trichophorum/Sphagnum end of the scale, were generally avoided in afforestation. Since that time, however, planting has been carried on to the poor peats on a substantial scale and, as mentioned earlier, this process is accelerating. At the same time the growth of earlier crops on peat has revealed that phosphate deficiency is more widespread than originally thought. The general use of phosphate has therefore been increasing sharply during the last three years and will continue to increase as will the use of potash. These increases are well illustrated by J. Atterson (1967) in a recent paper and are tabulated below.

TABLE I

Fertilizer Usage in Forestry Commission Forests in Scotland
(figures rounded off)
tons/annum

Fertilizer		Actual		Estimate
	1960	1963	1966	1969
Phosphate rock	650	1000	1500	3500
Phosphate + potash (20:20)	0	120	450	600

The original spot application of phosphate by hand is being replaced by broadcast application by machine - usually adapted agricultural lime-spreaders or specialised spreaders like the Metsa-Visca or Vicon. Application by helicopter or fixed wing aircraft is generally preferred when established crops are involved.

So far the main aim of nutrition on deep peat has been to obtain a reasonable or satisfactory crop but the possibilities of enhanced yield from crops already growing at an acceptable rate will become more important in future and it is also likely that specialised nutrition will be developed for crops on peat where exposure is critical.

Species

Over fifty species have been tried in experiments on peat in the course of research by the Forestry Commission. Most of them have proved unsuccessful, but in addition to Lodgepole pine and Sitka spruce, Scots pine, Mountain pine, Japanese and Hybrid larches, Omorika and Norway spruces and Western Hemlock have managed to establish themselves to some degree. The steady progress of afforestation onto the poorer peat sites is, however, rapidly limiting the choice. On the Juncus peats at the fertile end of the scale Norway spruce is still used because of frost or to avoid near complete monoculture of Sitka spruce, but Scots pine and larches are not now favoured. On deeper peats, Scots pine has been discarded and replaced by Lodgepole pine or Sitka spruce. Western hemlock, though often successful in establishing itself on poor deep peat, has usually been slow and malformed in subsequent growth. The rapidly narrowing choice as the less fertile peats are considered leaves only Sitka spruce and Lodgepole pine for use on peats of intermediate fertility, like the Eriophorum peats, and on still more infertile peat Lodgepole pine is at present considered the only possibility. The general trend in the Scottish Conservancies in the use of Lodgepole pine and Sitka spruce as afforestation has extended on to the poor peats is revealed in the following table.

TABLE II

Scottish Conservancies - Use of SS and LP for Planting
(Sitka spruce and Lodgepole pine as a percentage of all plants used for planing)

	SS	LP
FY 50	40%	3%
FY 60	34%	21%
FY 68	55%	28%

There is no standard practice or sharp margin in distinguishing sites for Lodgepole pine from those for Sitka spruce on the infertile peats. The abundance of Molinia is sometimes used as a guide, a marked frequency of Molinia being taken as indicating where Sitka spruce can be used. Frequent Calluna argues against Sitka, not so much on fertility grounds as on the certainty of subsequent check. Mixtures of Lodgepole pine and Sitka spruce are used as a means of increasing potential yield while insuring against failure of the Sitka, and as a means of suppressing Calluna without too long a delay. There is no reliable long term evidence but there are indications that Sitka spruce could successfully be grown on peats at the Trichophorum/Sphagnum end of the fertility scale if repeated nitrogen were to be applied in addition to phosphate and potash. Theoretical economic comparisons by Neustein (1967) equate Lodgepole pine, without nitrogen, of Yield Class 100 with Sitka spruce, with repeated nitrogen throughout its rotation, of Yield Class 160. If fewer nitrogen applications for Sitka spruce sufficed, a lower Yield Class would also suffice to recoup the additional cost of nitrogen application.

This problem is appropriate to the specialist paper on the economics of peat afforestation which follows later in this Symposium but it is worth mention here because of its importance now that planting is reaching the infertile peats.

The provenance of Lodgepole pine has greatly affected its performance on the deep peats - in Eire as well as in Britain. South Coastal provenances have generally grown rapidly, maintaining their performance well into exposure, but they have proved liable to sway. Some Alaskan provenances, though slower, are generally straighter and in north Scotland Conservancy, where the selection of Lodgepole pine provenance is particularly important, the Conservancy officers now often prefer Alaskan origins.

Planting

The type of planting stock for use on deep peat is decided more by the probability of weed growth and by exposure than by fertility, although this usually leads automatically to the use of smaller stock on the less fertile peats. 1 + 1 Lodgepole pine and 1 + 1, 1 + 2 or 2 + 1 Sitka spruce transplants are the most common. The use of small stock in exposed areas is generally accepted as right so as to avoid wind loosening after planting.

Planting methods are reviewed in the paper by Neustein and Rowan later in the Symposium and need not be covered here, but spacings have recently been coming under review as afforestation has extended onto the less productive peats. Until recently spacings of 5' to 6' in both directions were generally used, but the need to reduce afforestation costs where future timber production will be limited, and the economic advantages of delaying thinning and roading are leading to less intensive planting and towards 'extensive forestry', a term which will be used more than once at this Symposium.

ROADS, HARVESTING AND REGENERATION

Roads

The problems of roading deep peats lie in the future rather than now, but there have been some developments from the roads already constructed over peat. Earlier methods involved removing the peat to found roads on the mineral substrate, but the method is impractical on the deeper peats which will require roading in the future. More recent techniques rely upon imported mineral formations laid on top of the peat between side drains, with material from roadline fellings laid beneath the formation. Though these techniques are successful they are still expensive and roading is a main consideration in the economics of afforestation on infertile, deep and waterlogged peats.

Harvesting and Regeneration

The newness of plantations on the deeper and more infertile peats has already been mentioned, and harvesting and regeneration methods have yet to be developed for use in these crops.

RESEARCH

Many of the speakers at this Symposium will explain current and planned research in peat afforestation, not only in Britain but in Ireland. Some general points are worth noting here.

First, the increasing and extending interest in peat afforestation. Research in this field is now much more international than it was. This progress will continue as afforestation of peat, especially in Canada, forms more of the whole afforestation effort.

Secondly, as an introduction to later papers - the main lines of silvicultural research, in hand and planned at the present time in Britain, are, very briefly, as follows:-

Physical Treatments

The comparison of different depths and intensities of drainage and turf ploughing in replicated field experiments. (One of these experiments will be seen during the Symposium excursion to Flanders Moss).

The testing of a system of shallow drains, with intervening undrained strips covered with broken peat, as a method of accelerating nitrogen release, suppressing vegetation and delaying regrowth, and reducing drain maintenance costs. (The main objective is to enable Sitka spruce to be used in place of Lodgepole pine on infertile and waterlogged peats, and on deep peats where drainage will invigorate Calluna.) Trial of different methods of planting to reduce windsway in Lodgepole pine.

Species

Trials of possible alternative species to Sitka spruce, making use of nutrition to establish them.
Investigations into the value of nurse species.
Provenance trials of Lodgepole pine and Sitka spruce.
Trials of species and techniques, including extra nutrition, on deep peats in exposed conditions.

Planting Stock

Experiments with seedlings of Lodgepole pine and Sitka spruce grown in containers and in greenhouses, with the objects of lowering afforestation costs by lengthening the planting season, shortening the time required for plant production and facilitating mechanised production and planting of Lodgepole pine and Sitka spruce.

Nutrition

An extensive programme including the testing of different forms, combinations and regimes of N, P and K, Ca, and other fertilizers. Response being measured by foliage analysis, as well as by growth response of the tree crop.

Under this head also, in conjunction with the Macaulay Institute for Soil Research, an investigation of the nutritional status of deep peats previously classified by their vegetation and drainage characteristics, and further studies on the mineralisation of Nitrogen.

This list is by no means exhaustive but outlines some of the main lines of the Forestry Commission's silvicultural research at the present time.

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A REVIEW OF PEATLAND AFFORESTATION IN THE REPUBLIC OF IRELAND

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The first attempt to outline cartographically the distribution of the main bog types in Ireland was made by Barry in 1954. For this classification he recognised two main types (1) Raised bog, (2) Blanket bog with its sub-type high-level blanket bog. The raised bog type he shows concentrated in the central plain within the triangle Boyle (Co. Roscommon) to Cahir (Co. Tipperary) to a point 10 miles east of Drogheda (Co. Louth). The blanket bog he shows concentrated on the west coast, west of a line Letterkenny (Co. Donegal) to Boyle (Co. Roscommon), to Galway City to Kinsale (Co. Cork). The high level blanket bog occurs on high ground everywhere, generally at elevations over 1,000 ft and so it has never seriously been considered for afforestation.

RAISED BOG

Little attempt has been made to afforest virgin raised bog and what little was attempted was not very successful. However, peat was a traditional domestic fuel and in time large areas of cutaway appeared on the fringes of the bog and this cutaway was a different proposition to the virgin bog as a site for planting. Here a considerable depth of peat had been removed and the medium in which the trees were planted was the upper fibrous sphagnum layer, which had been disturbed and aerated and which had been thrown down on the rich fen peats near the bottom of the bog.

Drainage

Drainage of these disturbed cutaway areas is usually not difficult provided an adequate outfall is available, but as these bogs had their origin in a lake or waterfilled depression it is frequently necessary to do considerable excavation outside the bog itself to provide such adequate outfall. In many cases Bord na Mona, the organisation responsible for the commercial development of peat bogs for fuel, has had to provide suitable main outlets for its own operations on the high bog and these also serve the cutaway.

Sometimes the old methods of hand cutting of peat allowed the cutter to go below the level of the water-table by leaving walls of impervious peat much like a box within which he worked. These boxes were then filled with the young sphagnum from the top of the adjoining high bog, thrown off in preparation for the next cutting. This left a series of water filled boxes just below the new surface and these make it difficult to secure an adequate and uniform lowering of the water-table.

After acquisition drainage outlets were checked and deepened where necessary to provide sufficient fall and then existing drains and watercourses were cleaned and repaired. If the area was very wet and soft the single mouldboard Cuthbertson plough was used to open a network of drains to supplement the existing system, but this was seldom necessary. Ploughing for planting and surface drainage was done with the Cutherbertson double mouldboard plough at 10 ft intervals between drains. However, it was often found necessary to deepen a proportion of these mound drains some years after planting and as this had then to be done by hand it was an expensive operation. Now the practice is to introduce the single mouldboard plough into the preparation for planting, using this plough to produce every second, third or fourth drain according to the intensity of deep drains required. The generally accepted proportions are two drains with the double mouldboard plough to one drain with the single. It is expected that this amount of drainage will be sufficient to establish the crop after which the crop will achieve its own drainage.

For the early plantings fertility of the cutaway was generally at a level at which the crops could grow at an acceptable rate, but now in common with all peat plantings it has become standard practice to add 2 or 3 ozs of Ground Mineral Phosphate to each plant at planting. At first this was generally accepted as sufficient for the rotation and the possible benefit of a heavier initial dosage or of a second fertilizing is only now being seriously considered.

On some sites particularly those which, prior to the extensive arterial drainage of the Barrow basin, were subject to flooding and to deposits of limestone alluvium, the addition of phosphorus only is not giving the expected responses and the future development of these crops is causing some concern. In the Monvane area of Emo Forest, Co. Leix, where on 1 to 3 ft of a well humified phragmites peat overlying calcareous sand and gravel and with a past history of agricultural usage, Norway spruce (Picea abies) and Scots pine (Pinus sylvestris) had gone into check, O'Carroll diagnosed potash deficiency having first tested and ruled out the question of drainage. What the fertilizer requirements of these areas will be is now under investigation.

Frost

Perhaps the greatest hazard to afforesting midland cutaway raised bog areas is frost. Late spring frosts are common in the midlands and as the cutaway areas are at a lower level than the surrounding lands they hold the cold as frost hollows. Dry peat has a low thermal capacity, lower than either dry sand or clay, but when they are saturated the positions are reversed and the wet peat has the greater thermal capacity. A dry peat surface is thus quickest to warm up by day and cool down by night, a feature of great importance when the risks of late spring frosts are being considered (Connaughton 1969). This occurrence of frost limits the choice of species on these areas.

Species

Scots pine (P. sylvestris) is the traditional species for use on the cutaway raised bog and it has been so closely identified with it that it is often referred to locally as "Bog deal". When the influence of economics came to be felt the Scots pine, as a low yielder, found a rival in the spruce and becuase of the frost danger Norway spruce (Picea abies) was used. So as not to have all his eggs in one basket the forester usually chose a mixture of these two species but there was no set pattern to the proportions of each used. Norway spruce was planted pure only where success seemed assured and the proportion of Scots pine introduced with it on other sites often reflected the amount of Calluna present until on Calluna dominant sites Scots pine was planted pure. Today the main choice is still Scots pine and Norway spruce pure or in mixture, but now the mixtures assume firm proportions of 25-75, 50-50 or 75-25, and there is a tendency to line rather than intimate mixtures.

In recent years there is a trend to replace the Norway spruce with Sitka spruce (Picea sitchensis), as it is felt that Sitka with its great powers of recovery and its high yield can withstand a considerable check in its early years and still have at least as good and probably a better yield than the Norway spruce.

Contorta pine (Pinus contorta) is also finding a place on the midland bogs but it is confined to the poorest areas of cutaway and to those sections of uncut or virgin bog which were included in the acquisition of the block and which are planted with Contorta rather than left as bare areas within the property. It is unlikely to leave these sites but it is also unlikely to find a rival on them. The success of the Contorta pine on deep blanket bogs has led to a trend of extending planting inwards from the cutaway on to the virgin bog.

Japanese larch (Larix leptolepis) has a limited place on these bogs. It is usually found on the outer fringe where the peat is shallow and the tree roots can reach the mineral soil. It would seem to be considered more for its protective value against fire and its power of suppressing ground vegetation than for its production of timber.

Other species also have been tried, though in limited amounts, some in normal management planting and some in trial areas. From these small plantations we can get an idea of the productivity of various species on the cutaway raised bog areas.

Productivity

At Killyon in north Co. Kildare small stands of Norway spruce, Sitka spruce and Japanese larch were planted 43 years ago on cutaway where about 5 ft of peat still remained and it is most unlikely that these small stands had the advantage of any fertilizer application such as is standard practice today. The thinning history of these plots is not known so no estimates of total volume production are possible. Three Norway spruce stands were sampled, all aged 43 years.

	Plot 1	Plot 11	Plot 111
Age	43 years	43	43
Number of stands per acre	270	360	330
Mean B.H.Q.G.	6¾ ins.	7¾ ins.	8¼ ins.
Top height	48 ft	63 ft	63 ft
Volume per acre	1756 H. ft.^{3}	4212 H.ft.^{3}	4223
Basal area per acre	86 H.ft.^{2}	151 H.ft.^{2}	155
Yield class	100	160	160

Yield class was estimated on the age/top height graph of the B.F.C. Management Tables. Plot 1 is at present understocked and judging by the number of stems per acre and the mean B.H.Q.G. this has been due to an abnormally heavy thinning late in life. A comparison of basal area and volume per acre with the management tables would not in the circumstances be valid.

Plots 11 and 111 which on an age/height basis would fall into yield class 160 are fully stocked and do seem to have followed more closely the thinning prescriptions of the tables. Mean B.H.Q.G. Volume and Basal area per acre are all in excess of the tables but this is a pattern which has been noted as of regular occurrence between both Norway and Sitka spruces as grown in Ireland and B.P.C. Tables and is at present being investigated.

Figures for the Sitka spruce stand are

Age	39 years
Number of stems per acre	370
Mean B.H.Q.G.	7 inches
Top height	58 ft
Volume per acre	3408 H. ft.^{3}
Basal area per acre	126 H.ft.^{2}
Yield class	140

Again we find that while age/top height and number of stems per acre are in general agreement with the Management tables Mean B.H.Q.G. Volume and Basal Area per acre are in excess of the tables.

Japanese larch figures are:

Age	42 years
Number of stems per acre	180
Mean B.H.Q.G.	8 ins.
Top height	66 ft
Volume per acre	2592 H.ft.^{3}
Basal area per acre	80 H.ft.^{2}
Yield class	120

These figures show a reasonable correspondence with the management tables.

Scots pine is a low yielder; the management tables show 160 as the top yield class on national average. Figures from two Scots pine plots on cutaway bog, one at Emo Forest and the other at Tullamore forest, are:

	Emo Forest	Tullamore Forest
Species	S.P.	S.P.
Age	20 years	20 years
Number stems/acre	2260	1810
Mean B.H.Q.G.	3¼ ins.	3½ ins.
Top height	30 ft	33 ft
Volume/acre	980 H.ft^3	1250 H.ft^3
Basal area/acre	106 H.ft.^{2}	117 H.ft.^{2}
Yield class	120	140

The unusually large number of stems per acre is due to a management directive that no thinning was to be undertaken in Scots pine before its 30th years. The figures for number of stems per acre include, for the Emo plot, 840 trees of girth 8 inches and under, and for the Tullamore plot 480 trees of girth 8 inches and under and these trees have been excluded in estimating B.H.Q.G. Volume and Basal area.

Future of Raised Bog

The hand winning of peat for domestic fuel is dying out and cannot be expected to provide any substantial areas of cutaway in the future. Instead it is from the large scale operations of Bord na Mona that we may expect most of our areas. Bord na Mona operates two systems of cutting (1) sod peat and (2) milled peat.

Sod Peat Cutaway

The sod peat method operates essentially in a manner similar to hand cutting and produces the same type of cutaway. The upper layers are disturbed and deposited on the lower peats while the intervening layers are removed for fuel. In 1955 the Forestry Division acquired part of a cutaway trench, Trench 14 in Co. Offaly, and planted a number of species with and without phosphate. It quickly became evident that the addition of phosphate was essential for satisfactory growth particularly where the remaining peat was of any considerable depth. While the fertilized plots are unreplicated they do give a useful guide to the potential of the species used. It must be remembered however that the plots are only 13 years old now and estimates of yield class must be accepted with reserve.

Norway spruce is the most promising species but only where it was planted in intimate mixture with Japanese larch. As the ground vegetation tended to a dominance of Calluna throughout the trench no doubt the Norway spruce benefited from the vigour of the Japanese larch in suppressing the heather. The Norway spruce after 13 years has a top height of 23 ft which would correspond to a yield class of 220.

Sitka spruce also in intimate mixture with Japanese larch shows promise. It is now standing at a top height of 21 ft after 13 years which would correspond to a yield class of 200.

However neither the Norway nor Sitka spruces when planted pure in Trench 14 show the same promise. Both were on areas where relatively deep peat remained (up to 10 ft) and where a vigorous growth of Calluna had established itself after planting. Chemical control of the heather did give a significant increase in height growth for both species.

Japanese larch which was used only in the mixtures with Norway spruce and Sitka spruce showed the same height growth as those species, but as it is a low yielder this growth would correspond only to a yield class of 100. However its benefits to the high yielding spruces when used in mixtures will probably justify a place for it on cutaway peats.

Other species used in the trial and which show promise are:-

Monterey pine (Pinus radiata) has a top height of 25 ft after 13 years which indicates a yield class approaching 200. However this is a most irregular and uneven crop and it has a history of expensive beating up.

Contorta pine (Pinus contorta). It was unfortunate that the provenance used was that now recognised as Lulu Island and one which in present day thinking would not be used at all. Nevertheless a top height of 17 ft in 13 years suggests a yield class of around 100. One of the characteristics of the Lulu Island provenance is its inability to control and suppress the heather and this weakness is apparent in

Trench 14. In the same situation one could expect the coastal provenance to have suppressed the ground vegetation and to be showing promise of a higher yield class.

Hybrid larch (Larix eurolepis) which was planted pure showed slightly better growth than the Japanese larch, but was still in a low yield class and it is unlikely to be considered except as a sylvicultural mixture.

Thuja plicata shows considerable promise and has reached a top height of 18 ft in 13 years. On this showing which corresponds to a yield class of 180 it would have to get serious consideration as a possible species for the cutaway.

Tsuga heterophylla at a yield class of 160 is also a species which cannot be ignored.

Abies grandis and Abies nobilis. These two Silver firs were planted in the southern end of Trench 14, and both have shown promise. The A. grandis indicates a possible yield class of 220 and the A. nobilis a yield class of 160. However one of the main outlets for drainage of the bog adjoins these two plots and in excavating this outlet some mineral spoil was spread over the plots. How this may have affected growth is not known but nevertheless on their showing these two Silver firs cannot lightly be dismissed from consideration.

Roads

Midland cutaway bogs all have some road system developed and used in the cutting and extraction of the peat fuel and some have quite good systems with sound metalled roads. These latter were developed by Local Authorities to provide emergency fuel during the war. With some improvement these systems suffice for the establishment of the crops and no further road development is contemplated until thinning is due.

Cleaning

It is now the accepted practiceto carry out cleaning operations using chemicals and hand cleaning is used only on a limited scale. The usual method is spot cleaning around the plant using the Arbogard.

Costs

The costs of individual operations vary over a very wide range from site to site but by and large an average figure for the costs of planting one acre could be estimated at £59 based on the following average figures.

Ploughing and Drainage	12.10. 0.	Includes double and single mouldboard ploughs and such manual work as

		required but not work on outfalls exterior to the property.
Planting	16.15. 0.	Includes cost of plants and cost of beating up.
Fertilizing	2.15. 0.	Includes cost of fertilizer.
Cleaning	7. 0. 0.	Until crop is established.
Fencing	10. 0. 0.	Stock fencing of an average sized unit.
Roads	10. 0. 0.	Those necessary for establishment only.
	£59. 0. 0.	

Milled Peat Cutaway

The milled peat method removes a thin layer of peat dust from the entire surface area of the bog and so reduces the peat depth 1 to 1½ inches at a time. At the end will remain the lower bog layers undisturbed and with no covering of the upper sphagnum. No milled peat area is yet available for trials.

BLANKET BOG

Blanket Bog as the name implies ocvers wide areas uniformly the top-surface following in general the contours of the bog-floor. It develops in areas of high rainfall, high humidity and low temperatures. Its average depth is about 8 ft but in hollows considerably greater depths can be built up. The peat is usually well humified. Barry in his distribution of bog types gives the main concentrations of blanket bog as being west of a line from Letterkenny (Co. Donegal) to Boyle (Co. Roscommon) to Galway City to Kinsale (Co. Cork).

He also asserts that the 40 ins. (1,000 mm) isohet is rather decisive, marking a convenient boundary between the region of raised bog (below 40 ins. rainfall) and the region of blanket bog (above 40 ins. rainfall).

Drainage

Moisture content in blanket bogs as might be expected is very high being of the order of 93%-96% and the surfaces often carry a complex of pools and small lakes (Barry 1954). To the forester this presented a drainage problem which was insurmountable until the advent of specially designed ploughs and crawler tractors. In 1951 the Forestry Division purchased 22 such tractor-plough units and began the large scale planting of blanket bogs in the Republic.

In the early years the emphasis was on drainage and heavy expenditure was incurred in deepening the plough drains some years after planting. The first indications were that this expense would be justified as the plants assumed a healthier and deeper colour and there was a growth response, but in a few years this colour-change was no longer noticeable and the increased growth rate was not maintained (de Gruneil,1956). After several years the heavily drained areas showed no advantage in growth over normal ploughed areas. From observation it was argued that the responses had been due not to drainage, but to the mulching effect of the spoil from the drains. Work at the Agricultural Institute at Glenamoy, Co. Mayo, and elsewhere showed that the lateral movement of water through the peat to an open drain system was extremely slow and that the influence of the drain did not extend beyond 6 ft on either side. It was also shown at Glenamoy that deepening of the drain beyond 36 inches was of no advantage and could cause a reduction in the effectiveness of the drains with less water leaving the peat (Burke 1967). Work by the Forestry Division showed no significant advantage in the use of the single mouldboard plough over the double mouldboard despite the increase in the number and depth of drains provided by the former. The present practice in the Forestry Division is to aim at a drainage system which will quickly remove precipitation and give local aeration to the tree roots in the early years by providing excavated material on which to plant. It will be left to the tree crop itself to dry out the main bulk of the peat. This has led to a system in which ground preparation is achieved by ploughing with the double mouldboard plough at 12 ft spacing between drains, ploughing being done up and down the slope, while drainage is achieved by using the single mouldboard plough to provide drains angled across the previous ploughing and linked with outfalls. The distance between these drains varies with the degree of slope and ranges from 100 yds on the steeper slopes to 50 yds or less on the flats. It is not expected that any extension to or intensification on this system will be required during the rotation.

Species

Contorta Pine and Sitka Spruce: Only two species Contorta pine and Sitka spruce have been in general use on western peats. When foresters first tackled this job, there were those who believed that pines should not be grown pure but in a mixture, there were others who argued that Contorta was a pioneer species to be used only to prepare the site for a more valuable species and was not itself expected to produce a crop, and there was the ever-pervading influence of the economist which fostered a continual striving to grow a "better" species. The result was that Sitka spruce was introduced in widely varying proportions but always in intimate mixture with the Contorta, the hope apparently being that at least some Sitka would appear in the final crop. It was known that the addition of phosphate was essential to growth and in an effort to even the rates of growth of the two species and to prevent the more vigorous and heavily branched Contorta from suppressing the Sitka the initial fertilizing regime allowed only 1 oz of phosphate per plant to the Contorta and 3 ozs to each Sitka (Mooney 1957). The Contorta grew well for the first few years after planting. Early published reports of plantings of P. contorta which had received 2 ozs of Basic Slag per plant at planting in Nephin Bog Forest give the average annual growths of the first three years as 4, 8 and 16 inches, and suggest that smaller phosphate applications would be safer and sufficient (McEvoy 1954). Three years later in 1957 foresters were still optimistic and it was even suggested that more restraint in height growth should definitely be the aim with P. contorta (Mooney 1957). However this early promise was not maintained and large areas began to go into check. An examination of the P. contorta showed that the type which was going into check differed in many respects from the first introductions of Contorta which had shown promise in the 1930s and from those which continued to give satisfaction on the western peats. The origin of this seed was given as Lulu Island and trees of this origin despite early promise were markedly inferior to the heavily branched dark green trees of south coastal regions. Roche (1961) describing the Contorta on Lulu Island says that early growth is rapid, but after about 10 yrs there is an obvious lack of vigour in the stands and in some instances they appear in check. This prompted the Forestry Division to examine more closely the question of the provenance of P. contorta to be used on western peats. Three provenances are now recognised in the Republic (i) the Coastal (south) provenance (ii) Lulu Island and (iii) Inland provenance, but only the coastal is recommended for planting. The main features for identification of the three provenances have been given by O'Driscoll but he emphasis that in any feature overlapping between the provenances can occur and that identification should be based on whole crop characteristics, not on individuals.

None of the Lulu Island or the Inland provenances of Contorta on western peats are sufficiently advanced for any reliable indication of their productivity. By contrast the Coastal provenance has in places closed canopy and contains a measurable volume of material. Three such plots are: (1) Compt. 8 Cloosh Valley (2) Compt. 66 Cloosh Valley and (3) Compt. 1, Doolough Forest.

The figures for these plots are:

P. contorta (Coastal)

	Compts. 8 Cloosh Valley	Compt. 66 Cloosh Valley	Compt. 1 Doolough
Age	15	15	17
No. stems/acre	1235	1640	1465
Top Height (ft.)	24	23	24
Mean B.H.Q.G. (in.)	$2\frac{3}{4}$	$2\frac{1}{2}$	$3\frac{1}{4}$
Volume/Acre (H.ft.^{3})	535	511	831
Basal area/acre (H.ft.^{2})	64	75	100
Site Index	55	55	43

No yield class graphs or management tables are available for Coastal Contorta but on these figures of top height/age the site index would be 55 for both Cloosh Valley plots and 43 for the Doolough plot (Joyce and Gallagher 1966). This in turn suggests that with coastal provenances it would not be unreasonable to expect yields in excess of 140 H.ft.^{3}/acre/ann. from Contorta on western peats.

Other species were tried either in replicated species trials or in small blocks through the normal planting. They are yet too young to give a worthwhile indication of productivity, but in some cases tentative deductions may be made.

Scots Pine, the traditional species of the midland cutaway bogs has shown no promise and may be discounted as a possible species for western blanket bog.

Corsican Pine (Pinus laricio), has fared no better than the Scots pine and may also be discounted.

Monterey Pine (Pinus radiata) on the other hand has shown an ability to grow on the peat but it is a bad transplanter giving a patchy and irregular crop. It cannot be considered seriously until the difficulty of economically successful transplanting has been solved.

Maritime Pine (Pinus pinaster). Another difficult transplanter, also gives evidence of its ability to grow at an acceptable rate if the problem of successful transplanting can be solved.

Thuja plicata has managed to survive but has little else to recommend it.

Tsuga heterophylla has also managed to survive. One small plot in Cloosh Valley Forest has shown quite good promise but the overall performance of the species is not encouraging.

Abies nobilis as is its habit has managed to stay healthy and happy looking without putting on much height growth. Survival rate is very good and this notoriously slow starter may yet produce a good crop, but the delay will put a large question mark after its economies .

Norway Spruce has shown no promise and may be counted among the rejects.

The Leyland cypress (Cupressocyparis leylandii) and The Bishop Pine (Pinus muricata) have both been planted but only within the last 3 years. They are both still alive.

Planting

A method of dibble planting has been developed on western peats which is simple, cheap and successful. The dibble is a wedge-shaped piece of wood, 4 inches wide by 6 inches long by 1½ inches at the top and it is fitted with a D-handle. It is used to make a slit in the planting ribbon 4 inches long and 6 inches deep into which the plant is inserted and firmed with the foot. It is claimed to reduce costs of planting to ⅔ that of orthodox methods. Slit planting, notch planting, and "stepping down" of the ribbon have all been used, but as none show a distinct advantage over the dibble and none can compete with its low costs they are rapidly losing favour to it.

Time of Planting

Some years ago the Forestry Division were perturbed at the amount of beating up required in newly planted areas. Investigation showed that the percentage failures was much higher in autumn and winter planting than in spring planting. Instructions were issued that so far as was practicable all planting was to be confined to the spring and that autumn and winter plantings were to be discontinued.

Fertilizing

Although the necessity for an application of phosphate to new planting was recognised from the beginning and the use of 1 or 2 ozs of Basic slag or G.M.P. was routine, it has only been within the past 4 or 5 years that the need of a repeat dose was seriously considered. In the meantime the early P. contorta plantings were struggling to survive on a dosage deliberately aimed at "restraining their growth rate". In 1963 it was decided to apply a general fertilizer to a large area of the first Glenamoy plantings. The fertilizer used was a mixture of 4 cwts of sulphate of ammonia, 2 cwts of G.M.P., 1 cwt Sulphate of potash and 10 lbs of copper at the rate of 7¾ cwts per acre. The results were so encouraging that the Division has embarked on a policy of manuring a substantial area of retarded crops each year as routine.

In the meantime the effort continues to discover the most effective and most economical fertilizing regime for western peats. Early indications are that of the major elements phosphorus is still by far the most important even though it was applied at the time of planting. Minor responses have been recorded from nitrogen and potash, but the economics of the application of these elements in relation to the increased growth are not encouraging. Calcium as ground limestone, in large quantities, 6 tons or more per acre, has a depressing effect on growth but at lower levels - less than 1½ tons per acre,it is tolerated and may even be beneficial.

Analyses of western peats at the Agricultural Institute's Station at Glenamoy had indicated deficiencies of copper and molybdenum for agricultural crops and it was decided to test these minor elements with forest crops. The first trial using copper and molybdenum together (10 lbs copper sulphate and 4 ozs of sodium molybdate per acre) gave a significant increase in height growth for both Sitka spruce and Contorta pine. Foliar analyses of the spruce suggested that the response was due to the copper, but further trials with copper have not always given a positive result.

Common to all peat planting is the ribbon on which the plant is placed and it has been noted that the roots exploit this ribbon and are very slow to spread to the surrounding peat. This gives a condition of instability to the crop which can be dangerous. The method of spot application of fertilizer to each plant confines the fertilizer to the ribbon and aggravates the position as there is no inducement to the plant roots to spread, in fact the contrary obtains. It is to be expected therefore that the old method of spot application of fertilizer will lose favour and the present trend is to apply the first dressing broadcast before ploughing. This also allows for the use of machinery in spreading and while some fertilizer will be lost in the subsequent ploughing and drainage it is felt that the saving in costs of application will more than compensate for the additional fertilizer required to offset the losses.

Later applications of fertilizer to established crops do raise considerable problems and the use of machinery will be limited and often impossible. Aerial application by fixed wing plane has been tried with success and the costs of application for large areas could on average be expected to show a reduction of up to 50% on manual methods.

Roads

So far as is practicable, road sites are surveyed before ploughing and marked by a deep plough drain on either side. Because of the slow development of the crop and the accumulation of compound interest only the minimum yardage required for establishment and maintenance is put in and all other roads are deferred until they are required for thinning.

Costs

Average costs for the establishment of one acre on western peats would be £56 based on figures as follows:

Ploughing and drainage	£15.10. 0.	Includes double and single mouldboard ploughs and such manual work as necessary.
Planting	15. 0. 0.	Includes costs of plants beating up.
Fertilizing	3.10. 0.	Includes costs of fertilizer.
Cleaning	1. 0. 0.	

Fencing	7.	0.	0.	Stock fencing of an average sized block.
Roads	14.	0.	0.	Minimum requirements for establishment.
	£56.	0.	0.	

EXTENT OF PEAT PLANTING

Since the last peat symposium in 1961 just on 40% of the Forestry Division's total planting has been on deep peats. Of this peat planting three fifths have been on blanket bog west of the line quoted by Barry, one fifth has been on raised bog cutaway within the triangle he specifies while the remaining fifth was on peats elsewhere throughout the country.

The annual figures, rounded to the nearest 100 acres of peat plantings are:

Year	Western	Midland	Other	Total
1962	4400	1300	2700	8400
1963	5300	1500	2100	8900
1964	6800	2200	2500	11500
1965	6000	2500	1800	10300
1966	5800	2100	3200	11100
1967	5600	2100	1700	9400
1968	4700	2100	1100	7900
Totals	38600	13800	15100	67500

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KEY TO IDENTIFICATION OF PINUS CONTORTA PROVENANCES

	BRANCHES		NEEDLES			CROWN	STEM	BARK	REPRODUCTION	
	Form	No. per Whorl *	Colour	Retention	Length				Male Flowering	Coning
Coastal	Heavy, flat to moderately ascending	5-8	Dark-green	3-4 years	Short adpressed to branches	Heavy, dense, excellent supression of vegetation	Nodal swelling. Tendency to basal sweep	Rough, platy, fissured	Very little up to 15 yrs. and then on lower half crown	Little coning up to 15 yrs.
Lulu	Light, ascending	4-6	Metallic greyish green	3-5 years	Short and stand out from branches	Not as dense as Coastal due to "Gapping" where male flowers developed	Light	Not as rough as coastal	Continuous male flowering giving "Gapping" between each year's needles all over tree	Profuse on trees of every age
Inland	Light and wavy, tending to be horizontal. Internodal	3-5	Light-green	1-2 years	Longer than above. Stand out from stem in an untidy arrangement	Very light. Poor Supression of vegetation.	Straight and very fine	Smooth with lenticels prominent on younger stem or upper parts of older trees	Occurs, but not noticeable as "Gapping"	Profuse retention of old cones on stem and branches obvious

* Refers to main branches

THE GROWTH OF TREES ON PEAT IN NORTHERN IRELAND

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INTRODUCTION

Of the 95,000 acres afforested in Northern Ireland since 1920, by far the greatest proportion - some 80,000 acres - has been planted since 1945. Although some peat had been included in the early acquisitions this was mostly small areas of cut-over bog or of shallow peat over boulder till. From the late forties on, an increasing proportion of the area acquired each year (which was itself increasing) was of peat-covered ground and this also included an increasing proportion of deep peat (over 30 centimetres) until the late fifties. By this time the pattern was very approximately 40 to 60 per cent of all acquisitions deep peat and 15 to 25 per cent shallow peat and it has remained like this since then. The deep peat was virtually all blanket bog (climatic peat) with very little fen peat or cut-over peat. Detailed soil maps have not been prepared although a survey of forest areas is just about to commence. However, a very rough guess would give the present distribution of planted forest on peat as in Table I:

TABLE I

Approximate area planted on peat

Year of Planting	Deep Peat (over 30 cm)	Shallow Peat (5 to 30 cm)
P.43 and earlier	450 (3%)	2,300 (17%)
P.44 - 48	400 (7%)	1,800 (35%)
P.49 - 53	1,750 (15%)	3,300 (30%)
P.54 - 58	2,550 (17%)	4,900 (35%)
P.59 - 63	9,850 (40%)	6,450 (25%)
P.64 - 68	12,500 (50%)	6,250 (25%)
Total	27,500	25,000

Peat is an extremely variable soil and so it is possible to find all rates of growth of trees on peat. There are many areas where trees planted some years ago have virtually stagnated since planting, equally there are areas where, admittedly on flushed or fen peat, Sitka spruce (Picea sitchensis Carr) has reached a dominant height of over 90 feet at 40 years of age. This paper will generally deal with the blanket bog peats which reduces the heterogeneous nature of the medium being considered, although, of course, flushed and eroded peats are included. As Sitka spruce is the major species planted on peat in Northern Ireland the remainder of this paper will be dealing with this species except where others are specifically mentioned. As ploughing equipment can easily go much deeper than 30 cm and turn up mineral soil from below the peat, many foresters consider this depth to be too shallow for classification purposes and in the remainder of this paper deep peat is considered as being peat more than 30 inches deep.

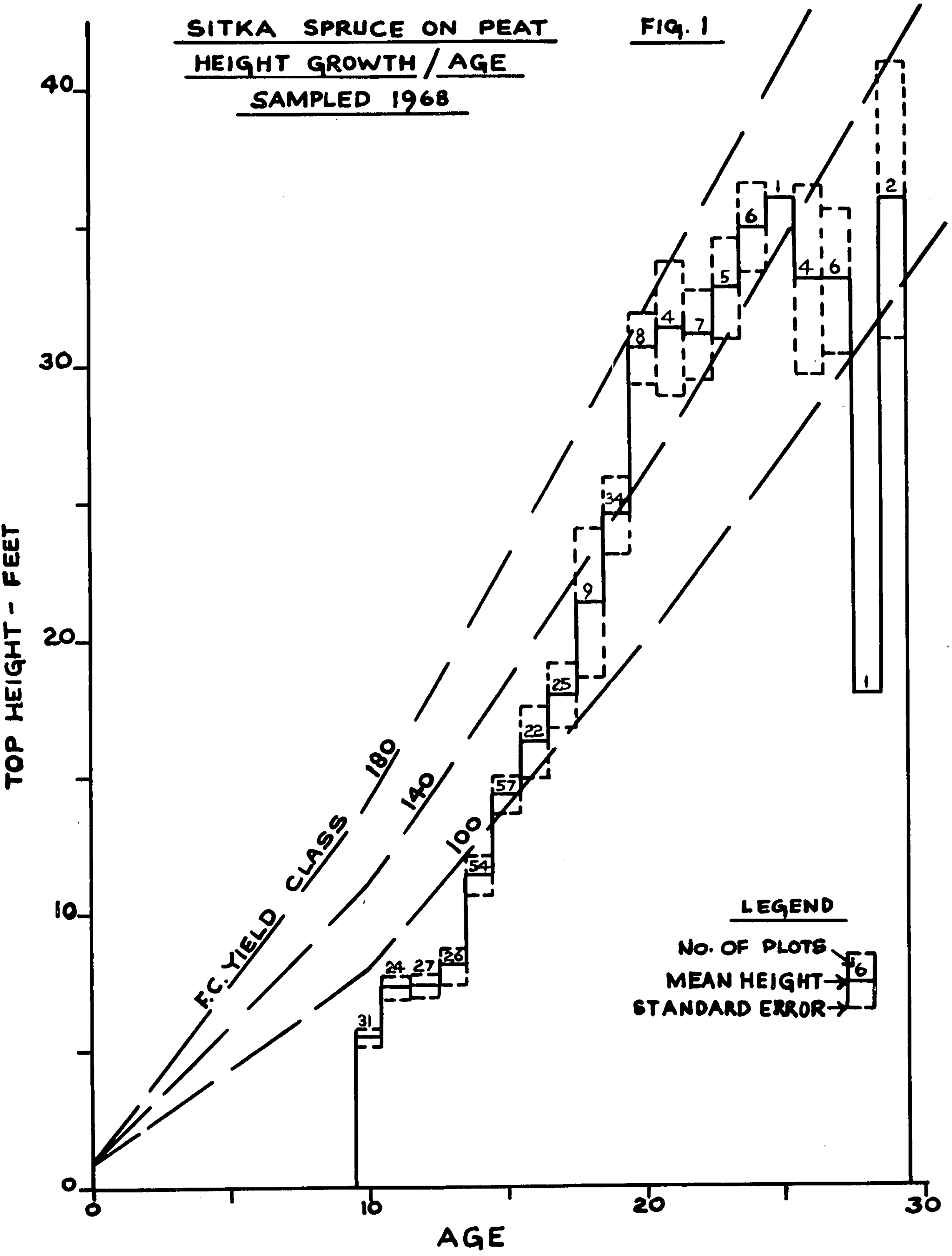
GENERAL SURVEY

A number of permanent sample plots have been located in certain forests in Northern Ireland. These are located at random in strata determined on the ground to contain as far as possible uniform conditions of soil and topography. They are not measured with the detailed intensity of the Forestry Commission code of sample plot procedure but are confined to the simpler measurements of girth at breast height and top heights of the dominant and mean trees. Within the area shown on the soils map of Northern Ireland (McAllister and McConaghy) as peat-covered mountain, and from personal knowledge of this region, sample plot details for forests or parts of forests which largely lay in deep peat were extracted and analysed for pure Sitka spruce stands. A total of 332 plots over 10 years of age were available.

A summary of the dominant height (100 largest trees per acre) by one year age classes is given in Figure 1, together with the standard errors of the mean and the number of samples in each class. Superimposed on this Figure are the curves of top height (40 largest trees per acre) by age from the Forestry Commission Management Tables for general yield classes 100, 140 and 180. It will be noted from this Figure that these plots suggest a yield class of 125. As the Northern Ireland figures are based on a larger number of dominant trees per acre, this comparison is not quite correct to estimate the appropriate yield class but experience has suggested that the relationship is such that the yield class is approximately 10 higher, i.e., that it is 135 for this sample of Sitka spruce.

Care should be taken not to interpret Figure 1 as meaning that on peat sites young trees (10 to 15 years) at yield class 100 will become, at 15 to 20 years, yield class 130 and, over 20 years, will become yield class 150, as it does not purport to show changes over time but is a sample of peat sites planted in different years. It probably reflects a trend to planting rather poorer peats in the mid-fifties.

Eighty-nine plots of this sample were over 20 feet top height and had been measured since the time of first thinning or had been unthinned. The criterion used to determine if a plot could be classified as being suitable for total crop yield investigation was that the present standing crop plus all known thinnings totalled over



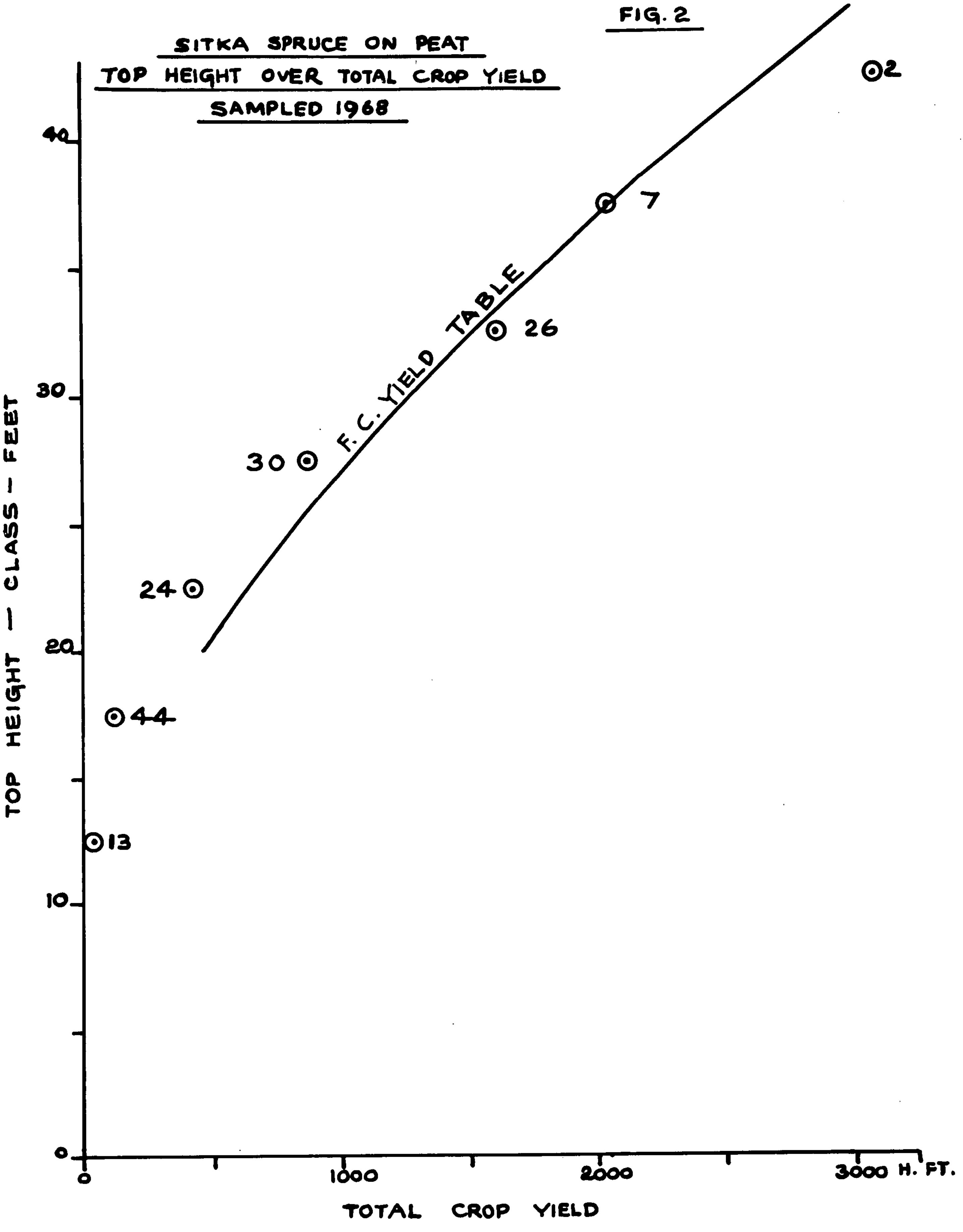
SITKA SPRUCE ON PEAT

HEIGHT GROWTH / AGE

SAMPLED 1968

FIG. 1

FIG. 2


SITKA SPRUCE ON PEAT
TOP HEIGHT OVER TOTAL CROP YIELD
SAMPLED 1968
TOP HEIGHT — CLASS - FEET
40
30
20
10
0
0
1000
2000
3000 H. FT.
TOTAL CROP YIELD
F.C. YIELD TABLE
2
7
26
30
24
44
13

1,000 stems. It is thus possible that for certain plots some thinnings had been removed without record but this was not considered to be very important. The relationship found between total crop yield and dominant height is shown in Figure 2 where it will be noted that all stands are reasonably close to production class "b" with a slight tendency towards production class "a" for the taller stands. In all cases the standard errors of the mean were low, rising from ± 35 Hoppus feet per acre for the 20 ft to 25 ft class to ± 80 Hoppus feet per acre for the 35 to 40 ft class. It can therefore be assumed that within the area sampled the Forestry Commission Management Tables appear to apply without any need to adjust for variation in local form, etc. Certain mensurational difficulties arise but need not concern us here.

SPECIFIC FOREST SURVEYS

A number of forest blocks in the blanket peat areas have been covered by a system of sample plots similar to those described above. It is intended that these permanent plots be re-measured every five to six years so that complete details of growth on a time scale can be analysed. A summary of the forests, with information on planting years covered, date of the initial survey, number of plots measured and number of plots on sites where the peat was over 30 in. in depth is given in Table II.

TABLE II

Summary of sample plots on blanket bog areas

Forest	Age group covered	Date of Survey	No. of Plots	
			Total	On peat over 30 in. deep
Glenshane	P.44-54	December 1964	142	92
Ballypatrick	P.48-55	December 1964	154	135
Davagh	P.45-56	December 1965	180	145
Goles	P.49-54	December 1965	120	98
Ballintempo	P.54-58	December 1967	60	18

It is intended that on re-measurement the survey will be extended to cover other areas which are then more than 10 years of age.

To avoid working with the very complicated equations relating height growth, age and site, these surveys have usually been analysed by comparing the yield classes, as determined from the Forestry Commission Management Tables. It is realised that the height age curves used to determine yield classes are not particularly accurate at the younger ages and that these surveys have generally been in crops of 10 to 15 years of age, but it is considered that they provide a reasonably reliable guide for present use. It should also be remembered that up to P.50 there was virtually no ploughing, planting on peat was usually on hand turfs and from then until P.55 ploughing was frequently at 20 ft spacing or even wider with hand spread turfs cut from the peat ribbon. Very little manuring was done in the forties and in the younger parts of the areas covered by these surveys, fertilising was at the rate of 2 oz slag (equivalent to approximately 40 lb P_2O_5 per acre) put in or round the planting hole. These forests are fairly typical of the site conditions found in the blanket peat areas.

In the Glenshane survey yield classes were recorded in steps of 20 from 80 upwards but the mean of the three tallest trees per plot was taken and as the plots were usually one-eightieth of an acre this is equivalent to 240 stems per acre which is much in excess of the Forestry Commission Management Table 40 per acre and therefore will tend to underestimate the yield classes. Where the height growth was insufficient to reach yield class 80, the plot was recorded as 0. Twenty-eight of the 71 strata (40 per cent) had a mean yield class of under 50, while the remainder had a plot mean of 129. At a probability level of P = 0.05 the yield class for these 43 strata lies between 120 and 138. Inclusion of all strata brings the forest mean down to 78. Considering plots on peat over 30 in. in depth it was found that over 50 per cent of these had a mean yield class of under 50. The remainder had a mean class of 122 which shows that they have not been very far behind the shallow peat over clay and clay areas which made up the remainder of the forest.

In 40 per cent of the strata Sitka spruce and Lodgepole pine (Pinus contorta) were growing in mixture. In half of these the spruce was taller than the pine and the reverse was true in the remaining half. However, it must be remembered that Lodgepole pine normally shows a rather different pattern of leader growth with its maximum leader length culminating at a much earlier age than for Sitka spruce of similar volume potential. As a result, when the heights are transformed into yield classes the spruce was generally found to give quite considerably higher yield classes than the pine.

Ballypatrick is very largely a deep peat forest. As in Glenshane, dominant heights were taken as the 240 largest per acre and thus tend to give an underestimate in comparison with the Forestry Commission yield tables. Of the strata with Sitka spruce which showed a mean yield class of over 50, there were 57 (80 per cent) and the mean was 81 giving, at a probability level of P = 0.05, a yield class lying between 72 and 89. Inclusion of all Sitka spruce strata reduced the forest mean yield class to 61. The Sitka spruce on peat over 30 in. in depth had a forest mean of 56.5.

There was a very definite trend for the younger (ploughed) P year areas to be better than the older stands, except P.48 where most of the mineral soil plots were to be found. A summary of details can be seen in Table III.

TABLE III

Ballypatrick May 1965 Inventory
Summary of possible maximum M.A.I., Sitka spruce

P. Year	Mean Maximum M.A.I.	No. of plots	Remarks
48	77	14	5 plots under Yield Class 80; 8 plots under Yield Class 100
49	46	22	13 plots under Yield Class 80; 15 plots under Yield Class 100
50	26	20	15 plots under Yield Class 80; 16 plots under Yield Class 100
51	49	16	8 plots under Yield Class 80; 12 plots under Yield Class 100
52	84	14	3 plots under Yield Class 80; 7 plots under Yield Class 100
53	94	16	2 plots under Yield Class 80; 6 plots under Yield Class 100
54	72	22	5 plots under Yield Class 80; 14 plots under Yield Class 100
55	58	26	8 plots under Yield Class 80; 23 plots under Yield Class 100
Weighted Mean	61	150	

Maximum M.A.I. from Forestry Commission Management Tables.

The leader growth on the three tallest trees per plot for the three years immediately prior to the survey were also taken in Ballypatrick. These suggested a falling off in growth over the complete forest from 1962 to 1964. Regression coefficients were computed for each plot to indicate changes in annual leader growth. These were done for linear equations which removed some 80 per cent of the total variance. Where the mean change was significantly different (at P = 0.05) from its standard error the appropriate regression coefficients for each P year (i.e. average change in leader growth in inches from one year to the next) are given in Table IV, which also shows the length of the 1964 leader and the equivalent 1964 leader for crops of yield class 100 from the Forestry Commission yield tables.

It will be noted that six of the P year areas showed a significant drop during the three-year period under review, although the average yield table figures for yield class 100 would normally involve changes of + 0.6 to + 0.8 for the ages being considered. The P.52 to P.54 areas show between-strata coefficients significantly greater than within-strata coefficients and this was apparently due to mulching with spoil from drain bottoms in these areas. From a dot diagram there was obviously no correlation between these regression coefficients and top heights before the leader growth was put on and therefore differing rates of change of leader growth cannot be related to the past vigour of the trees in each plot.

TABLE IV

Ballypatrick May 1965 Inventory
Summary of Sitka spruce dominant tree leader growth 1962, 63 and 64

P.Year	Age in Years	Dominant Tree Leader in in. 1964	3-year change in Leader Growth	Equivalent 1964 Leader F.C. Y.C.100	No. of Plots
48	17	11.9	- 1.4	15.6	14
49	16	8.5	- 1.4	15.0	22
50	15	7.9	- 1.0	14.4	20
51	14	8.9	-	13.8	16
52	13	9.6	- 1.1	13.0	14
53	12	10.7	- 0.4	12.3	16
54	11	7.2	- 0.9	11.6	22
55	10	8.6	-	10.8	26

NOTES: Dominant tree is equivalent to the mean of the 240 tallest per acre.

Forestry Commission Management Tables used for 1964 leader for 40 tallest trees per acre.

Examination of these leader changes in conjunction with possible mean figures taken from the Forestry Commission Management Tables for yield class 100 (see Figure 3) suggests that the leader growth during 1962 and to some extent during 1963 was rather better than the yield table average for crops growing at a similar rate while 1964 growth, when there was a fairly serious attack of aphids, was rather less. The pattern is fairly similar for all P. years. These changes suggest the over-riding influence of some factor of general importance such as climate or the aphid attack rather than purely local competition and nutrient problems although these are important for determining the total growth level.

In Ballypatrick 34 plots contained both Sitka spruce and Lodgepole pine and these were generally in the P.49 and P.50 areas. A comparison was made of top heights of both species and it will be seen from Figure 4 that in this forest the growth of Lodgepole pine is considerably behind that of Sitka spruce. The sites planted with this mixture were generally considered to be poorer than the sites planted with pure spruce and the strain of the Lodgepole

FIG. 3

BALLYPATRICK FOREST MAY, 1965 INVENTORY

SS LEADER GROWTH 1962, 1963 AND 1964

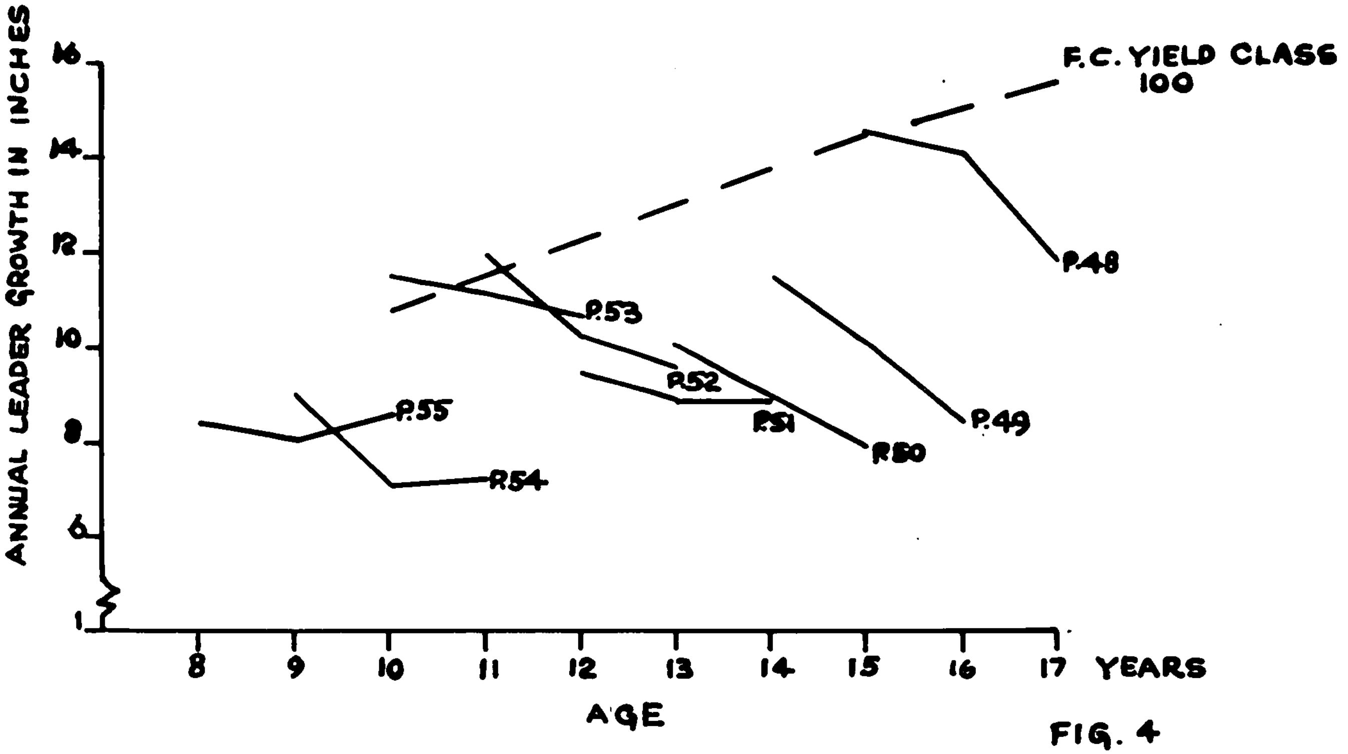
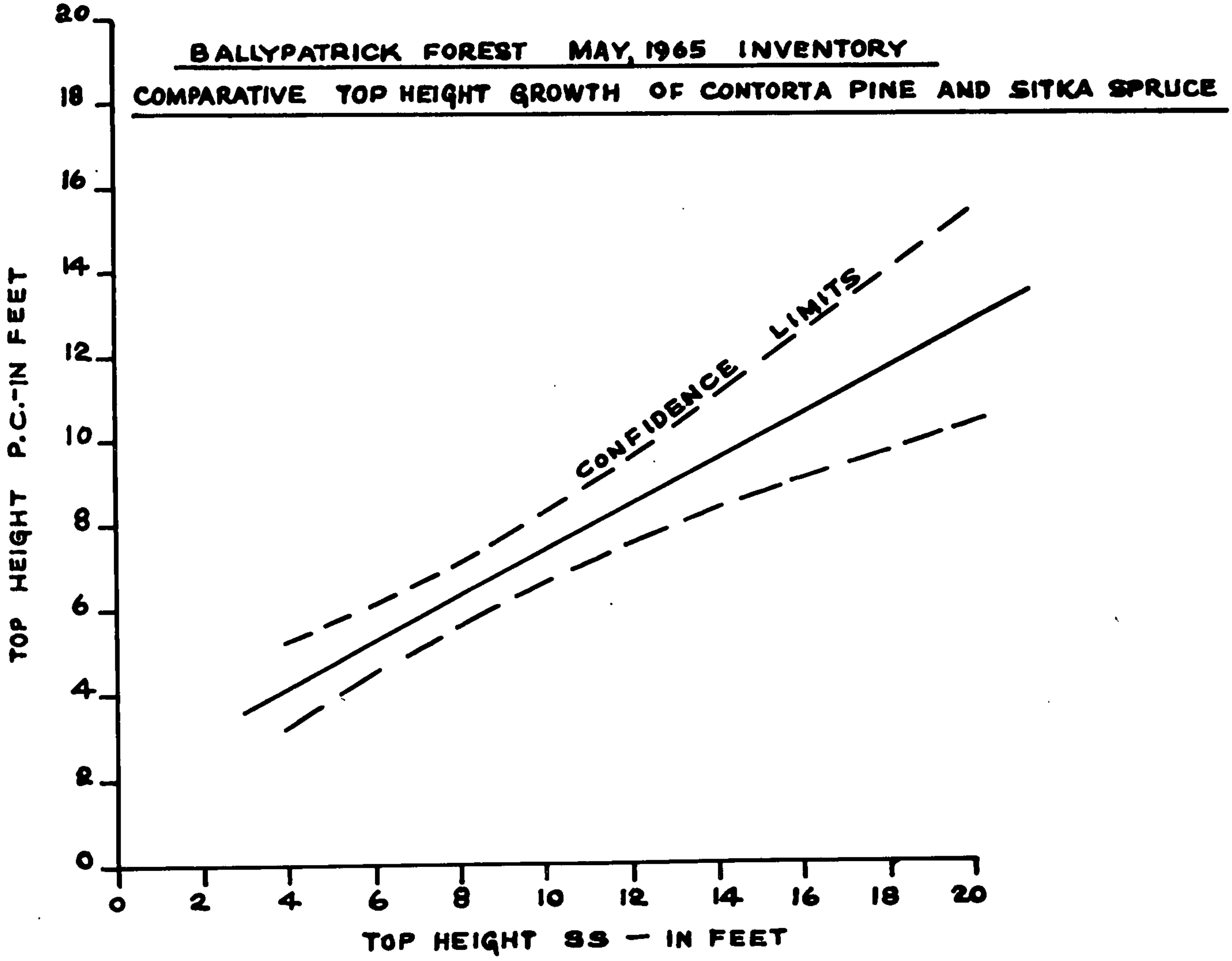


FIG. 4

BALLYPATRICK FOREST MAY, 1965 INVENTORY

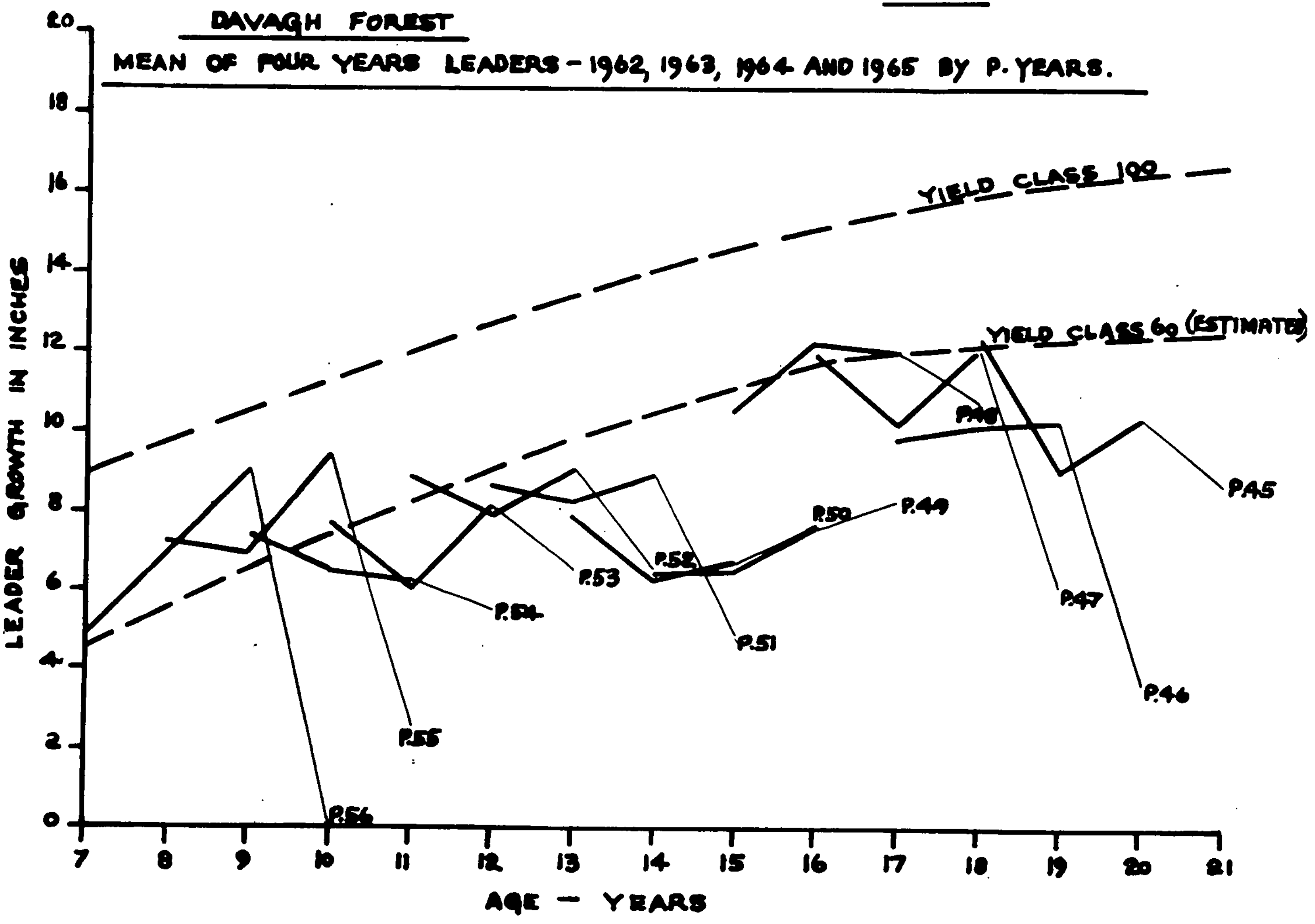
COMPARATIVE TOP HEIGHT GROWTH OF CONTORTA PINE AND SITKA SPRUCE



pine is not known exactly although it appears not to be a true coastal form.

The Davagh survey was carried out at the end of the 1965 growing season. Of the 180 plots sampled in the forest 145 were on peat over 30 inches deep with a crop of pure Sitka spruce or with a SS/PC mixture. Using the mean of the 240 largest trees per acre to enter the Commission Management Tables indicated that the 101 plots of P.50 and younger fell very close to the 60 yield class while the 44 plots in older stands fell below this figure. Leader growth of the three tallest trees in each 1/80 acre plot were also taken for the four years immediately prior to the survey. These suggested that in 1962, 1963 and 1964 the leaders were generally increasing and were very close to the expected leader growth of the appropriate yield class, but that in 1965 which had very severe frost in the late spring in this forest leader growth was very poor indeed in all P. years except P.49 and P.50. The mean leader growth in all 145 plots was in 1965 only two-thirds that for 1964. This is illustrated in Figure 5.

FIG. 5



In Goles the 122 plots of Sitka spruce had a mean yield class of 104 based on the tallest tree per plot which was equivalent to the tallest 80 per acre and included yield classes from 60 upwards. There were quite big differences between the deep peat areas which averaged 95 and the remainder which contained some peat over gravel sites and which averaged yield class 140. However, as this forest is sited on both sides of a valley and contains some planting at fairly high elevations it is interesting to examine the effect of aspect and elevation on Sitka spruce growth on peat over 30 inches deep. A summary is contained in Table V. It will be noted that there is a fairly marked fall in yield class with increasing elevation with the suggestion that southerly facing slopes may be growing better than north facing slopes. Elevation is, of course, often related to the inflow of nutrient from above and it is not possible to state how much of the result given here may be due to actual exposure and how much may be due to nutrient deficiencies.

TABLE V

Mean Yield Class by Elevation and Aspect
Deep Peat Sites Only

Goles Forest

Elevation	Aspect	
	South	North
Under 1,000 ft	125 (8)	110 (10)
1,000 ft-1,250 ft	110 (4)	100 (42)
Over 1,250 ft	Not Applicable	80 (34)

Note: Number of plots shown in brackets.

The Ballintempo survey contained a high proportion of shallow peat plots although this extensive forest has vast areas of deep peat, mostly planted during the past 10 years and which has not been sampled at this stage. This forest was all largely ploughed and was all given 2 oz slag round the planting hole at time of planting. Any poorish growing areas have been treated since 1963 by re-manuring with broadcast phosphate usually Semsol, but more recently rock phosphate and with some mulching. Using the tallest trees in 1/80 acre plots for comparison with Commission Management Tables the mean yield class is as shown in Table VI. The mean yield class for the part of this forest sampled to date is just over 105 which is low but it will be noted that this is largely due to the low production of Lodgepole pine.

TABLE VI

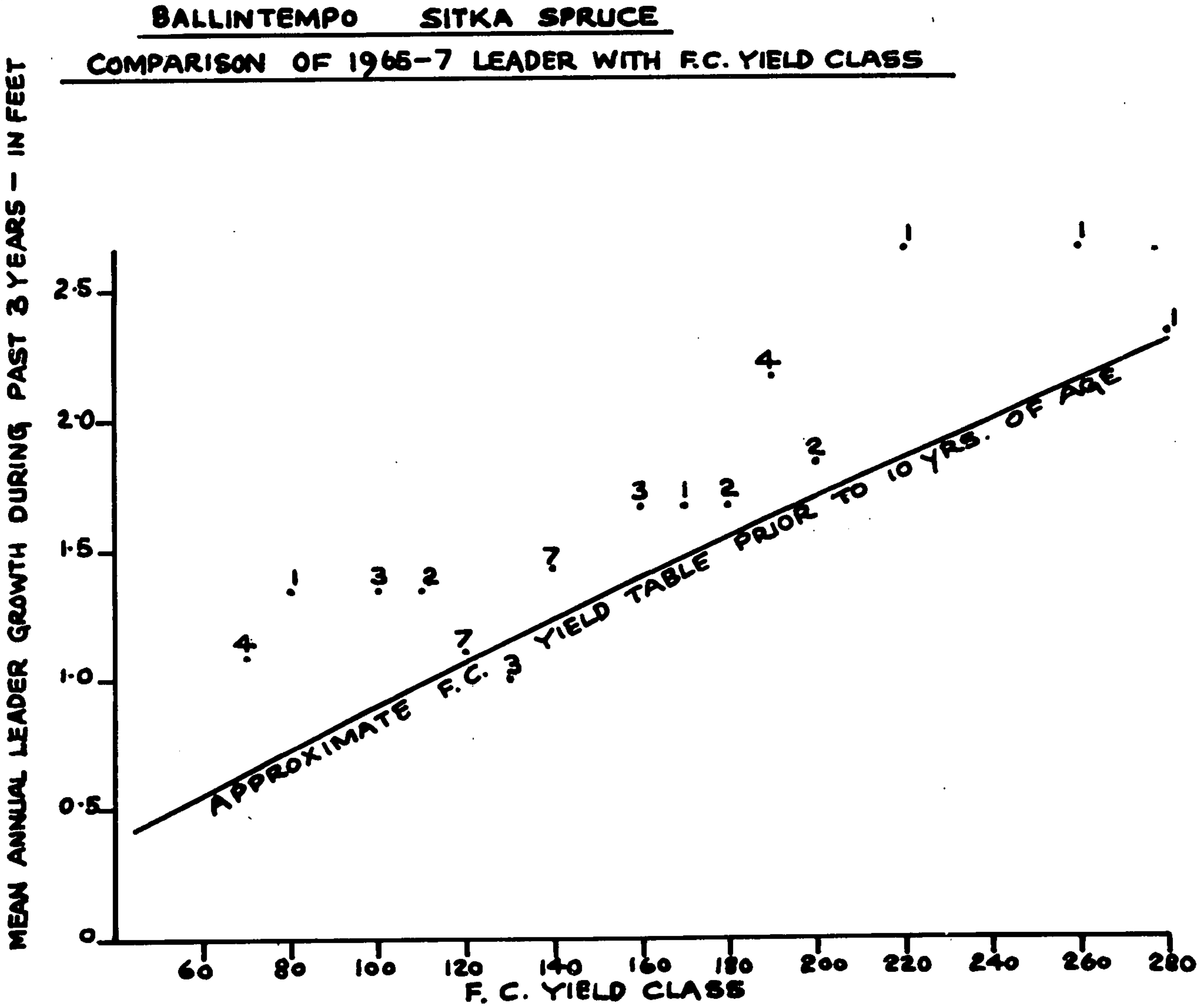
Mean Yield Class by Site and Species
Ballintempo Forest

Soil	Species	
	Sitka Spruce	Lodgepole Pine
Deep peat	137 (18)	60 (6)
Other - mostly shallow peat over clay	148 (24)	85 (12)

Note: Number of plots shown in brackets.

It is interesting to compare the mean of the last three years' leader growth at Ballintempo with the present yield class as determined by top height and the mean of the past three years' leaders as would be expected by the yield tables. This is done in Figure 5a for the range of Sitka spruce sampled in Ballintempo, i.e. yield class 60 to yield class 280. This has been possible because all the area surveyed was approximately 10 years old at the time of measurement. It will be noted that the actual three years' leaders are in virtually all cases well above the expected means.

FIG. 5a



BALLINTEMPO SITKA SPRUCE
COMPARISON OF 1965-7 LEADER WITH F.C. YIELD CLASS

The yield class of the Sitka spruce in Ballintempo is quite encouraging although it must again be stressed that there is no guarantee that the current rate of growth will be maintained at the level of the Forestry Commission Management Table. The growth rates of most other forests sampled are very low particularly when trees on peat over 30-inch depth are considered. Most of these have received only a very low fertiliser dose which has been shown by recent experiments to be quite inadequate compared with other possible treatments. A subsequent section will consider the effects of such treatments in some detail.

VARIATION OF GROWTH RATES

On peat over 30-inch depth there is considerable variation in growth rate and yield classes ranging from 0-240 are not uncommon in a single survey. In Glenshane the coefficient of variation of the error term for 43 strata which had a mean yield class greater than 50 was very approximately 30 per cent. The design of the sampling gave the coefficient of variation between strata as greater than 50 per cent indicating the advantage gained in precision by the stratification. In Ballypatrick the error variance was somewhat greater with a coefficient of variation of 55 per cent, but there was a similar reduction due to the stratification. In replicated experiments it is frequently found that between block differences are significant even when the sites are expected to be quite similar.

There is also very considerable growth variation between individual trees growing on peat. It is not unusual to have individuals of 20 ft high in 1/40 acre plots which have a mean of approximately 5 ft and dominants are generally between 50 per cent and 100 per cent greater than the height of the mean tree at least until canopy closes. This is probably greater than in plantations growing on mineral soils although this comment has not been tested. It has been proved that further fertilising can increase the height of the mean tree without giving similar, or at times indeed any, increase in height of the dominant. It has also been shown in a number of experiments that improvements in the growth of Sitka spruce are likely to be of a far higher order than improvements with the same treatment on the growth of Lodgepole pine.

Growth is also affected by exposure and a very high correlation of minus 0.75 has been found between the height of Sitka spruce at five years old and tatter flag loss in square inches per day. As this relationship is also affected by different nutrient levels on lower slope it is the subject of a separate study using multivariate regression techniques and is not reported on further in this paper.

HEIGHT DEVELOPMENT WITH VARIOUS TREATMENTS

A number of experimental treatments have been tried from time to time and it is important to attempt to determine what their effect has been and how long they are likely to last so that the economics of the treatment may be adequately judged. Most of these were only started recently but they provide a number of useful pointers. They were usually sited on the poorer deep peat areas. In the subsequent discussion reference will frequently be made to comparisons with Forestry Commission Management Table growth rates. As these are taken from the very low end of the height age graphs they are even more unreliable than the sections used to compare with the specific forest surveys as noted above. They have, however, been included as a guide which permits comparison with the height development in an experiment and also permits cross referencing of growth between different experiments. As most experimental plots have 20-36 permanently marked trees for measurement the tallest tree has been taken for comparison with the Forestry Commission yield table 40 dominants per acre.

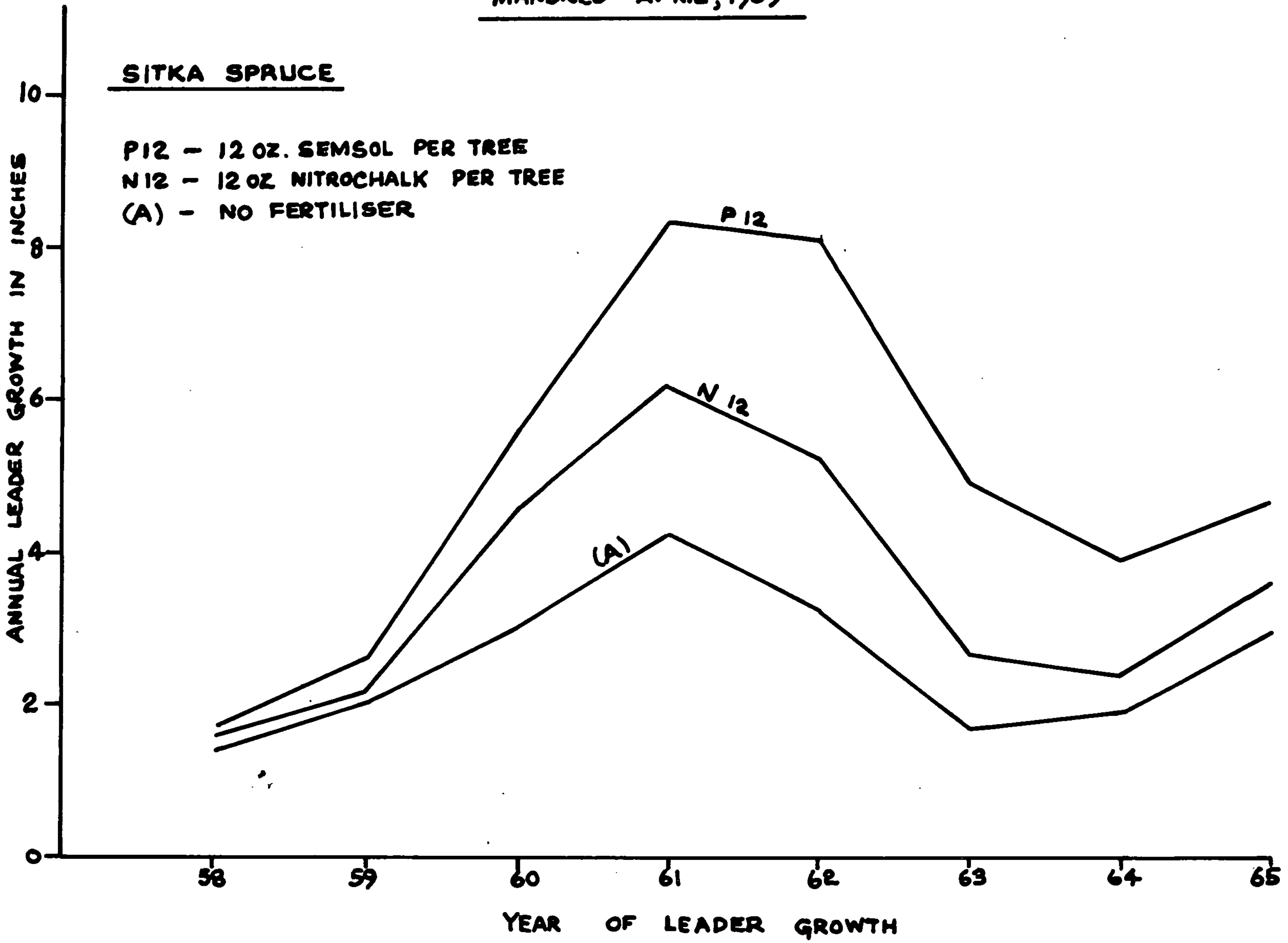
Some species trials have been started using Sitka spruce, Lodgepole pine, Scots pine, Japanese larch, White spruce, etc., but these have generally indicated that only the two former species are likely to survive and grow on the deep peats in the exposed site where these are normally found. Trials of various provenances of Sitka spruce and Lodgepole pine and small plots of other Picea species have been planted too recently (P.64-P.67) to give any reliable pointers on future growth and are not considered further in this paper.

In 1959 very poor areas of Sitka spruce/Lodgepole pine mixture P.41 in Cam, Springwell and Binevenagh Forests were fertilised with nitro-chalk at 6 oz per tree, Semsol (soluble and insoluble phosphate) at 6 oz per tree, both these combined, and all three at double this rate. The area had been hand turved probably with 2 oz slag given at time of planting and there was a dense ground cover of heather (Calluna vulgaris). The Cam block averaged only 4 ft high when this fertilisation was applied at 18 years of age and the pattern of its subsequent mean annual leader growth until the most recent measurement in December 1965 is given in Figure 6 for a few selected treatments. This shows a fairly typical pattern following fertilising of poor crops with the bulk of the improvement lasting for some four to five years only. It also shows a general variation from year to year in the untreated control. It will be noted that although the major effect of the fertilisers wore off quite quickly there has apparently been some lasting benefit even if not of the same magnitude as two to three years after initial treatment. No one could suggest that the current growth in this block is satisfactory, but it must be remembered how poor the crop was in 1959.

CAM EXPT. 1/59 P.41

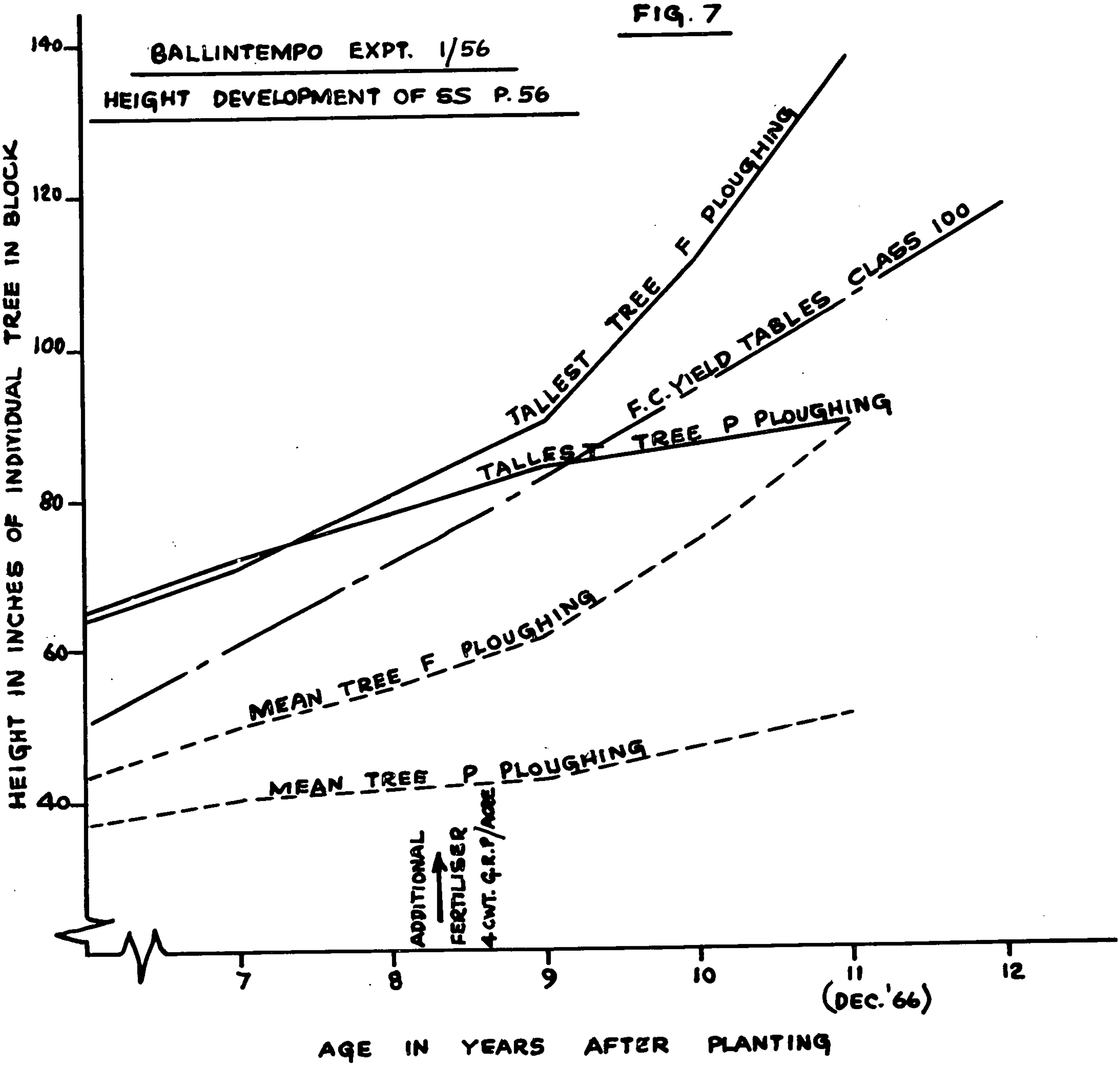
MANURED APRIL, 1959

FIG. 6



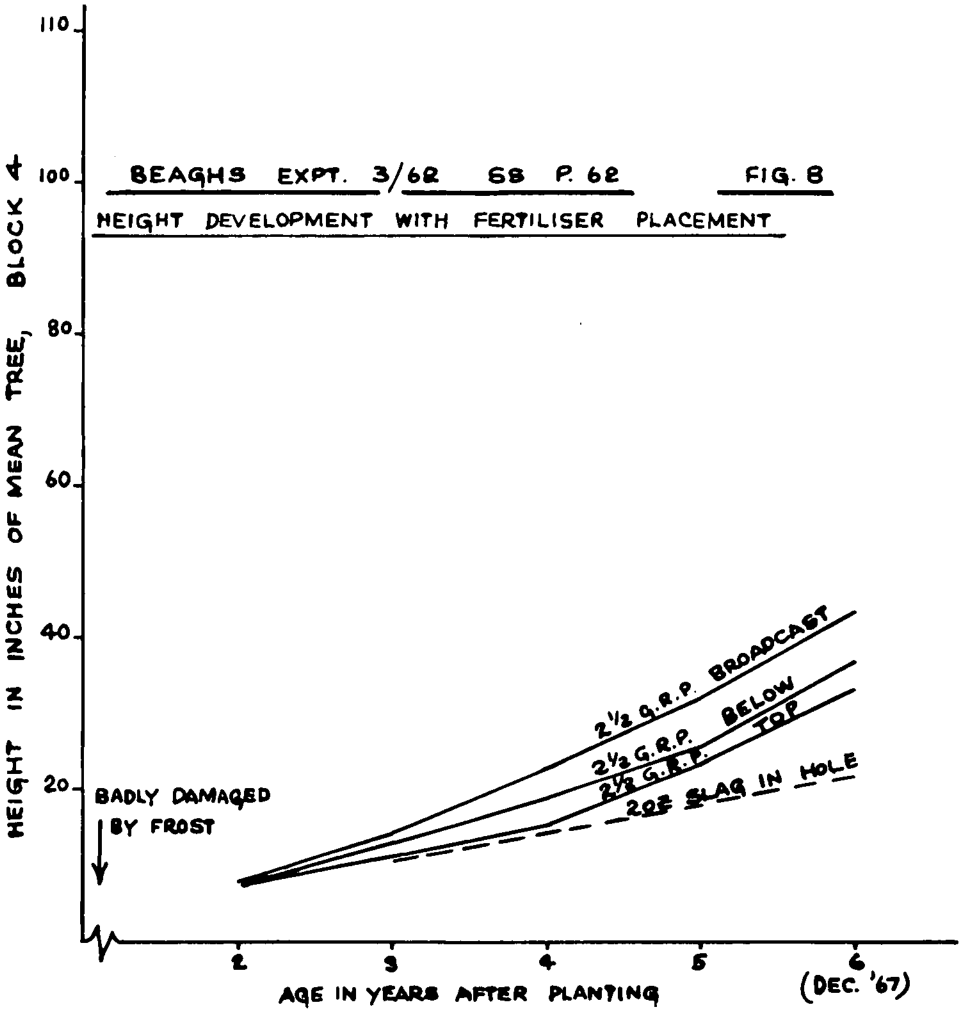
The intensity of plough cultivation and drainage of deep peat needed to establish an economic crop is not yet clearly understood. Examination of various patches of forest and some unreplicated trials suggest that the effect of drainage, apart from a shallow surface ploughing to remove surface water, is almost negligible on the growth rate except in so far as growth is enhanced by the killing of ground vegetation and the mulching effect of spoil from the drains. It is, however, of interest to examine Ballintempo Experiment 1/56 P.56 Sitka spruce, particularly those plots which were ploughed by an F-type single mouldboard and by a P-type double mouldboard plough. See Figure 7.

FIG. 7



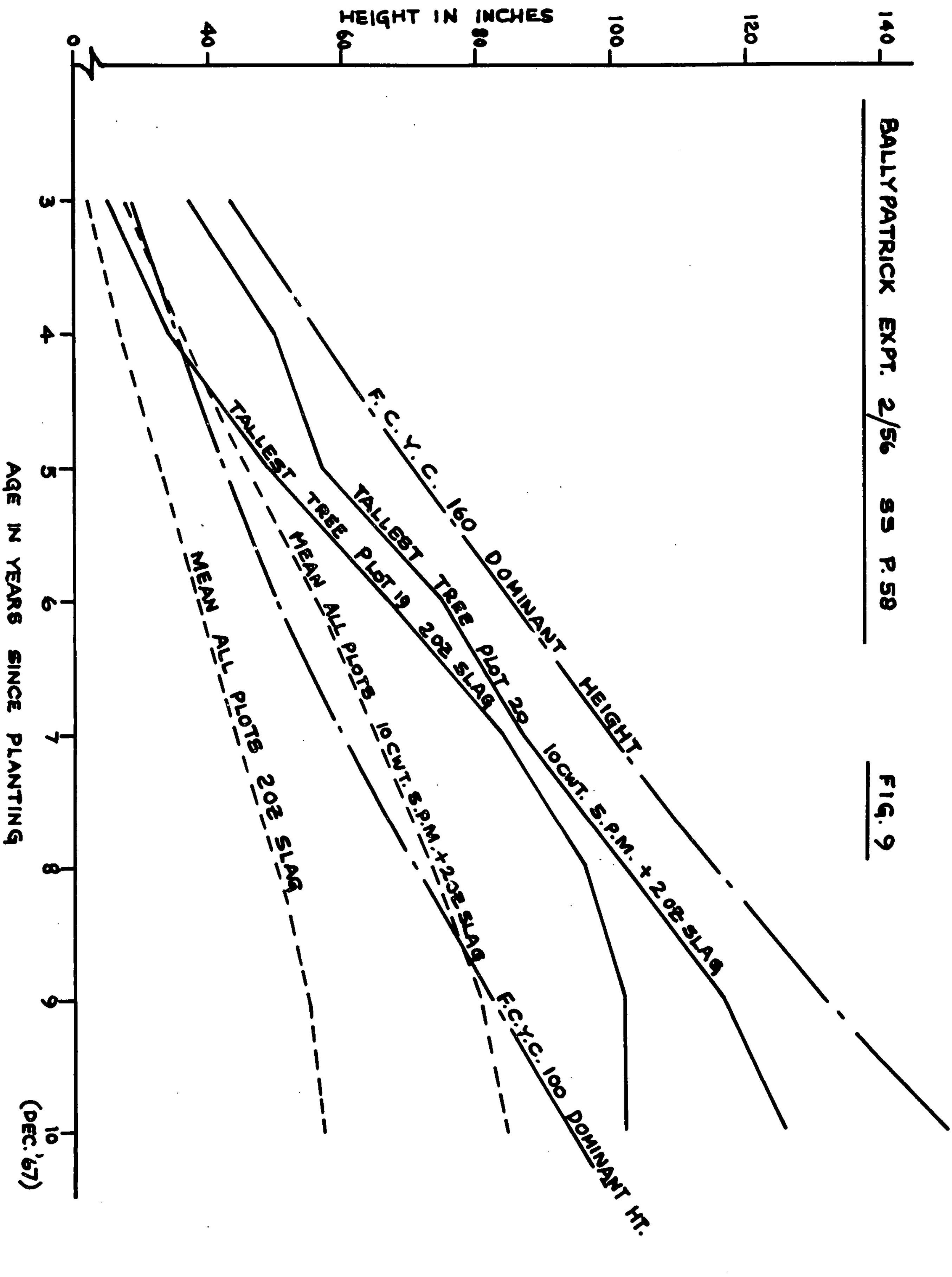
All plots considered here had 2 oz slag per tree at time of planting plus 4 cwt ground rock phosphate broadcast in the spring of 1964. The plots have now a very dense ground vegetation which is largely Calluna. The growth of the dominants was slow and fairly steady, but mean leaders were apparently falling off by 1964 so that additional fertiliser was prescribed. This has not helped the dominants in the P ploughed plot although it has boosted the average tree height. However, the more intensive ploughing has responded dramatically both in terms of the tallest tree and the average. Recent leader growths have, from a visual inspection, been closely similar to those in 1966 with the P ploughing somewhat improved. Unfortunately this was an unreplicated trial with a small flush in one corner of the F ploughing plot and the results must be treated with caution. Replicated experiments to specifically test the effect of drain depth and frequency have only been laid down in Forest Year 64 to 67 and are too young to report anything of value.

Although it suffered very severe damage by frost in the winter after planting Beaghs Experiment 3/62 with P.62 Sitka spruce at almost 950 ft elevation on a very exposed deep peat site provides some interesting data on the effect of fertiliser placement.



BEAGHS EXPT. 3/62 SS P. 62 FIG. 8

HEIGHT DEVELOPMENT WITH FERTILISER PLACEMENT



BALLYPATRICK EXPT. 2/56 SS P.58

FIG. 9

It will be noted from Figure 8 that the treatment which was fairly general field practice up to P.63/64 of putting 2 oz of slag in the planting hole has given mean trees at the end of the 1967 growing season of only half the height of the best treatment. Although less of the fertiliser placed below the ribbon should be lost via run off than broadcast placed manures, quite substantial improvements in growth have been obtained by the latter method with placement on top of the plough ribbon being poorer than either of these. There tends to be much more vigorous Molinia, Deschampsia and Eriophorum in the ground vegetation where fertilisers have been broadcast than in those areas where spot treatments have been done and where Calluna appears to become dominant fairly soon after the areas have been ploughed.

An interesting example of height development under differing fertiliser regimes for an 8-year period is provided by Ballypatrick Experiment 2/56 on Sitka spruce planted 1958. The mean heights of all plots in two treatments and the height of the tallest tree in two plots which in December 1967 had means very close to the treatment means are shown in Figure 9. The amount of phosphate added in the treatment where 10 cwt special potato manure (4:13:8 NPK compound) per acre were broadcast 2 years before planting together with 2 oz slag at time of planting is approximately 125 per cent of the present field practice of 4 cwt rock phosphate per acre. Where the fertiliser regime was only 2 oz slag per tree the dominant trees grew very well in the sixth and seventh years after planting but then began to fall off very badly. With the heavier fertiliser treatment dominant growth has remained fairly steady and reasonably satisfactory up to nine years after planting. There is, however, a suggestion particularly relative to the mean growth of all plots receiving this treatment that the 1967 growth fell off to some extent.

A factorial experiment with nitrogen phosphate and potassium added at time of planting and again in the seventh year after planting provides further evidence of the effect of heavier fertiliser treatments than would have been considered 10 years ago. Selected treatments from one block of this experiment at Lough Navar in County Fermanagh are shown in Figure 10. This figure shows that no fertiliser gives no growth apart from that carried over from the nursery and eventual death and stagnation indeed reduces even the height of the tallest trees. Most treatments shown on this figure gave reasonably acceptable dominant growth up to four years after planting and since then have given extremely satisfactory results. During 1968 many of the plots had started to close canopy provided phosphate had been given and particularly where potassium had also been added. Mean growth was little better for the heavier phosphate than for half this dose although there was a suggestion in 1966 that the latter was falling off somewhat. In the early stages potassium and in the last year nitrogen gave added benefit again with level 1 being as good as level 2.

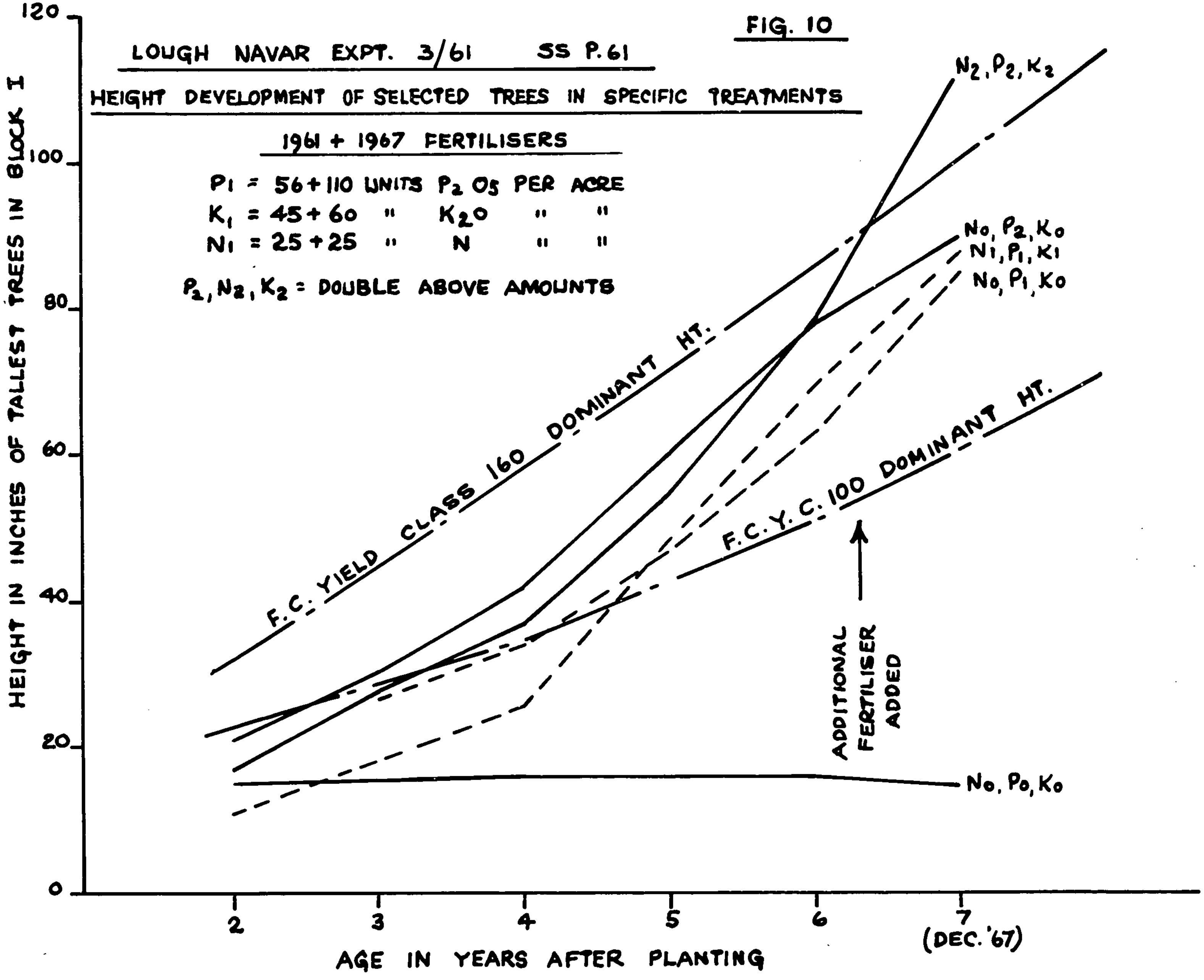


FIG. 10

LOUGH NAVAR EXPT. 3/61 SS P.61

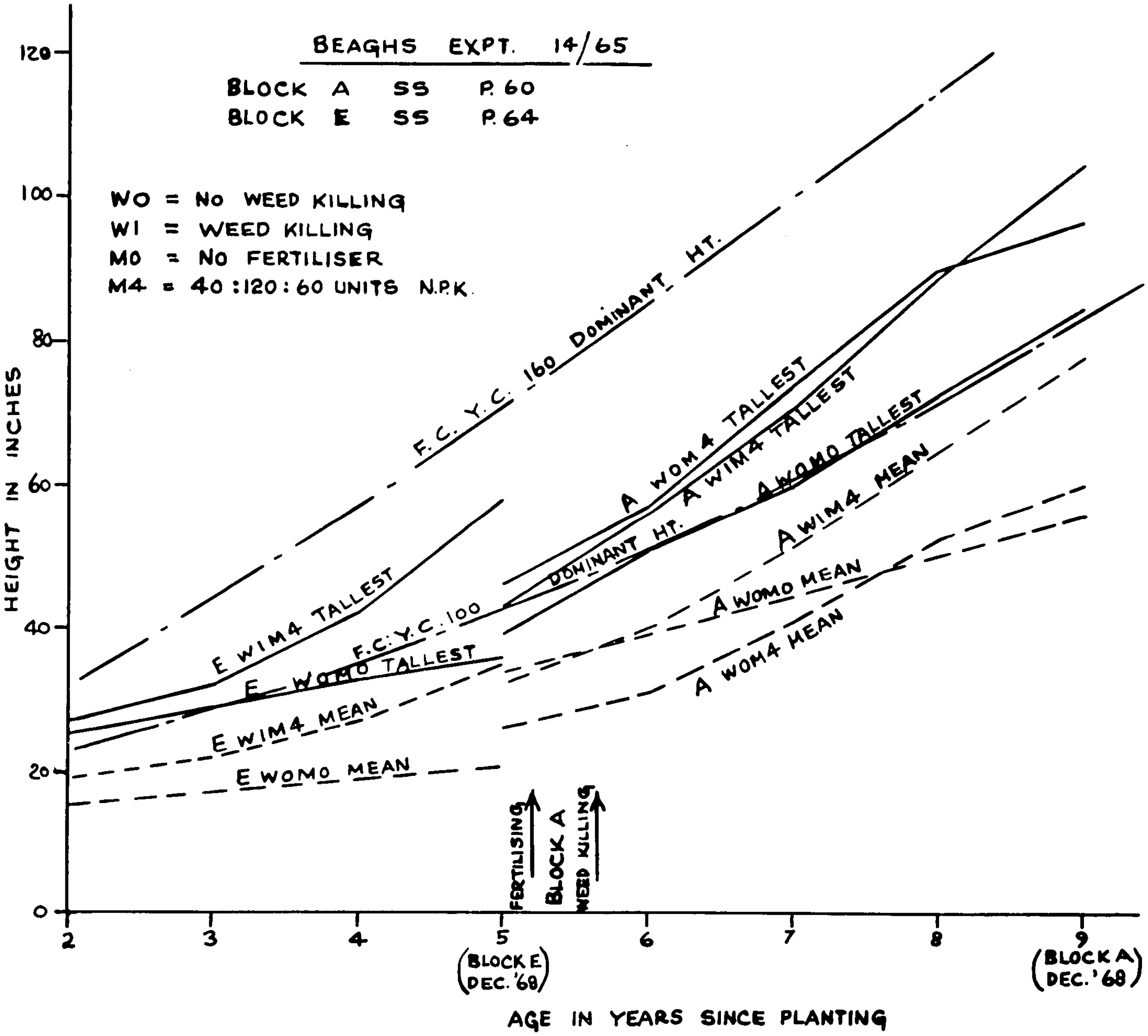
HEIGHT DEVELOPMENT OF SELECTED TREES IN SPECIFIC TREATMENTS

1961 + 1967 FERTILISERS

P1 = 56+110 UNITS P_2O_5 PER ACRE
K_1 = 45+60 " K_2O " "
N1 = 25+25 " N " "

P_2, N_2, K_2 = DOUBLE ABOVE AMOUNTS

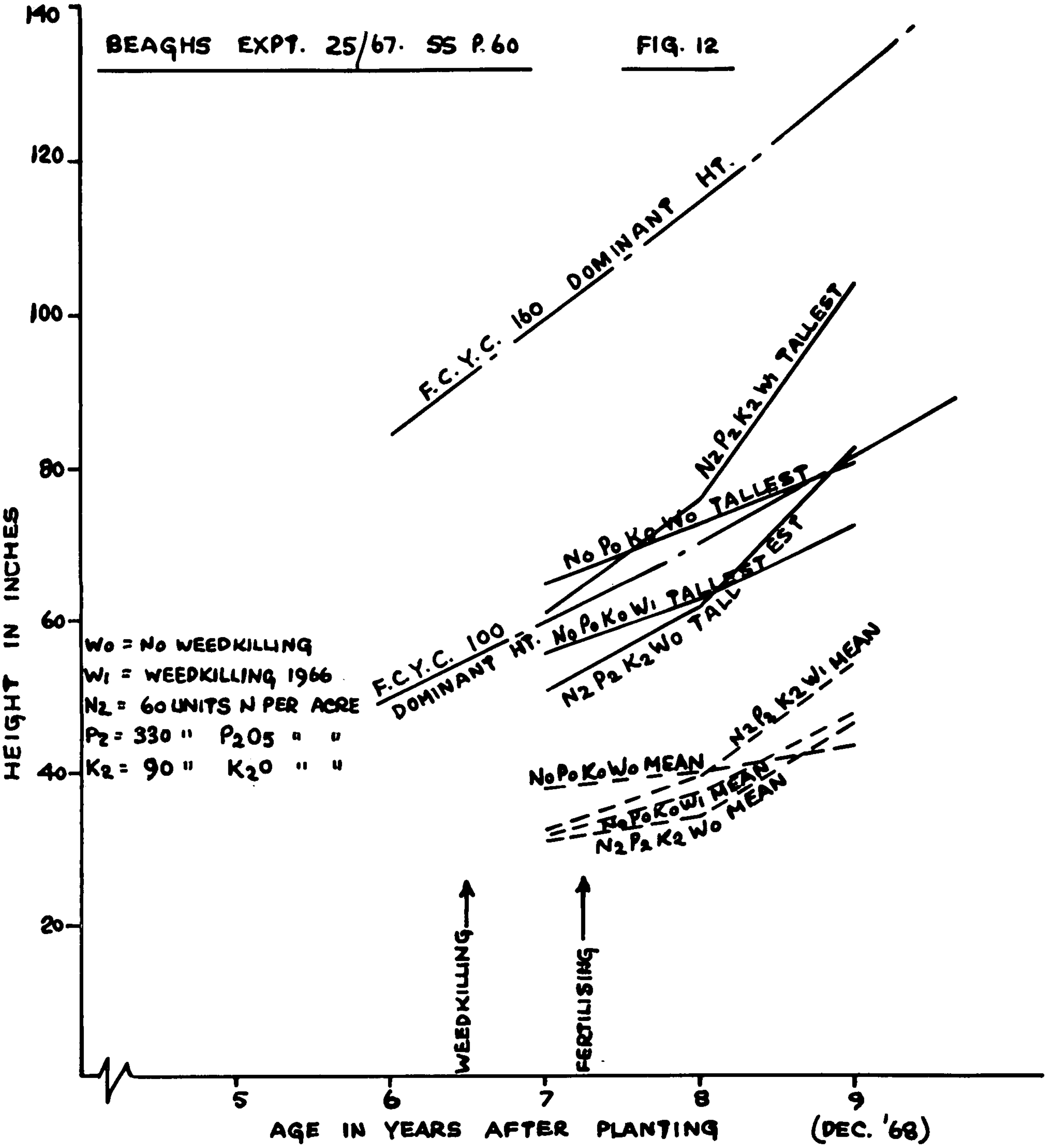
FIG. 11


BEAGHS EXPT. 14/65
BLOCK A SS P.60
BLOCK E SS P.64
WO = NO WEED KILLING
WI = WEED KILLING
MO = NO FERTILISER
M4 = 40:120:60 UNITS N.P.K.
HEIGHT IN INCHES
0
20
40
60
80
100
120
F.C.Y.C. 160 DOMINANT HT.
A WOM4 TALLEST
A WIM4 TALLEST
A WOMO TALLEST
DOMINANT HT.
A WIM4 MEAN
A WOMO MEAN
A WOM4 MEAN
E WIM4 TALLEST
F.C.Y.C. 100
E WOMO TALLEST
E WIM4 MEAN
E WOMO MEAN
FERTILISING
BLOCK A
WEED KILLING
2
3
4
5
(BLOCK E DEC. '68)
6
7
8
9
(BLOCK A DEC. '68)
AGE IN YEARS SINCE PLANTING

Fairly considerable acreages have been planted with the low fertiliser regime of under 36 units P_2O_5 per acre and it is necessary to determine if anything can be done to get these moving to a reasonably productive state which can be maintained. One such area was at Beaghs P.60 where average leader length in 1963 and 1964 were some 6 and 4 inches only and the trend was that they were becoming smaller. An experiment to test various fertilisers including phosphate in a soluble form and nitrogen with and without weed killing was started in 1965 and replicates were also laid down in a piece of very exposed failed Lodgepole pine which had been replanted with Sitka spruce in P.64. Details from certain treatments are included in Figure 11. The dominant heights in block A were not particularly good and it is remarkable how closely they have followed the Forestry Commission yield class 100 line over the past five years where no further treatment was given. Manuring has considerably improved the leader growth of both the dominants and the mean size of tree in the plot with little added effect due to weed killing. Although not shown, there was almost as good a response to half the fertiliser dressing shown in Figure 11. There was some response to weed killing alone but not as marked as where fertilisers were added. A similar pattern is evident in the younger block E and this is of some significance as this block is at 1,000 ft on the crest of a very exposed ridge where flag tatter had averaged some 2 square inches per day over one year's observations.

A further experiment of interest is Beaghs 25/67 from which some details are recorded in Figure 12. This is in an area very similar to where Beaghs 14/65 was sited and the control plots have followed the same yield class 100 line although apparently getting poorer. Part of the experimental area was treated with 2 4D in 1966 and the complete area was refertilised with water insoluble phosphate, nitrogen and potassium in a factorial arrangement in 1967. The kill of the vegetation by 2 4D was far from complete and in most plots could only be assessed as 50 per cent. This treatment, however, resulted in some considerable increases in leaders over the non weed killed area although where no fertiliser was added the dominants have been little affected although the plot means have increased. Where phosphate fertiliser was added the 1968 leaders are slightly greater in the weed killed than in the non weed killed area. There has also been a 20 per cent better mean growth where nitrogen was added and the effect of this element is more apparent in the non weed killed areas. Half the rates of phosphate and nitrogen have given almost as good growth as the higher levels and potassium has had no effect on this experiment.

Other experiments on thicket and pole stage crops of Sitka spruce on deep peat are of too recent origin to give any results. The same applies to experiments designed to test the effectiveness of a few large, relative to a number of small, applications of phosphatic and potash fertilisers.



BEAGHS EXPT. 25/67. SS P.60

FIG. 12

FUTURE GROWTH

Existing plantations are too young and experiments too recent to permit a precise estimate to be made of the future growth pattern of trees growing on peat in Northern Ireland. Nevertheless a forecast has to be made and while the evidence may be scanty or insufficient to please those who wish to see all problems solved experimentally before any field work is done, the results to date can be used. I am prepared to forecast that with some improvement in the provenance of Sitka spruce, broadcast fertilising with 4 cwt per acre rock phosphate, deep ploughing for planting with under 2 chains of deep drains per acre, subsequent refertilising with phosphate (and possibly either potassium, nitrogen or other element) at seven to ten years after planting and a further manurial application of nitrogen and perhaps some other element, it should be possible to grow Sitka spruce on blanket bog to Forestry Commission yield class 160. This may be an over-optimistic forecast but if it cannot be achieved without large expenditure on further treatments then our existing and future research work will not have given the result it is capable of producing.

THE INTEGRATED USE OF PEATLANDS

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INTRODUCTION

Since the end of World War 11 many scientific disciplines have concentrated on the problems of peatland. The range of investigations can be seen in the programmes of three International Peat Congresses held in Dublin in 1954, Leningrad 1963 and recently in Quebec, August 1968. The published proceedings of these meetings represent a reservoir of world knowledge on the problems of peat and its utilisation. Since 1954 there has been a gradual change in emphasis from the utilisation of peat for industrial purposes to an appreciation of its merits as a medium for plant growth. Studies in soil/plant relationships have demonstrated the production potential of peat and indeed of many of the world's problem soils. The special mechanical difficulties in developing and managing peat soils have been resolved by rapid advances in engineering. The research objective for the future will be the economic assessment of peat as a land resource, using the knowledge derived from past scientific work. National land use research programmes will require information on the distribution of peat deposits, their chemical and physical characteristics, and the particular development requirements of their country.

DISTRIBUTION AND ORIGIN

In the following table Taylor (1964) has estimated the world's peat deposits from sources made available at the second International Peat Congress which was held in Leningrad. He considers the estimate conservative.

Many factors contribute to each country's development policy for peat. In the U.S.S.R., which has 60 per cent of the world's peat, the main effort has been in its utilisation for industrial purposes. By contrast, the United States has developed its peat resources mainly for agriculture and horticulture. Much of the Canadian bogland is still uninhabited and unexploited despite the very significant contribution of Canadian peat utilisation research. Ireland, with only 54,000 hectares under development for fuel production, has devised a sophisticated range of peat harvesting machinery unequalled in any other country. Part of Ireland's success in using peat as a fuel can be attributed to the importance attached to the detailed scientific study of the properties of a natural deposit before large scale exploitation was planned. This same approach is equally important in the utilisation of virgin and cut-over[1] peatlands for agriculture or

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[1] Peatland from which the upper layers have been removed.

TABLE I

World Peat Resources

	Country	% of world resources	Total area in million hectares
(1)	U.S.S.R.	60.7	73
(2)	Finland	8.2	10
(3)	Canada	7.8	9.5
(4)	United States (without Alaska)	6.2	7.5
(5)	Germany (East and West)	4.3	5.25
(6)	Great Britain and the Irish Republic	4.3	5.25
(7)	Sweden	4.1	5.0
(8)	Poland	1.3	1.5
(9)	Indonesia	1.1	1.35
(10)	Norway	0.7	1.0
(11)	Cuba	0.4	0.45
(12)	Iceland	0.26	0.3
(13)	Japan	0.18	0.2
(14)	New Zealand	0.14	0.165
(15)	Denmark	0.01	0.12
(16)	Italy	0.01	0.12
(17)	France	0.01	0.12
(18)	Hungary	0.08	0.1
(19)	Netherlands	0.041	0.045
(20)	Argentina	0.041	0.045
(21)	Roumania	0.041	0.045
(22)	Czechoslavakia	0.025	0.30
(23)	Austria	0.018	0.022
(24)	Yugoslavia	0.013	0.015
(25)	Spain	0.005	0.006
(26)	Others	0.026	0.03
	Total	100.000	121.433

forestry. Barry (1954, 1969) has described in detail the formation of Irish peat deposits since the end of the last European glaciation, some 10,000 years ago. Many of the factors which determine the formation of a peat deposit have general application, irrespective of the geographical location of the deposit.

In general, peat deposits develop under conditions of heavy rainfall, high humidity and low summer temperatures. The botanical, chemical and physical properties of the deposit will be influenced by the nature of the mineral subsoil, the topography of the surrounding land and by the amount and chemical composition of the ground water present during the deposit's formation. Peat deposits which develop under the influence of ground water often reach depths of 8 metres or more and exhibit a complex and varied stratification. Where climate is the chief factor influencing the accumulation of peat, deposits are on the whole less deep, and seldom show marked horizon differentiation.

CLASSIFICATION OF PEAT TYPES

Peat has been defined as a soil that has less than 50 per cent of mineral matter on a dry-weight basis, and is more than 30.5 cm (12 in) deep. In 1903 Weber divided the bogs of Germany on the basis of surface configuration, and classified three main types, low moor (Niedermoore), transitional moor (Ubergangsmoore) and high moor (Hochmoore). Scandinavian countries favour a classification system based on the botanical composition of the deposit. Smith (1963) has described the development in the United States of a new system of soil classification which defines the new taxa[2] in terms of observable or measurable soil properties rather than soil forming factors or processes. In this system organic soils are called histosols and described as soils with over 20-30 per cent organic matter and at least 30.5 cm of peat, (46 cm if undrained). This new system is only an approximation and is being refined to embrace all soil types. Since under the system, only the top metre of a peat deposit is classified, classification difficulties are created where the upper layers of a deep deposit are being removed for industrial use, and the lower layers retained for agricultural or forestry use. A special issue of "Soil Science", (96, 1, 1963) contained 10 papers dealing with aspects of the new system.

It is because of the past confusion of classification systems for peat and the apparent general acceptance of the new system that special attention is now drawn to the new name for peat soils - histosols. At present, however, the terms high, transitional and low bog as used by Weber (1903) are generally understood and used throughout Europe. All three types of peat can, and usually do occur in a high bog profile. The high bog is the uppermost layer and the low bog rests on the mineral or mud floor.

[2] Taxon (pl. taxa) is a name used in classifications for a single class. It may be broadly or narrowly defined according to the category. A soil order is a taxon, as is a soil series, a family, or a great soil group.

In the Western part of Ireland, Great Britain and Norway, a "blanket" of peat covers the undulating countryside; it has developed under extreme maritime climatic conditions and is not accommodated in Weber's system.

CHEMICAL CHARACTERISTICS

The ash content of bogland vegetation seldom exceeds 3 per cent, so that peat formed from this vegetation is low in minerals. Where minerals have been washed in from the surrounding countryside the ash content may be higher in some low lying peats and the bottom layers of some raised bogs. The moisture content, often in the region of nine parts of water to one of solids, causes considerable dilution of the minerals present. Much fen and basin peat has a satisfactory pH and calcium status, but all of the high and "blanket" bogs are highly acidic and deficient in calcium. Peat soils tend to be acid but range from pH 4.4 to 4.8 for the top 20 cm. The levels of major and minor elements are usually inadequate for crop production. Table II illustrates the very great differences between mineral soils and peat soils.

TABLE II[1]

Percentages and amounts of soil constituents in 0-20 cm layer

Soil constituents	Mineral soils		Peat soils		
as % of dry matter	Podzol-grass-land	Black soil	High bog	Transitional bog	Low bog
Organic Matter %	2.0	8.0	96	93	86
N %	0.15	0.30	1.7	2.0	2.5
P %	0.04	0.08	0.03	0.06	0.08
K %	1.74	1.90	0.08	0.12	0.16
Ca %	0.08	1.32	0.21	0.71	2.10
Soil constituents - metric tons per hectare					
Organic Matter	60	160	336	359	374
N	4.5	6.0	5.9	7.8	11
P	1.32	1.76	0.12	0.24	0.39
K	52	38	0.29	0.48	0.74
Ca	2.05	26	0.75	2.78	9.42

Reserves of nitrogen are higher in peat than in mineral soils but they are usually held in chemically unsuitable forms for plant nutrition. Reserves of phosphorus, potassium and calcium are extremely low and obviously inadequate to meet the requirements of either agriculture or forestry.

Assuming the installation of a satisfactory drainage system, the successful reclamation of peatland for agriculture depends largely on the application of adequate balanced fertilisers. It is also necessary to provide for deficiencies of minor elements, which are most likely to occur in the early stages of development. Different crops require minor elements in varying degree, but copper, molybdenum, boron, zinc, manganese and perhaps iron are particularly important. Where livestock systems are planned for reclaimed peatland, cobalt will also be

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[1] Derived from tables given in E.S. Translation No. 678 (see references).

required. Workers in many countries have shown that liberal dressings of the major elements are required initially, and that these must be supplemented annually by lighter dressings, (Grennan and Mulqueen, 1964; Hupkens van der Elst, 1963; Rayment and Chancey, 1966).

On Blanket peat in Western Ireland grass/clover swards have been successfully established using the following initial dressing:

	Kg per ha[1]
Ground Limestone (40% Ca)	3,763
Superphosphate (8% P)	502
Muriate of Potash (50% K)	250
Calcium Ammonium Nitrate (23% N)	250
Copper Sulphate (25.4% Cu)	22
Cobalt Sulphate (20.9% Co)	2.2

These same swards have been maintained for grazing with annual dressings of:

Superphosphate (8% P)	376 Kg per ha
Muriate of Potash (50% K)	188 Kg per ha

Slightly higher dressings are required if the sward is intended for hay or silage. Calcium status is maintained with approximately 1,200 kg per ha of ground limestone every third or fourth year. To some extent calcium and trace element requirements are met if basic slag, (8% P), is used in alternate years as the source of phosphorus.

The development of successful tree planting methods for the afforestation of peat soils has been described in detail by Zehetmayr (1954) and Meshechok (1961, 1968). A small amount of phosphatic fertiliser is applied to each young tree, planted on an upturned furrow. The necessity for a further combined nutrient dressing, three to five years after planting has been confirmed by O'Hare (1967) and Meshechok (1963).

An important chemical characteristic of peat soil is the high percentage recovery of applied nutrients in grass herbage. There is little of the "fixation" problem associated with mineral soils. However, as peat soils have very weak storage capacity for nutrients it is generally recommended that plant nutrients should be applied in relation to annual requirements.

The position of afforested peatland is different. Nutrient conservation and utilisation may be more efficient because of (a) absence of annual cropping and (b) nutrient contribution from the atmosphere and rainfall over the lifetime of the forest.

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[1] Kg per ha x 0.892 = lb per acre

PHYSICAL CHARACTERISTICS

Because of its dominantly organic nature, peat has a high water holding capacity - a feature of considerable importance in relation to its physical properties, and probable land use. The degree of decomposition also affects its physical properties. Generally, the more decomposed peats are more difficult to drain and less easy to manage with regard to water control. The degree of decomposition varies considerably, even in the same profile, and this complicates the planning of an effective drainage or water control system.

Burke (1967) and Galvin and Hanrahan (1968) have described in detail the development of techniques at Glenamoy, Ireland, to measure particular physical properties of peat, related to drainage. On the experimental area the permeability was approximately 1 cm per day. Mineral soils with good drainage would have a permeability of 25 cm a day. At Glenamoy the recommended drain depth is about 107 cm (3 ft 6 in) with the drain spacings not greater than 4.57 metres (15 ft).

There is a very wide range in drainage recommendations for peat in different countries (Burke and O'Hare, 1963) but the methods developed by Burke and Galvin can be adapted to predict the required depth of drain and drain spacing for a range of peat soils, provided there is complete weather data for each particular area.

Drainage causes subsidence, sometimes unevenly, but the rate of subsidence largely depends on the final height of the water table relative to the surface. Local climatic conditions also influence the degree of subsidence.

In prolonged dry periods peat surfaces may become irreversibly dried with serious reduction in crop yields. In wet weather it is a most difficult medium to cultivate and transportation is severely restricted. Peat surfaces also have high radiative properties which result in a frost hazard during the spring months. However, given a proper understanding of the many interactions, counter-measures can be devised to reduce or remove the hazards.

Drainage, cultivation and nutrient applications improve the physical condition of peat, but there is also evidence of the beneficial effect of forest trees in lowering the water table and improving the permeability of difficult peats (O'Hare, 1967).

In Table III results are presented for a preliminary study on water tables, beneath a grass sward and a shelterbelt, on peat 4 metres deep at Glenamoy, Co. Mayo. The shelterbelt is 100 ft wide and was planted in 1956. In 1967 the trees were approximately 12 ft high. The grass fields were parallel to the shelterbelt and separated from it on either side by a drain 3 ft deep.

TABLE III

Water level below surface (inches). Mean of weekly readings January-December 1967

	Grass field south										
Distance of bore hole from drain (feet)	25	12	6	3	1						
Water level below surface (in)	8	9	10	17	21						
	Shelterbelt										
Distance of bore hole from drain (feet)	1	3	6	12	25	50	25	12	6	3	1
Water level below surface (in)	33	33	29	24	15	9	11	19	26	30	33
	Grass field north										
Distance of bore hole from drain (feet)	25	12	6	3	1						
Water level below surface (in)	8	9	12	13	20						

LAND USE OF PEAT SOILS

Some countries are already committed to a policy of utilising peat deposits for fuel and industrial purposes but it is now generally accepted that to burn peat is the least efficient use of this unique organic material. Despite the physical and chemical problems mentioned previously, peat is recognised as an excellent growth medium both in situ and in the glasshouse. Even in those areas already under development for fuel and industrial purposes, successful utilisation of the underlying mineral floor is possible if something like 1 metre of peat is left behind.

Crop production on peat soils depends on water control, nutrient balance, weed control, mechanical expertise and local climatic conditions. For any particular situation it may be possible to select more than one form of land use but the final decision will depend on such factors as depth of peat, topography, accessibility, capital available for development, distance from suitable commodity outlets, national economic necessity and population pressure.

Generally speaking the elements of crop production, with the exception of climate and gradient, are now controllable, and the effect of climate can be largely off-set by crop selection. While there is a vast worldwide technical literature on the many aspects of crop production on peat soils, the scientific investigation of land use criteria is of comparatively recent origin.

Good land use has been defined as (a) the avoidance of environmental deterioration and (b) efficient and economic utilisation for a stated purpose. The land uses for sloping or hill peats are restricted mainly to improved hill grazings, afforestation, the production of game birds and animals and as areas for leisure and recreation. Peats with relatively flat topography can be used for (a) intensive horticultural or tillage crop production where rainfall is moderate, summer temperatures warm to very warm, and where there is easy access to markets; (b) intensive grassland/livestock husbandry systems where climatic conditions are similar to (a) but where the deposit is not near large centres of population; and (c) afforestation where rainfall and humidity are high, summer temperatures cool, and where the peat surface is too weak to support the continued mechanical activity of a grassland/livestock system.

An interesting recent development is the use of peat as a growth medium in glasshouse systems. The necessary major and minor nutrients are added to the peat substrate and the prepared growth medium spread 20 cm deep in troughs or "pillows", in the glasshouse (Woods, 1966). Cropping can continue for three years without soil sterilisation, after which the material is removed and replaced with a fresh supply of peat. Under the controlled conditions of glasshouse cropping, the type of peat had no significant effect on the yield of tomatoes in any of the three years of the experiment (Woods, 1969). This is a most important discovery.

Peats of low horticultural value, located in climatically unsuitable areas for intensive horticultural production, may still be of considerable economic importance if used in glasshouse systems. There are exciting implications in this development for (a) countries with peat deposits in remote areas and (b) countries with population pressure and declining land resources.

The integrated use of these alternative forms of land use for peatland must be studied in great detail in future. Basic requirements for such studies are detailed soil maps and local meteorological records. Ball (1964) has referred to the superiority of soil maps over land-utilisation maps in planning efficient land use. Webster and Beckett (1968) have noted the great variation in the quality of existing soil maps and the need for general standards. There are many examples of correlation between the growth of plant species and several soil factors (Jackson, 1962; Rennie, 1963; Avery, 1962). Jackson (1962) in a study of Slash pine in the United States noted that growth, measured as height increment, was highly correlated with mean annual precipitation and average diurnal temperature range, March to June. If detailed information on soil and climate are important generally, in land use planning for mineral soils, it is no less important in the efficient land use of peatland. There has been a dramatic build up of meteorological data throughout the world due mainly to the requirements of air transport. Progress on soil survey is slow, but is gaining momentum as the need for better inventories of soil resources and reliable predictions in land use planning is demonstrated.

Productivity increases, and thus better land use, can be achieved by the breeding and selection of plants and animals adapted to specific soils and climatic regimes. The soil - in our case peatland - is an energy convertor, whose efficiency is controlled by the interaction of many complex factors. Detailed information on these factors will permit rational planning of our peatland resources.

Let us consider the practical application of these view points for authorities charged with land use decisions referring specifically to peatland. Peat deposits are usually extensive and topographically variable. The traditional practice of individual and independent selection of areas best suited to particular activities has proved unworkable. The interests of forestry and agriculture have sometimes been in conflict, not through the fault of field officers, but rather to the mandates under which each operated. The interests of forestry, agriculture and wild life promotion have also been in conflict, sometimes because of the sincerity of officers to plan well for their own particular activity.

The most obvious desirable integrated land use for peatland is forestry and agriculture. They are, in fact, complementary. Blocks of forest trees interspersed with blocks for agriculture, provide a very workable framework for integrated land use. At Glenamoy we have seen the advantage of a shelterbelt system for reclaimed peatland in exposed areas. These shelterbelts are 100 ft wide and may be a little too narrow for the economic production of timber. The fields within the shelterbelt system are approximately 10 acres.

Where gradient or altitude preclude agricultural development, the integration of forestry and wild life promotion should be considered. Even on those flat areas where either forestry or agriculture alone might be considered, the new developments in the production of "silage cellulose" allows for rapid changes in land use (Herrick and Brown, 1967). If this system were adopted, fields within a shelterbelt complex could be closely planted with a fast growing species which regenerates from the base when cut. Young trees and shoots 4 to 6 years old would be harvested with a forage harvester for pulp. At short notice this temporary plantation can be removed to make way for a more lucrative tillage or horticultural crop.

In very extensive peat covered areas, forestry and undeveloped areas can be integrated to provide economic forestry and areas for leisure and recreation. In Northern Ireland, and more recently in the Republic of Ireland, the recreational value of State forests has been demonstrated. Car parks and walks are being provided to meet a growing demand for such amenities. The increasingly high level of public responsibility for the conservation and enhancement of natural beauty is most encouraging to planning authorities. It is hoped that road improvements and the provision of parking and roadside amenities through our boglands will be a further extension of the integrated use of peatland.

In Ireland, research is in progress on the agricultural and forestry potential of virgin and cut-over peatland. In 1966 the Department of Lands commissioned Foras Taluntais (The Agricultural Institute) to initiate a research programme aimed at increasing numbers of Mallard duck and Red grouse. This programme is part of a major effort on the part of the Department of Lands to promote the wildlife potential of the Irish countryside. The Mallard and Red grouse projects have a special significance in planning integrated use of our peatlands.

In summary, it is apparent that peatland can now be used for a variety of development activities. The planning and location of particular features of integrated use can best be served by basic information on soil and climatic factors, coupled with the co-ordinated technical expertise of biological and engineering science.

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ECONOMIC ASPECTS OF TREE PLANTING ON PEAT

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The biological and silvicultural scientists are concerned to improve understanding of the physical relationship between trees and their environment. Technical foresters are concerned to interpret these relationships in terms of treatment and the effects on production. The job of the Forest Manager is to decide on the treatments to be carried out. The job of the economist is to help the manager to identify, from among the courses described by the scientists and technologists, those which contribute most effectively to the pursuit of the objectives of his enterprise.

The remarks which follow aim to indicate the types of information, first, which will be helpful to managers involved in deciding treatments, and last, which will be helpful to managers involved in deciding about research. The points are intended to be quite general, but, by reference to a number of examples, their application to tree planting on peat will be demonstrated.

THE DECISION TO DO FORESTRY

It may be supposed that forestry is carried on mainly for the production of timber as raw material for industry though it is certainly carried on with other outputs in view, whose importance varies with the particular circumstances. For the purposes of this discussion it is sufficient to think of the timber output alone; the rules developed will apply equally to other outputs.

The forestry process involves the occupation of land (to the virtual exclusion of other uses of the land) and the investment of labour, machinery and materials. If the decision to invest in this way is to be sound, the resulting output must be preferred to that which would have been obtained using the land, labour and other resources involved in other ways.

To decide to embark on a forestry scheme it has first to be decided that the land is not more suitably used in other processes. It is apparent from Mr. O'Hare's paper that the exploitation of peat for fuel, for horticulture and for agriculture is profitable only in a few combinations of circumstances, as the special recreational uses that peatland can be put to may also prove to be. However, it must not be assumed that because other uses are impracticable then forestry, where it is feasible, must be done.

In order to judge whether forestry should be done it is necessary to know the amounts of labour, machinery and materials necessary for the forestry process and the timber output which will result. This means we have to know what it costs to drain, plant and fertilise the peat and the value of the resulting timber. This value we can compare with the value of products which would result using these resources for other purposes. On the poorer peats extensive in North Scotland, Lodgepole pine is the only commercial forest tree which can be relied on to grow without substantial manuring. Such plantations will produce timber whose cash value at the time of harvesting at 50 years of age is two to four times greater than the cash cost of the resources invested in planting it. The alternative uses of those resources have to be very poor before such an investment would be preferred on commercial grounds. The alternatives available may, in fact, be poor or there may be other reasons for wishing to carry out the investment.

HOW MUCH FORESTRY

When it is decided to carry out forestry on the peat the question remains, what is the best combination of treatments to adopt? What are the effects of varying the intensity of draining or the quantity and timing of fertilization, on the cost and the outcome? The manager seeks that combination which will achieve his objectives to the greatest possible extent. This means, if we may assume diminishing returns from increasing intensity of treatment, that the combination will be sought where a reduction in intensity will cause a reduction in cost equal or less than the resulting reduction in value of output, while an increase in intensity will cause an increase in cost equal or greater than the resulting increase in value of output. For example, it was found that to justify fertilizer regimes thought necessary to ensure sustained growth of Sitka spruce on certain peats in North Scotland, an increase in Yield Class of 20-40 H.ft. would be required over the potential of Lodgepole pine to justify the expense. On the other hand, the fall in value of yield if one were to omit the phosphate dressing at initial planting of Lodgepole pine would be much greater than the cost of the dressing.

Certain types of research are directed at obtaining reduction in cost by improvement in method without affecting final output. Much Work Study is directed at obtaining such improvement. The example of dibbling plants was mentioned by Swan in his paper. Improvements in output through modification of specification, without increasing resources, may also be unequivocally welcomed. Jack mentioned in his paper improvements in growth obtained through modifying the way in which fertilizer was distributed.

UNCERTAINTY

Up to this point I have said that, in order to decide the course of action to adopt, we have to know the cost and outcome. Of course we cannot know what those things that will occur in the future will, in fact, turn out to be; we can only estimate what they will be and those estimates are subject to uncertainty for various reasons. A very valuable type of information is information about estimates. We know with some assurance, for example, that Lodgepole pine can be established and grown on most uncongenial peat bogs in North Scotland, given that we follow tried treatments, and that, with the same treatments, Sitka spruce will fail. We have good grounds for believing that Sitka spruce would succeed if certain nutrient deficiencies are made good. We have, however, no experience of it and can only state expectation about the degree of success, and even the achievement of most modest results cannot be predicted with complete certainty.

WHAT THE MANAGER WANTS FROM RESEARCH

Management has to go on, and although full information makes his life easier, most of the manager's decisions are made on imperfect information in the face of uncertainty.

So far as the manager is concerned, he wants information about the possible treatments and their outcome. As treatments can usually be varied continuously, he wants to know about change in output with change in treatment over the whole feasible range, so that he can judge where in that range he should operate to achieve his objectives to the greatest extent. It is desirable to know what is the most likely outcome; sometimes, however, the thing that varies is the uncertainty of the outcome and it is extremely useful to know whether this most likely outcome lies within a narrow range of possible outcomes or in a wide range. And are outcomes approximating to that regarded as the most likely much more so than other possible outcomes? Knowledge of the uncertainty of an outcome is much greater knowledge than uncertainty owing to ignorance of the outcome. The first desideratum then is that the researcher should overcome his diffidence and let us know his view of the results of treatments intermediate between and beyond the range with which he has actually experimented. A second is that he should state the range within which the result of treatment is expected to lie and indicate the likelihood of outcomes in various positions over the range, as well as the most expected outcome. Early if imperfect results have their value so long as the imperfection is recognised. It is to be hoped that, in presenting a probabilistic result, its meaning is not lost in a maze of obscure statistics.

HOW DOES THE RESEARCH MANAGER DECIDE WHAT RESEARCH?

In considering the choice of investments in research, the following questions arise:-

i) Is the subject major? That is, will a lot of activity be affected if the result suggests changes? The development of treatments for peatlands might for example affect some million or so acres in Britain.

ii) Are large changes expected to result? Elimination of hand draining operations on deep peat might reduce cost by, say, £5 per acre.

iii) Does one expect the research to produce results shortly or only after a long time, and, in the case of a long-term study, are early results to be expected? Have we got to wait a whole rotation to know whether fertilizers will support Sitka on poor peat.

iv) Is there reasonable expectation of obtaining a result?

The Forest Manager will place great weight on early results in areas of immediate importance to him. The researcher has to bear in mind the likelihood that circumstances will change, and put sufficient effort into basic research which will maintain his ability to produce answers for circumstances which could not be predicted.

THE WATER RELATIONS OF TREES GROWING ON PEAT

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INTRODUCTION

The utilization of wetlands such as peatlands for forestry purposes presupposes regulation of the water relations. Land of this kind can be changed into excellent sites for tree growth because, at least theoretically, the water relations can be adjusted to an optimum level. This is usually not possible on normal forest sites, i.e. mineral soils, because such sites are often impaired by lack of moisture. At present, forest drainage is carried out on a large-scale basis in the Soviet Union, Finland, the Scandinavian countries, Great Britain, Ireland, and the southern states of the U.S.A. as well as to some extent in the wetlands of the tropical rainforest region. On a world-wide basis, I estimate the current annual drainage area at 800,000-900,000 hectares. In so far as the Soviet Union, Canada, and the U.S.A. enter upon effective utilization of the possibilities offered in this field, the extent of drainage for forestry purposes may even rise to millions of hectares annually.

Considered against the brief background outlined here, the question how to achieve optimum water relations of the sites is interesting and of economical importance. Thus, it is quite natural that this problem has drawn attention earlier, too.

THE INFLUENCE OF DITCH SPACING ON TIMBER GROWTH

In the following I am going to consider certain problems of water relation mainly against the background of Finnish studies. In order to facilitate comprehension of the results of observations on, and investigations into, the effect of drainage of varying intensity on the growth of trees, there might be reason to describe briefly the techniques of drainage that have been employed in this practical forest drainage activity in Finland. When this activity was started in the 1910's and 1920's, the ditch spacing employed was about 100 m and the ditch depth, 1.5 m. One must remember, however, that at the time the drainage was carried out on peatlands covered by forest growth. During the whole time of drainage activity, the trend has been towards a network of denser and shallower ditches. At present we use a distance between ditches of 25-40 m and a ditch depth of 60-90 cm. In addition, shallow water furrows are used when open peatlands to be afforested are in question. Usually these furrows are about 4-5 m apart, the same as here in Scotland.

The reason for a development of this kind can be found in the general observation that tree growth improves as the distance between ditches is reduced. Already in the 1920's Lukkala (1929) presents the following figures on the growth of trees as a function of their distance from ditches.

Distance from ditch, m	5	6-20	21-40	41+
	Diameter growth, mm/5 years			
Pine	13.6	9.0	7.4	6.6
Spruce	11.4	8.7	7.7	6.4

The latest investigations carried out at the Finnish Forest Research Institute also include calculations on the correlation between ditch spacing and tree growth. Generally speaking, the results reveal that the growth of trees is the better the closer to the ditch they are growing. Usually, the growth decreases at a very rapid rate with increasing distance from the ditches. As an example of these experiments I shall present the following data, published by Huikari and Paarlahti (1967):

Ditch spacing, m	5	10	20	40	60	80	100
Girth growth, mm/year 1)	11.0	7.7	5.6	4.0	4.4	-	-
Height growth, cm/year 1)	-	26	17	13	10	8	7

Even today, areas that were drained years and decades ago offer excellent material for the study of this problem. My institute, for instance, has measured several hundreds of sample plots during recent years in peatland areas which were drained about 35 years ago. These areas were covered by forests at the moment of ditching. The measurements were carried out in such a way that the volume and growth of the timber could be studied as a function of the ditch spacing. According to the calculations published by Seppälä (1968), the results were as follows:

Site type 2)	RhK	VK	VSR	IR	TR
Ditch spacing, m	Total volume in per cents of the value for the narrowest strip				
20	100.0	100.0	100.0	100.0	100.0
30	98.6	96.4	98.7	99.6	93.8
40	96.5	95.0	98.2	95.5	86.3
50	95.8	92.4	95.3	93.9	85.8
60	94.6	91.3	94.7	93.9	81.5

1) Measured in the middle part of the strip.

2) RhK = Rich spruce swamp. VK = Ordinary spruce swamp. VSR = Sedge pine swamp. IR = Pine swamp with undershrubs. TR = <u>Eriophorum</u> pine swamp.

These figures indicate that the influence of ditch spacing on the growth of the whole strips between ditches is not so marked as one could assume when studying tree growth as a function of ditch spacing. It must be kept in mind that even on broad strips the trees growing close to the ditch display quite a good increment.

The final aim of the last-mentioned measurements is to find out the most profitable ditch spacing from an economical point of view. Unfortunately, however, these calculations have not yet been completed. However, it seems that the highest interest for the drainage costs is achieved by employing 30-50 m ditch spacing, depending on the fertility of the site and other factors. As a matter of fact, the most important thing to know in practical ditching activity would be the most economically profitable ditch spacing. To this end, however, we should know, for instance, the timber prices after 40-100 years, at which time the areas which are drained today will yield money through cuttings. In so far as we are not able to make such prognoses, we must be satisfied with present-day prices, in consequence of which our calculations for this part are only assumptions. In spite of this incompleteness, I consider the clarification of the most economically profitable ditch spacing as being the final aim of the investigations into the water relationships of peatlands.

A problem of more primary nature, however, is that concerning the most biologically advantageous water relations. When the problems involved here are known, the final end, i.e., the most economically profitable drainage, can be solved by simple calculation.

IMPORTANCE OF THE DITCH DEPTH

In the foregoing, I have mainly dealt with the influence of the distance from ditches as well as ditch spacing on the growth of tree stands. However, the water relations are also influenced by another factor pertaining to ditching techniques: namely, the ditch depth. Results obtained from studies carried out in Finland point to the fact that the ditch depth is nowhere as important for the efficiency of drainage as the ditch spacing. This seems to depend on the circumstance that movement of the water located in deeper peat layers is insignificant. According to experiments carried out by Huikari (1959), the relative mobility of the water of various peat layers is as follows:

Peat layer, cm	0-10	10-20	20-30	30-40	40-50
Water mobility	100	20	6	2	0.5

In this experiment, the so-called auger hole method was employed, and a result of this kind depends partly on the higher degree of humification in deeper peat layers and partly on the higher pressure prevailing at greater depths. This leads to a marked decrease in the water permeability of the peat. Several studies have shown that the active surface layer of drained peatlands is extremely thin. The distribution of roots, too, is very superficial, even in efficiently-drained peatlands. The bulk of the roots occurs at depths between 0-10 cm, and only in exceptional cases are roots encountered at depths exceeding 20 cm (Heikurainen, 1955, Paavilainen, 1966). Changes in the microbial activity owing to drainage reach a depth of 10-15 cm only (Huikari, 1953), and the limit zone with almost anaerobic conditions ranges from 20 to 40 cm in depth even in efficiently drained peatlands (Lähde, 1966). Paavilainen (1967) has proved that the 5% air limit in peat at the same time forms the limit of root penetration.

An increased drainage depth seems to deepen the active surface layer only at a very slow rate. According to Paavilainen (1966), for instance, the regression between the average depth of the ground water table and the penetration of roots takes the following shape:

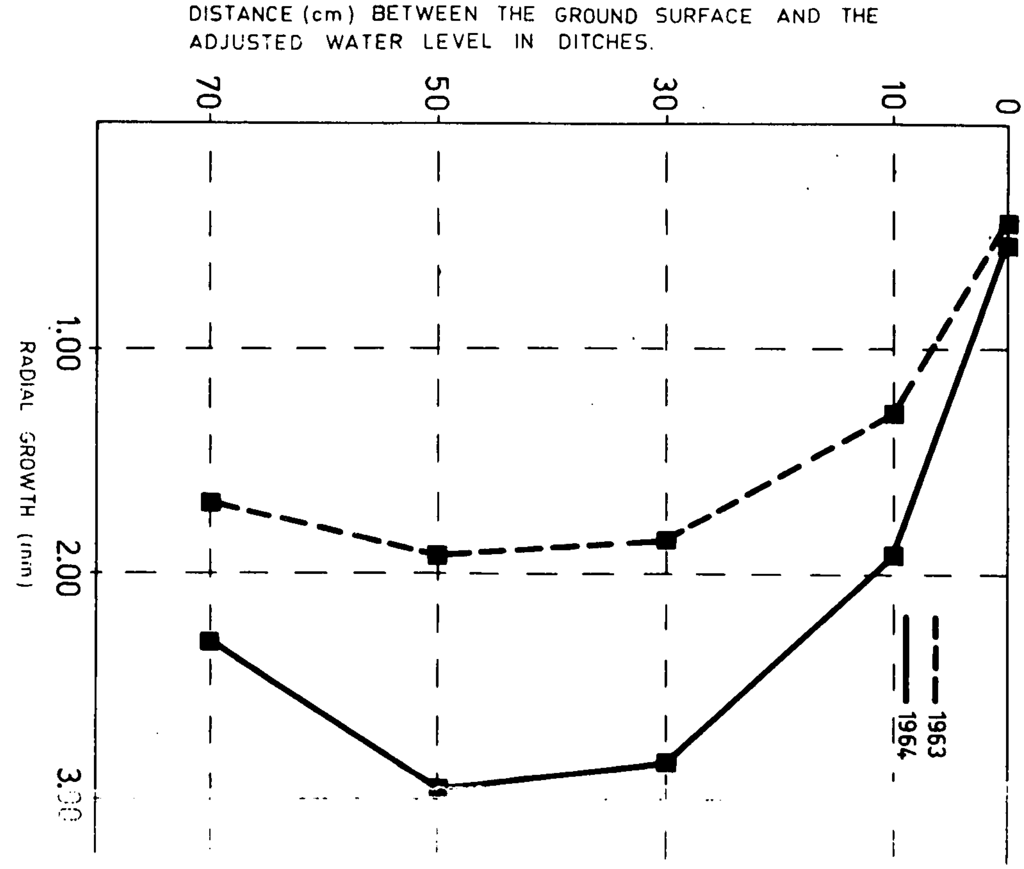
$$y = 12 \log x - 1,$$

in which y = penetration of the roots and x = depth of the ground water table, cm.

Altogether, the Finnish investigators' general conception is that the ditch depth is determined by other technical factors, such as the capacity of ditches to remain in good repair, etc. Consequently, ditch spacing is the only factor that influences the efficiency of drainage to a decisive degree.

Naturally, the ditch spacing and ditch depth are not per se parameters of drainage efficiency. The depth of the ground water table, on the other hand, can be considered such a dimension. In all our experiments aiming at a detailed clarification of the problems connected with ditching, the depth of the ground water table has been used as a dimension for the efficiency of drainage. For instance, Huikari and Paarlahti (1967) have established experiments in which the ground water table has been regulated to a certain level by means of weirs: namely 0, 10, 30, 50 and 70 cm below the ground surface. The growth response of the stand has been followed over several years. Generally speaking, the results obtained from various experimental areas seem to indicate that growth increases with increasing depth of the ground water table up to 50 cm. However, in areas where the water table was regulated to 70 cm depth, the growth was in several cases inferior to that measured in areas with a water regulation at 50 cm depth (cf. Fig. 1). This experiment probably indicates that a drainage depth of 70 cm already means over-drainage, and this information is extremely valuable. On the other hand, the experiment indicates that regulation of the water table to 30 cm already produces growth similar to that obtained with a regulation to 50 cm and, on several occasions, 70 cm, too. Consequently, the range of variation of proper water relations is evidently quite large.

Fig. 1. Dependence between the radial growth and ground water level (according to Huikari and Paarlahti 1967).



THE PROBLEM OF OPTIMUM DRAINAGE

By means of the experimental design described in the foregoing we are able to solve on each separate occasion the problem of drainage efficiency in a reliable manner. However, nature displays great variation. The climate of different regions varies, and, even within the same climatic regions, considerably different peat types are encountered. Solution of the problem of optimum drainage also deserves theoretical consideration. Interpretation of the results obtained from field experiments of the kind mentioned is possible only when based upon theoretical research. As stated by several investigators (e.g., Richard, 1953), the influence of drainage on the water content of the soil can be explained primarily by studying soil-water-energy relationships. In the following, I am going to consider the problem of optimum drainage on the basis of the studies carried out lately at the Department of Peatland Forestry, Helsinki University. The presentation is of a methodological nature, but two examples were chosen for the illustration of the solutions arrived at when using the method to be presented. The examples represent extreme cases, one of the peat kinds being well humified, wooded sedge peat and the other, poorly humified Eriophorum-

Sphagnum peat.

The problem of optimum drainage may be divided into three partial questions: 1) What is the optimum water content of the rhizosphere, or the topmost soil layer which is utilized by roots, for the growth of trees? 2) At what ground water depth, or drainage depth, is the desired water content of the rhizosphere achieved? 3) What measures, or ditch-depth and ditch-spacing combinations, lead to the desired drainage depth?

Indication of the water content of the rhizosphere by means of the soil-water-energy relationships enables us to compare the water content of different soils in respect of the water utilization of plants (e.g. Schofield, 1935; Heinonen, 1954). In the present connection, the pF-concept is used to indicate the soil water tension.

It still remains unclear what soil water tension corresponds to the optimum water relations in respect of tree growth. We know that when the substratum is saturated by water or when its water content exceeds that presupposed by the field capacity, it is anaerobic to such a degree that tree growth is arrested. Further, we know that the wilting point, too, means difficulties with regard to the water supply for trees (e.g. Richard, 1953; Godman, 1959). In order to exhibit the idea of the presentation at hand, it might be permitted to assume that the optimum curve of the water relations of the sites growing certain trees takes such a form that pF 2 corresponds to the optimum water content, while 1.5 represents maximum and 3.0 minimum water content. The pF-values thus would limit the range of variation within which the water content ought to be kept when striving for satisfactory growing of timber.

Fig. 2 presents the sorption curves for the two different kinds of peat - the poorly humified Eriophorum-Sphagnum peat (ErS-t, H_{1-2}) and the well humified woody sedge peat (LC-t, H_9). According to the figure, the water content values corresponding to the limits and an optimum as assumed previously are as follows:

	pF 1.5 Maximum	pF 2.0 Optimum	pF 3.0 Minimum
	water content, percentage water of the volume		
ErS-t, H_{1-2}	64	45	32
LC-t, H_9	70	58	44

The drainage depth. Several investigations have proved the existence of a marked correlation between the depth of the ground water table and the water content of the rhizosphere (cf. Richards, 1941; Juusela, 1945; Eggelsmann, 1957; Heikurainen et al., 1964). In drained peatlands in Finland - the subject of this presentation - the thickness of the rhizosphere is only 15-25 cm (cf.

Fig. 2. Moisture sorption curves. The water content is expressed as per cents of the soil volume

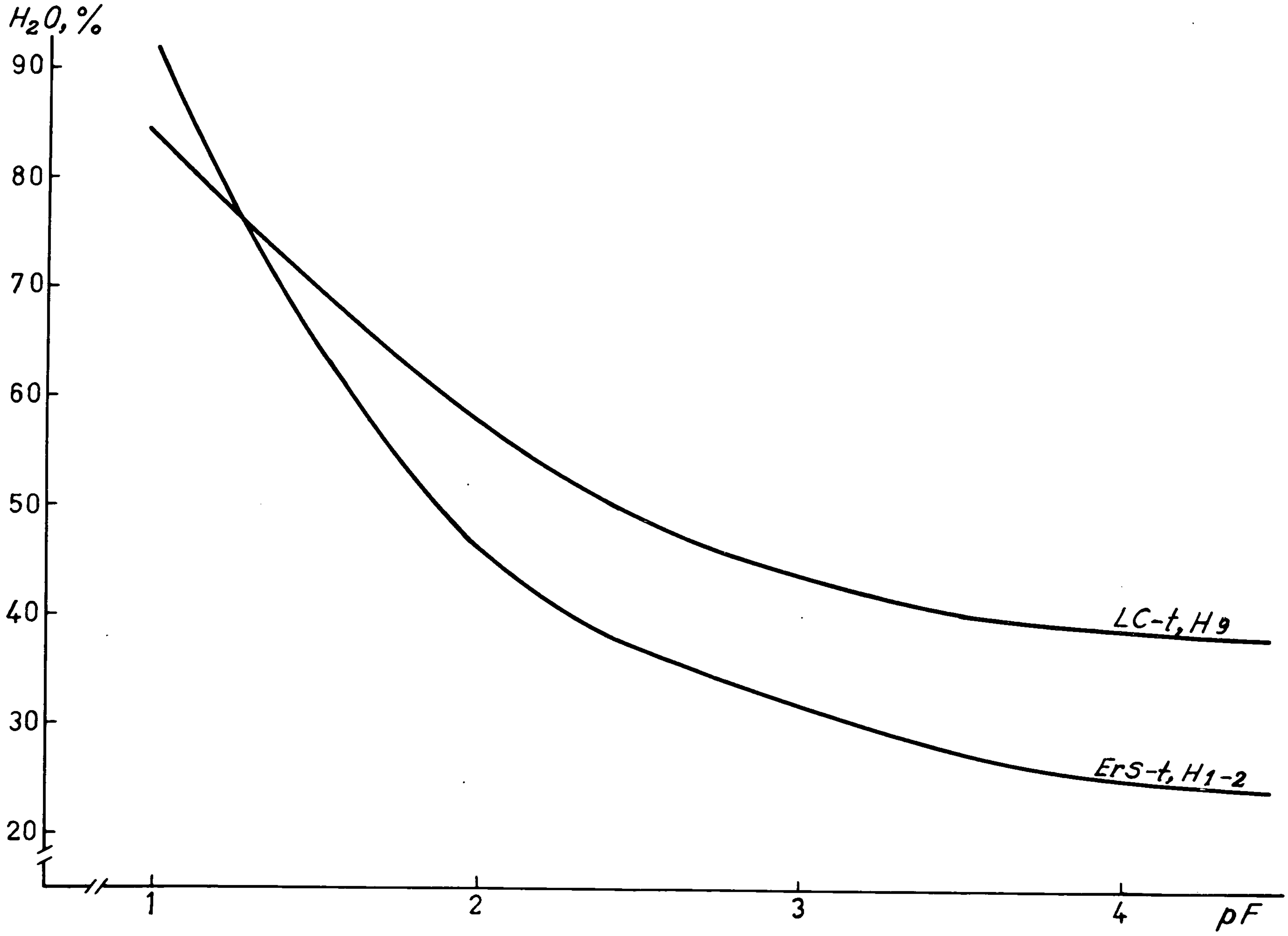
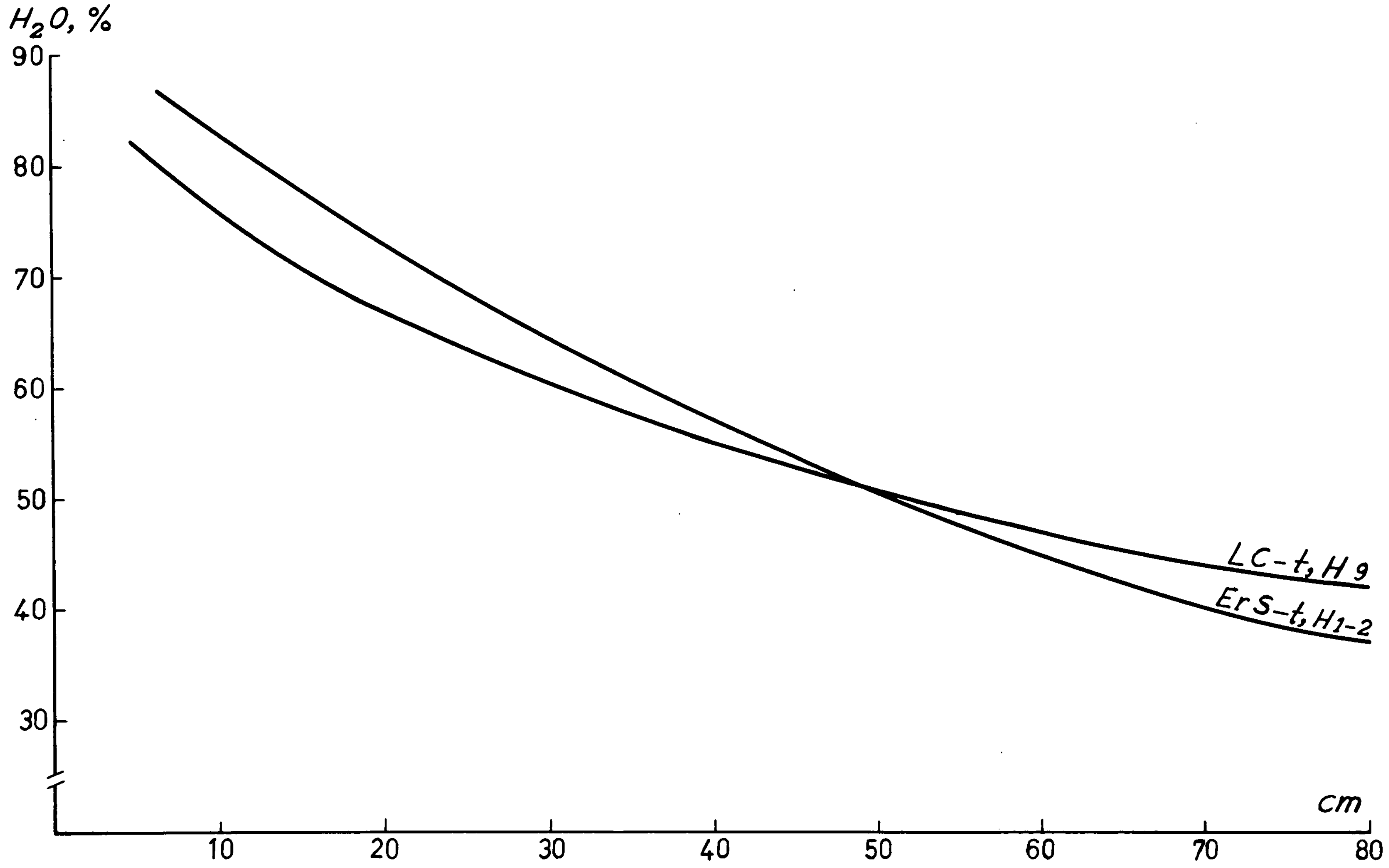


Fig. 3. The dependence of the moisture content (volume basic) on the depth of the water table



Heikurainen, 1955; Paavilainen, 1966). In the present study, the water content was measured for a superficial peat layer 17 cm in thickness. Fig. 3 shows the correlation between the water content of the rhizosphere and the depth of the ground water table in our examples. The drainage depths corresponding to the assumed limit values of the water content of the rhizosphere are consequently as follows:

	Minimum	Optimum	Maximum
		drainage depth, cm	
ErS-t, H_{1-2}	30	60	> 80
LC-t, H_9	17	34	69

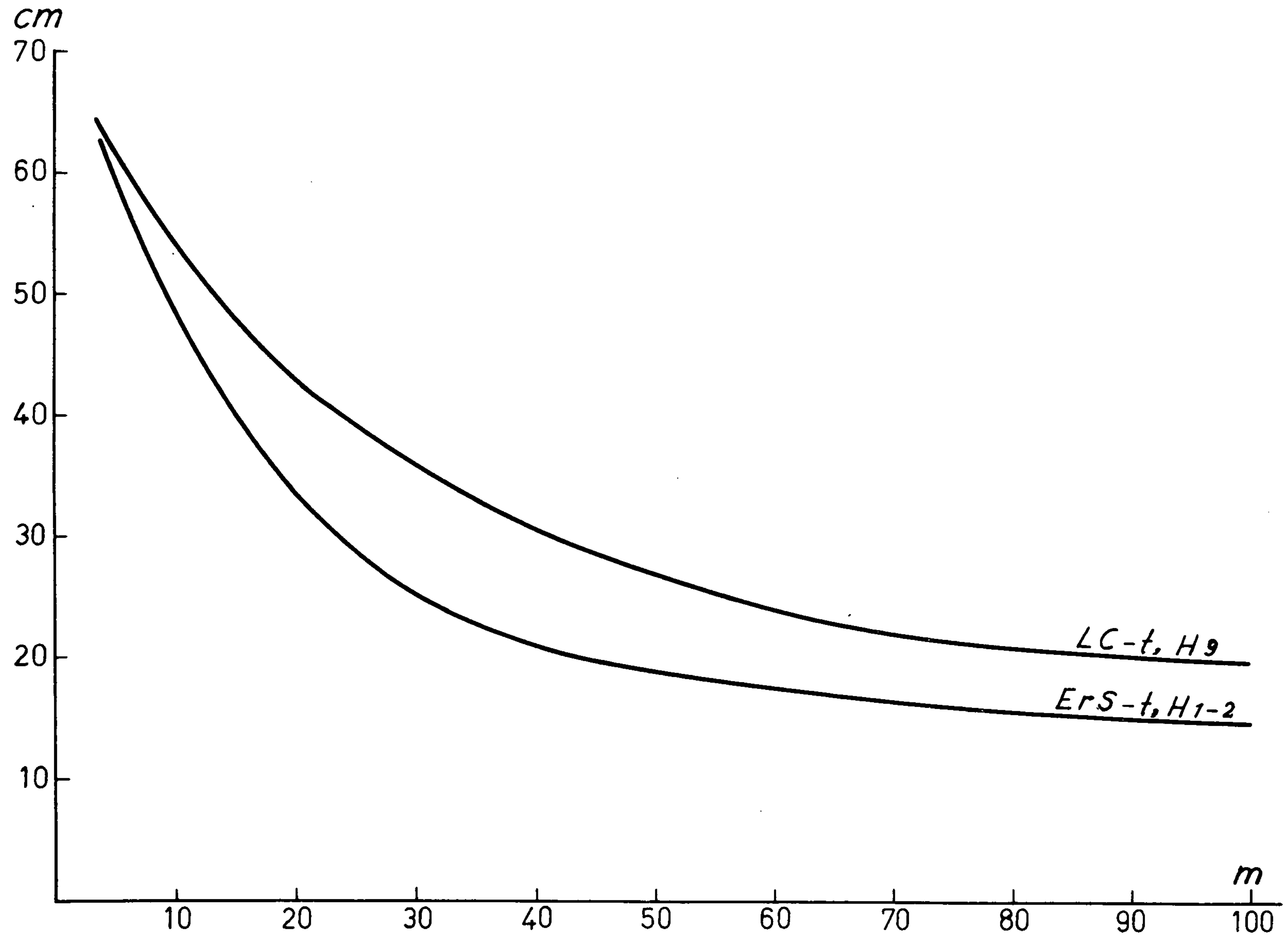
The combination of ditch depth and ditch spacing. When using customary means of regulation of the water relations, the desired drainage depth can be attained by numerous combinations of ditch depth and ditch spacing, as has been proved, for instance, by Meshechok (1960) in Norway. Certain technical factors may limit the number of combinations: for instance, when the ditching machine used only makes ditches of a certain depth. In Finland, for instance, the ditching ploughs usually used in forest drainage dig ditches 60-80 cm in depth. The climate conditions, too, or possible special properties of the peat, may influence the combination to be employed either toward dense and shallow or sparse and deep ditching.

When it is attempted to find out the ditch spacing and ditch depth which leads to the desired drainage depth, field experiments are probably the most reliable means. In our example, the means for June through August in 1965, 1966 and 1967 was used. These three summer periods were more or less average with regard to rainfall. In our experiment, the ditch depth was constant (75 cm) and Fig. 4 shows the dependence of the mean drainage depth on the distance between ditches. The following table shows the ditch spacing which corresponds to the minimum, optimum and maximum drainage depths as obtained from the Figure.

	The ditch spacing (m) leading to a drainage depth of		
	Minimum	Optimum	Maximum
ErS-t, H_{1-2}	24	5	Δ
LC-t, H_9	∞	34	2

In the case of our example, the assumed minimum effect of drainage could be achieved only by a ditch spacing as dense as 24 m in poorly humified *Eriophorum-Sphagnum* peat. Optimum drainage, however, would require a distance of 5 m between the ditches, the ditch spacing corresponding to maximum drainage being small enough to be of only theoretical significance. In well-humified, woody sedge peat the greatest distance permitted between the ditches would be very great; optimum drainage would be achieved by 34 m ditch spacing and about 2 m between the ditches

Fig. 4. Mean depth of the water table at varying ditch spacing



would lead to over-drainage.

ABSTRACT AND CONCLUSIONS

Table I examines the water content and drainage depth provided by different water relations of the rhizosphere for the kinds of peat presented, as well as the varying ditch spacing leading to these different conditions in the water relations when the ditch depth is 75 cm. The Table allows rather free interpretation of the results: for instance, in the case in which the growing of timber would presuppose values of the water relations that differ from the assumed limit values of this presentation.

TABLE I

The water content, drainage depth, and ditch spacing corresponding to the variation (pF 1.5-3.0) in the soil water tension in the rhizosphere in the cases of our experiment when the ditch depth is 75 cm

Soil water tension, pF	Water, per cent of the volume	Drainage depth, cm	Ditch spacing, m
	ErS-t, H_{1-2}		
1.5	64	30	24
2.0	45	60	5
2.5	37	77	2
3.0	32	80	Δ
	LC-t, H_9		Oo
1.5	70	17	
2.0	58	34	34
2.5	49	53	11
3.0	44	69	2

We can see from the table that there is actually no drainage corresponding to pF 1.5 in well-humified woody sedge peat. In the poorly humified <u>Eriophorum</u>-<u>Sphagnum</u> peat, however, we can already speak of a drainage corresponding to a soil water tension of pF 1.5. As a matter of fact, according to several investigators, this tension forms the lower limit of the saturated water content. On the other hand, drainage corresponding to pF 2.0 already seems to be a reality in both of these two cases. For the woody sedge peat it would correspond to a drainage that at present is quite normal in Finland. For the <u>Eriophorum</u>-<u>Sphagnum</u> peat, on the other hand, drainage should be extremely efficient. It would be attained only by employing ditch spacing as narrow as 5 m. It is probably possible to attain water relations corresponding to pF 2.5 in woody sedge peat even in practical ditching activity; on the other hand, in practice, such a degree of drainage can never be reached in <u>Eriophorum</u>-<u>Sphagnum</u> peat. If we assume that pF 3.0 corresponds to over-drainage, we may conclude that there is no risk of over-drainage in either of the peat types studied.

The thought presented in the foregoing is based upon the somewhat uncertain assumption that there would be a correlation between the soil water tension and tree growth. Apparently, lack of oxygen is a factor that arrests growth to an essential degree in the lower end of the soil water tension, i.e., when water is abundant; the excess water per se is not such a factor.

The study results that I have dealt with in the foregoing point to the fact that the concept of optimum drainage may virtually be of purely theoretical interest. Actually, the growth of tree stands is almost the same within a quite large range of different water relations. Of course, there exists a limit of minimum drainage. On the other hand, the possibility of over-drainage, at least in the climatic region covering Finland, is of no more than purely theoretical importance. In practical ditching there is hardly any risk of over-drainage. However, one can conclude on the basis of the studies carried out that the limit values of a proper drainage differ to a large extent in peat of different types and degrees of humification, as well as within different climatic regions.

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THE BASIC PRINCIPLES OF DRAINAGE ON PEAT

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INTRODUCTION

The basic principles of drainage on peat are essentially the same as those on any soil. The objective in drainage is to remove, as quickly as possible, surplus water that would interfere with crop production. This interference with production is exhibited in many ways. Root development may be restricted due to inadequate aeration, or roots, which have developed while the soil was dry, may be killed if sustained water logging takes place. Excess water in the soil interferes with cultural operations and the structure of soils which are tilled while wet can be adversely affected. As soil strength is related to moisture content, the bearing strength of soil can be greatly reduced by excess water and this can cause problems in all farming operations. Tillage and harvesting operations are difficult and treading damage by livestock is acute on wet soils.

The thermal properties of soils are also affected by drainage. Wet soils are colder and slower to warm up than dry soils.

Thus the specific reasons for draining soils are:

(1) to provide a suitable medium in which plant roots can grow and ramify, and to ensure that the roots are protected against subsequent prolonged water logging.

(2) for operational purposes, soils are drained so that they can be tilled easily at the required times and carry the necessary traffic - livestock and machinery.

(3) to improve the thermal properties.

Drainage for root development

A healthy and vigorous root system is essential in crop production and there is a close relationship between degree of drainage and root development. Kramer (1966) has described the principle functions of the roots as follows:

1. Anchorage
2. Water absorption
3. Mineral absorption
4. Synthesis of hormones and other organic compounds.

Many plants can tolerate poor drainage to some degree and while some plants thrive in waterlogged conditions, most of the economic crops grown here require well drained soils. The oxygen/carbon dioxide ratio in the soil appears to be the most important factor.

It is known that root respiration depends on the rate of oxygen supply and on the relative amounts of oxygen and carbon dioxide that are present. Plants vary in their requirements and the morphology of the plant root in conjunction with the physical properties of the soil determines the pattern of root development. Aquatic plants often have large intercellular cavities through which gaseous exchange can take place. In other plants the intercellular space is small and this restricts internal gaseous exchange. Woolley (1966) has shown that in an average corn root with 8 per cent intercellular space enough oxygen can diffuse down the root to supply 10 cm. of root length while in an aquatic root with 75 per cent intercellular space enough oxygen can diffuse to supply 50 cm of root length. When waterlogging of the soil occurs the O2/CO2 balance is upset and if the condition persists roots may be killed.

When the development of roots in what are normally deep rooting plants is restricted, it is usually due to mechanical or chemical impedence in the soil, or to a permanently high watertable. Examples of factors causing mechanical impedence to roots are iron pans, cemented layers and plough soles. Chemical impedence can occur when roots meet a layer with a very low or very high pH. Whatever the cause of impedence the effects are the same, although here we are more concerned with impedence caused by waterlogging.

A restricted root system gives poor anchorage and very often trees that are uprooted in a storm are seen to have shallow roots. Because of the small soil volume occupied by a restricted root system, nutrients may be in short supply and in dry weather water also.

The effects of a fluctuating watertable on roots are even more serious than those of a permanently high one. Such factors as type of crop, time of year, temperature, composition and chemical properties of soil and the duration of saturation in the root zone are all involved. When a fluctuating watertable falls new roots can develop in the drained soil space. When the watertable rises again these roots are submerged. While all crops can tolerate some submergence of roots, prolonged submergence is serious and damage varying from slight to complete destruction of the crop can occur.

Drainage for operational purposes

The strength of a soil is related to its moisture content - the higher the moisture content the weaker the soil. In most forms of land use it is necessary for either machines or livestock to move over the ground. Drainage, by rapidly removing excess water preserves, increases the soil strength thus guarding against difficulties in the use of machinery and against poaching or pugging damage by livestock on pastures.

Drainage and thermal properties

Baver (1959) states that the specific heat of the mineral portions of soils ranges from about 0.2 to 0.25 and that the specific heat of dry humus is about 0.16. The specific heat of water is 1. As it takes about 4 times more heat to raise the temperature of a volume of water than it takes to raise the temperature of an equal volume of the mineral part of the soil by the same amount, it is obvious that water logged soils are slow to warm up and tend to remain cold throughout the year. This "coldness" in soil is further aggravated by evaporation from wet soil. Heat which could otherwise raise the soil temperature is used instead to evaporate water.

PHYSICAL FACTORS IN DRAINAGE

In considering drainage as a physical process, it is necessary to take into account most aspects of the hydrological cycle as well as the physical properties of the soil. The important hydrological components are precipitation, evaporation, infiltration,deep seepage and water storage.

Precipitation and Infiltration

Water arrives at the soil surface as precipitation and enters or infiltrates into the top soil. The maximum rate at which water can enter a soil surface is called the "infiltration capacity". This varies with soils, surface conditions, crop cover and season. Measurements on Irish soils (by double ring infiltrometer) have shown infiltration capacities that varied from 0 to 0.33 mm per hr on heavy soils to 10 mm per hr on good pasture soils. Musgrave (1955) has given a tentative list of some U.S. soils in order to Minimum Infiltration Capacities as follows:

Lowest group	0 - 1.25 mm/hr
Below average	1.25 - 3.8 mm/hr
Above average	3.8 - 7.6 mm/hr
Highest	7.6 - 11.4 mm/hr

The importance of infiltration capacity lies in its relationship with rate of rainfall. While rainfall rate exceeds infiltration capacity only some of the rain gets into the soil, and the surplus flows over the surface to open ditches or streams but often gets trapped in depressions. These depressions act as reservoirs to keep the soil saturated in patches for long periods. This effect can be seen in wet patches that persist in fields through the winter or in the continually wet top soil in a badly poached pasture. The hoof marks here provide the storage space.

When water has infiltrated into the soil, the excess seeps through. If the soil is highly permeable it passes quickly to greater depths, but if the soil is only slightly permeable or if impedence occurs due to an impervious layer, the soil becomes waterlogged, (temporarily or permanently) and it is necessary to provide artificial field drains.

Evaporation

Since evaporation removes a large amount of water from the soil it must be considered as a factor that is related to drainage. About 15 to 18 inches of water are evaporated from the soil in Ireland through a grass cover each year, and most of this loss takes place between April and October. Over much of Ireland evaporation and rainfall are nearly equal during the Summer, and very little drain flow takes place. In winter there is a surplus of rainfall and almost no evaporation. The soil becomes wet and there is much drain flow.

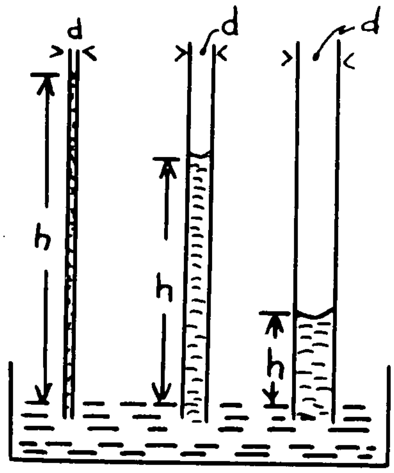
Changes in vegetation on peat may cause some change in evaporation rate. This change is mainly due to the different physical properties of the surface of the altered vegetation and to changes in root systems within the peat. While the magnitude of these changes has still to be measured it is likely that they are often relatively small.

Water Retention

When drainage is complete and no more water flows from the soil it still remains moist and the amount of moisture retained varies with the soil. This moisture is held by surface tension forces in small soil pores, and as thin water films on soil particles.

Soil consists of particles of material in contact, with pore spaces between the particles. The finer the particles the finer the pores and a series of fine pores connected together vertically resemble a capillary tube. If one end of a capillary tube is placed in water, water will rise in the tube to a level which depends on the diameter of the tube (Fig. 1). Water will rise to different levels in tubes of different diameters and it can be shown that at 20°C the approximate relationship $h = \frac{0.30}{d}$ cm holds where d = diameter of tube bore (cm) and h = height to which water rises (cm). The watertable in a soil may be regarded as corresponding to the water in which the end of the capillary tube is placed. Depending on pore diameter, water will stand at varying heights above the watertable in the finer pores but some of the larger pores will not hold water. Similarly, when a drain is made in soil that has a watertable, the watertable is lowered to the level of the drain bottom, but the finer pores still retain some water. The total amount of water held in a soil after drainage depends on the amount of pores of different sizes in the soil.

Fig. 1. Capillary Rise



Peat which has a high colloidal content and many small pores retains much water after drainage. Peat with larger pores often shrinks with drainage due to collapse of the pores. The net effect is that the moisture content of such peat is sometimes only slightly reduced by drainage, although a reduction in volume with accompanying subsidence may have taken place.

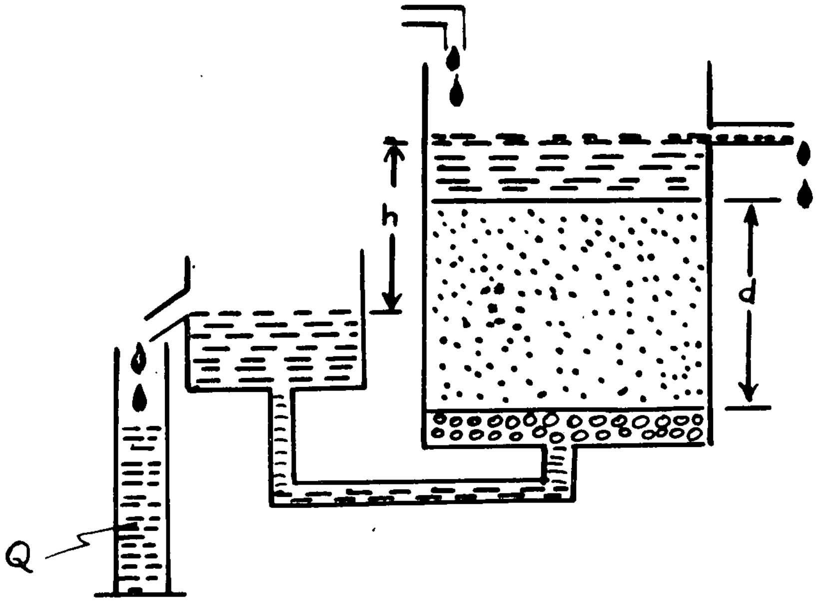
Water Movement

The most important early studies relating to water movement through soil were probably those carried out in 1856 by a French engineer called Darcy. His experiments resulted in the following equation which is regarded as the basic equation for water flow through a saturated soil.

$$\frac{Q}{t} = \frac{K.A.h}{d}$$

Q is the quantity of water that flows in time t across an area A under a hydraulic head h through a medium of thickness d (Fig. 2). K is a coefficient that depends on the physical properties of the medium and is called the hydraulic conductivity.

Fig. 2. Darcy's Law



Darcy's experiments laid the foundation for the development of equations describing the continuity of flow in porous media. Equations to describe watertable draw-down, unsaturated flow, and various other aspects of soil moisture movement are now available. The importance of K (hydraulic conductivity) is apparent from Darcy's equation. It occurs in all equations that relate to soil water flow. It determines the rate at which water can move through the soil and is mainly dependent on soil porosity.

Hydraulic Conductivity

Water moves more freely through large than through small pores. Therefore a coarse textured soil with large pores will drain faster than a fine textured one, and the latter soil will hold more water by capillarity than the former after drainage has taken place. Childs (1957) has shown that the hydraulic (K) conductivity is dependent on soil structure and pore geometry but that there is little hope of being able to calculate hydraulic conductivity from pore geometry in real soil because of the complexity of the porosity. Hydraulic conductivity must be measured and this in itself can be a difficult operation.

DRAINAGE DESIGN

While the factors discussed above are basic to any broad consideration of drainage, it is usually necessary to look closely at the immediate situation. All drainage problems do not arise directly from precipitation excess (in rate or amount) at the problem area. Water often moves either over or through the ground to cause problems related to seepage, springs and flooding. These are special problems and are dealt with by locating the drain or drains in the proper place and at the required depth.

When the need for drainage arises from a simple excess of water in the soil without complications due to flooding or excess piezometric pressures, drainage design is based on the relationship between rainfall and hydraulic conductivity, taking into account such factors as the required rate of water removal, the level to which the watertable will be let rise, and the length of time which it will be allowed to remain at this high level. A knowledge of these factors permits the required depths and spacings to be estimated. The factors apply equally to peat and mineral soils with some differences where peat is concerned.

When hydraulic conductivity is very low, and it can approach zero, the drainage system is limited to some form of surface drains or open drains with or without surface levelling and cambering to assist rapid run-off of precipitation water.

PEAT DRAINAGE

Peats differ widely in their physical characteristics and therefore in their drainage properties. There are 2 main sources of difference - the botanical material from which peat is derived and the degree of decomposition of this material. Examples of different materials are woody residues, reeds and sphagnum mosses. The raw peats derived from these materials are very different in composition. When decomposition sets in, the original materials are modified and changes take place in their physical properties. Subsequent operations such as reclamation, drainage and fertilisation bring about further changes. The net result of the interplay of these factors is that a great range of peat types occur and, just as different types of mineral soil have different drainage requirements, so also have different types of peat soil. Apart from visible differences in colour and texture, or differences measured on the Von Post Scale, there are also variations in hydraulic conductivity, water retaining capacity, colloidal content, strength, density etc.

Drainage design in peat must take into account the physical properties of the peat and the purpose for which it is to be drained, in addition to the components of the hydrological cycle at the site. Very often it is unnecessary to make detailed measurements of the physical properties of the peat. If it is uniform, experience can be a good guide in predicting the drainage requirements. When necessary it is possible to measure the hydraulic conductivity and estimate the type and intensity of drainage required.

In measurements made on Irish peats, hydraulic conductivity ranging from almost nil to more than 30 cm/day have been found. The high conductivities were found on unworked woody peats on raised bogs in the midlands and the low ones on the highly humified blanket peats in the west of Ireland and some highly humified basin peats in the midlands.

However, drainage in peats and particularly in soft peat is not a simple matter of depth and spacing. The peat is often too unstable to permit deep open drains to be made and in these circumstances, where drain depth is limited, water control must be achieved by placing drains as near to each other as necessary for the maximum depth that can be achieved, or by installing a covered drain system. For example, the control of the watertable in the type of peat that occurs at Glenamoy requires drains spaced at 12 to 15 feet. This intensive spacing has been found necessary because of the low permeability of the peat which is so weak that drains deeper than about 2½ to 3 feet will not stay open. Furthermore, it has been demonstrated (Galvin and Hanrahan, 1968) that in this peat drains placed at greater depths than 3½ feet have disadvantages due to a reduction in the hydraulic conductivity of the peat when deep drains are installed. Some discharge values with corresponding hydraulic conductivities are given for different well drawdown depths for Glenamoy in Table I.

TABLE I

Daily Discharge figures from Well (Steady state assumed) and corresponding permeability values

Well Drawdown (ft)	Measured Discharge per day (ccs)	Average Permeability cms/day (Dupuit)
1	12,816	0.97
3	24,804	0.65
5	21,859	0.38
7	19,911	0.29

The use which will be made of the drained peat arises in the provision of a suitable drainage system. Open drains which are quite suitable for forestry have serious disadvantages in livestock farming. The main disadvantages are danger to livestock, drain maintenance, and loss of land surface when intensive drainage is required. Open drains 2½ feet wide at the surface at 4 to 5 yards spacing reduce the land surface by 16 to 20 per cent.

In the final analysis a drain is merely a channel to facilitate the rapid removal of water from the soil. Its most important properties are that water must get into it, it must be stable and it must have adequate capacity. In peat, stability is usually the most critical factor.

Peat is seldom a stable material and when drains are opened in it this lack of stability causes problems. The opening of a drain about 3 feet deep reduces the load on the drain bottom by about 1½ lbs per square inch. Loads imposed by drain banks, excavated spoil, and horizontal and vertical seepage forces may cause total or partial closing of the drain in peat. This type of drain failure is a major factor in the high maintenance costs of open drains on soft peat. If covered drains can be installed, most of this instability can be eliminated. However, heavy drainage materials like clay tiles and stones are unsuitable. Soft drain bottoms result in uneven subsidence and tile and stone drains go quickly out of alignment and fail. There is a saving in time and labour and drain stability is improved, if drainage can be done by ploughing as against drainage by excavators. The modern trend towards fully mechanised drain installation by ploughing seems to be particularly suitable to bog drainage.

Shrinkage often causes serious difficulties in peat drainage. Peat usually shrinks when it loses water and an effective drain system in peat can quickly lower the surface level of the peat to such an extent that the drains lose their effectiveness. Where such conditions are expected, open drains, which can be deepened as necessary, should be installed.

It is often claimed that the drainage properties of undisturbed peat improve with time after drains are installed. Drained peat usually improves with time and while the physical properties of the peat may improve, a change may not occur in the drainage properties. In one experiment, at Glenamoy, where watertable levels have been carefully monitored over 5 years, a slight change has taken place in the shape of the watertable, but the overall drawdown has not shown any worthwhile improvement. In another experiment where drains were also installed 5 years ago at 10 ft spacing no improvement has occurred in the average depth to watertable, but the physical properties of the surface peat have improved.

This is not a claim that improvement in drainage properties does not occur in peats with time. It probably does in many peats depending on peat type. The physical improvement in the peat after drainage comes mainly from consolidation following a reduction in surface water content and lowering of watertable. These changes are usually accompanied by a change in vegetation which further improves the bearing strength of the peat, e.g. soft mosses may be replaced by harder heather.

Where intensive drainage is required, drainage materials must be as cheap as possible. In order to test out various types of drains at Glenamoy, a large number of drains made from different materials was installed. These included several types of plastic pipes with and without porous backfill materials, peat sods, expanded polystyrene mesh, broken stone, coarse gravel and sea sand laid on strips of polythene. While most of these systems appear to be almost equally effective the main differences are in cost. At present, the type of drain which appears to offer most hope for success at Glenamoy consists of a band of coarse gravel approximately 3 inches by 3 inches in cross section laid on a layer of polythene. A prototype plough to instal such drains has been made. These drains can be installed with minimum disturbance of the peat. There is no excavation and the introduction of the 3" x 3" band of gravel causes but little change in internal pressures in the peat. The polythene layer by distributing the load provides a safeguard against uneven subsidence.

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EFFECT OF WATER TABLE HEIGHT ON GROWTH OF PINUS CONTORTA ON DEEP PEAT

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INTRODUCTION

Considerable areas of both upland and lowland peat have been afforested in recent years and the amount of tree planting on this type of ground is increasing annually. This is necessary if afforestation in this country is to be extended, desirable because it is the most productive use to which much of this land can be put, and practicable because of the development of tractors and ploughs which can operate on organic terrain.

Almost without exception ground conditions have to be modified before trees can be established on deep peat. This usually involves fertilization and some improvement of the physical condition of the peat. Direct notch planting of trees in peat is not generally successful, and some form of turf planting, for example on an upturned sod or plough furrow, is usually adopted. It is generally assumed that the upturned turf provides a more aerobic environment for tree roots than the undisturbed peat, but little attempt has been made to confirm this assumption by direct measurement under field conditions. Such information is obviously required if the rooting habits of trees planted on peat are to be fully understood, and could be immensely valuable in assessing the potential of new ploughing and drainage techniques which are continually being developed.

It was with this in mind that an experiment was set up at Inchnacardoch Forest, Inverness-shire, to investigate the effect of water-table height on the growth of Lodgepole pine (Pinus contorta) on deep peat. The experiment is still in progress and many studies are as yet incomplete. The purpose of this paper is to outline the work being done and to present some of the preliminary results.

EXPERIMENTAL

The experiment was laid out on a flat, shelf-like area of blanket bog (Grid ref. NH 328065) lying about 210 metres above sea level on the northern side of the Great Glen. The average depth of the peat on the experimental area is about 2 metres.

The experiment comprises five plots each measuring 30 metres by 3 metres and separated from each other by buffer strips 3 metres wide. Around every plot a ditch, 0.5 m wide, was dug and the water levels in these have subsequently been artificially maintained at the following fixed levels -

Plot I - 0 cm from the surface
II - 10 cm from the surface
III - 20 cm from the surface
IV - 30 cm from the surface
V - 50 cm from the surface

The levels are maintained by running a continuous supply of water into the ditch surrounding plot I, and allowing it to overflow, by connecting ditches, to the other four plots in succession. A weir of fixed height, installed at the outlet ditch from each plot, ensures that the water behind it is kept at the prescribed level. This system has operated satisfactorily since the outset, the only maintenance required being the occasional removal of debris from the ditches and weirs.

In April 1963 one third of each plot was planted with 105 transplants of Pinus contorta (1 + 1 of Skagway Alaska origin). Close spacing was adopted so that any effects of the trees on the peat would be intensified and apparent sooner. The planted areas were given fertilizer as were half the remaining parts of each plot. Each plot, therefore, comprised an untreated control section, a fertilized section, and a planted and fertilized section, all of equal area. The plants were notched directly into the undisturbed peat surface. The fertilizer application consisted of 344 Kg/ha each of nitrochalk (21%N), muriate of potash and triple superphosphate. The plots were given the same fertilizer treatment again in May 1965.

RESULTS

Height growth of the trees was assessed after the growing seasons of 1964, 1965, 1966 and 1967, and the results (Fig. 1) show the marked response to the lowering of the water table. This is further illustrated in Figure 2. The mean shoot increment over the four-year period is 0.05 m in plot I as against 0.27 m in plot V. This, in fact gives too favourable an impression of the growth in the waterlogged plot where the figure was derived from a sample of the surviving trees which, by the 1967 assessment, numbered only about one half of those originally planted. The trees showing growth in these waterlogged conditions are those which had been planted on slightly elevated areas such as tussocks of Sphagnum or Eriophorum. Tree heights increase progressively with increasing depth of water table although the response is least marked between plots II and III.

Response in terms of root development is being investigated but these studies are incomplete and results are not available at this stage. It will be of interest to see how root growth matches shoot growth under these conditions, because other aeration studies being carried out at the Macaulay Institute suggest that there is no straightforward relationship.

Fig. 1. Height of trees by treatment for years 1964-67

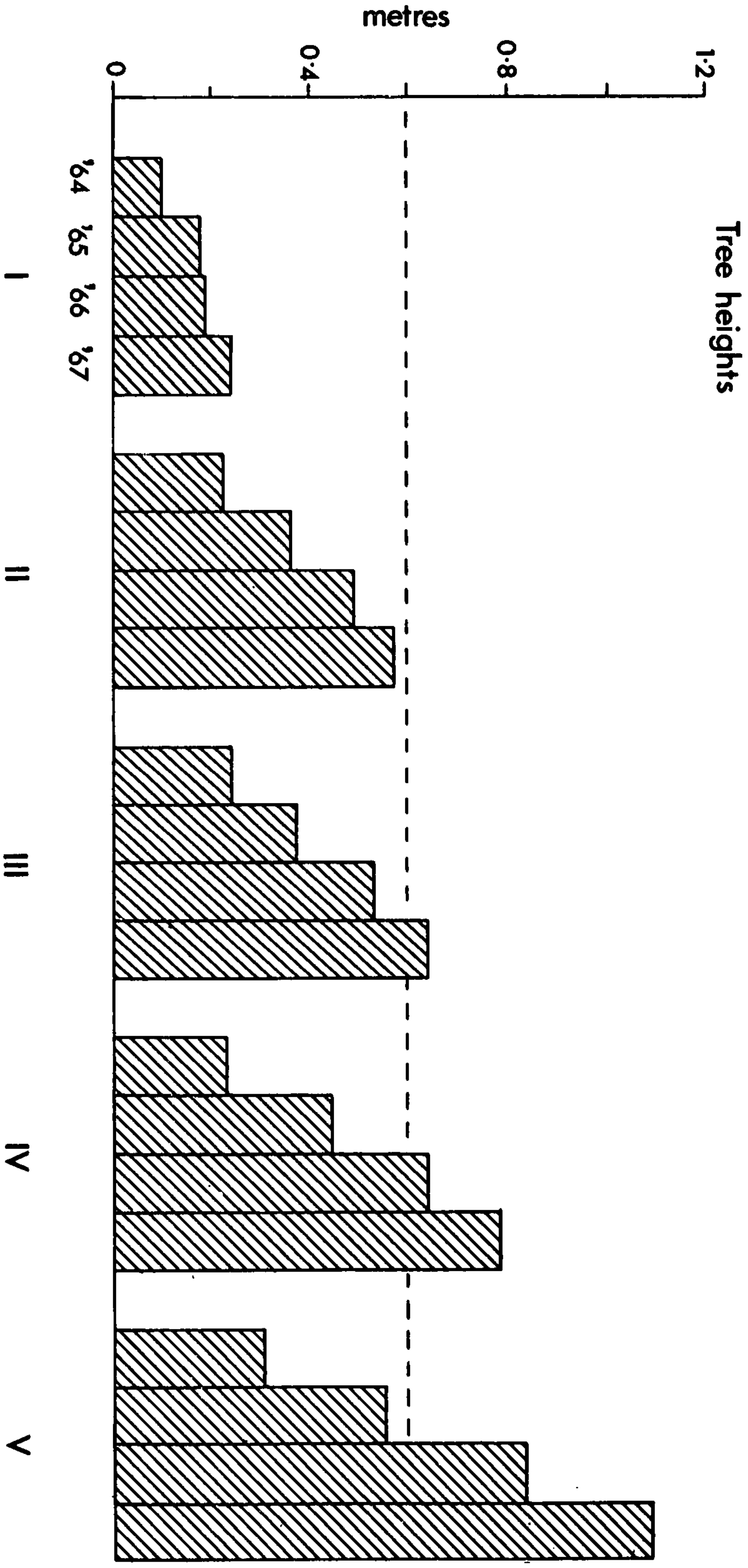


Fig. 2. Tree crops on plots I, III and V. (photographed September, 1968)

Foliage samples were taken at three-weekly intervals over a complete growing season and analysed chemically. The results showed certain irregularities but these are consistent across treatments and so far there is no indication that differences in contents of N, P, K, Ca and Mg are attributable to the water-table depth.

Water-table levels were recorded in each plot over two growing seasons. This was done by weekly measurements of water-levels in two wells positioned along the centre of each plot. From Table I it can be seen that in treatments I, II and III the main water-levels in the plots are very close to those in the surrounding ditches. In treatments IV and V, on the other hand, water-table levels are well short of those maintained in the ditches indicating a fall off in the response to treatment. The mean annual rainfall for the area is approximately 120 cm but for the two seasons during which water-table observations were made both quantity and distribution of rainfall differed considerably. Despite this, there is a remarkable similarity in water-table levels for the two periods, suggesting that under the prevailing conditions rainwater input has had little effect on water-table level.

TABLE I

Mean water table levels over growing seasons 1966 and 1967 (all measurements are from the surface)

Treatment	Mean Water Table Levels (cm)		Depth of Water in ditch (cm)
	1966	1967	
I	0.19 ± 0.10	0.09 ± 0.18	0
II	10.71 ± 0.35	10.99 ± 0.46	10
III	18.88 ± 0.55	18.81 ± 0.62	20
IV	24.14 ± 0.69	24.78 ± 0.76	30
V	33.94 ± 1.02	33.22 ± 1.00	50

Over the same periods the moisture contents of the peat profiles in each plot were studied. Duplicate samples were taken at intervals of three weeks from two widely separated points located at random on the centre line of each plot. Samples were taken from the depths 0-10, 10-20, 20-30, 30-40, 40-50 cm using a specially-designed sampler, and the moisture contents determined gravimetrically. The results for 1967 are shown in Figure 3. The overall pattern is not that which might have been expected. In plot I the moisture content is high at the surface and to a lesser extent this also occurs in plots II and III, but below a depth of about 10 to 20 cm there seems to be no consistent trend either within or across treatments. A series of pF curves for samples taken at the same depth as those for moisture determinations showed that for all five plots moisture retention characteristics at corresponding depths are

Fig. 3. Moisture contents by treatment and depth for growing season 1967

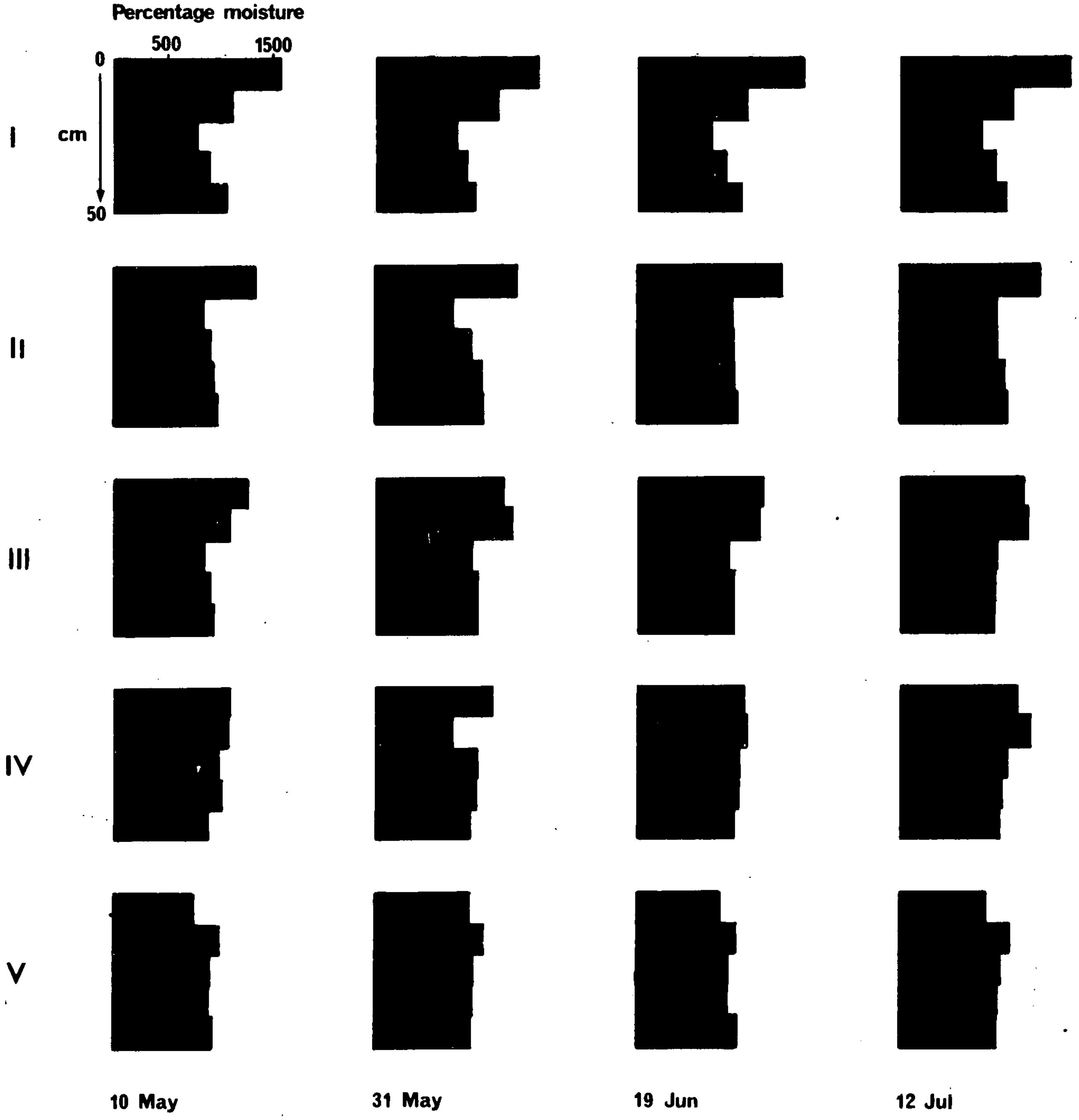


Fig. 3. Moisture contents by treatment and depth for growing season 1967.

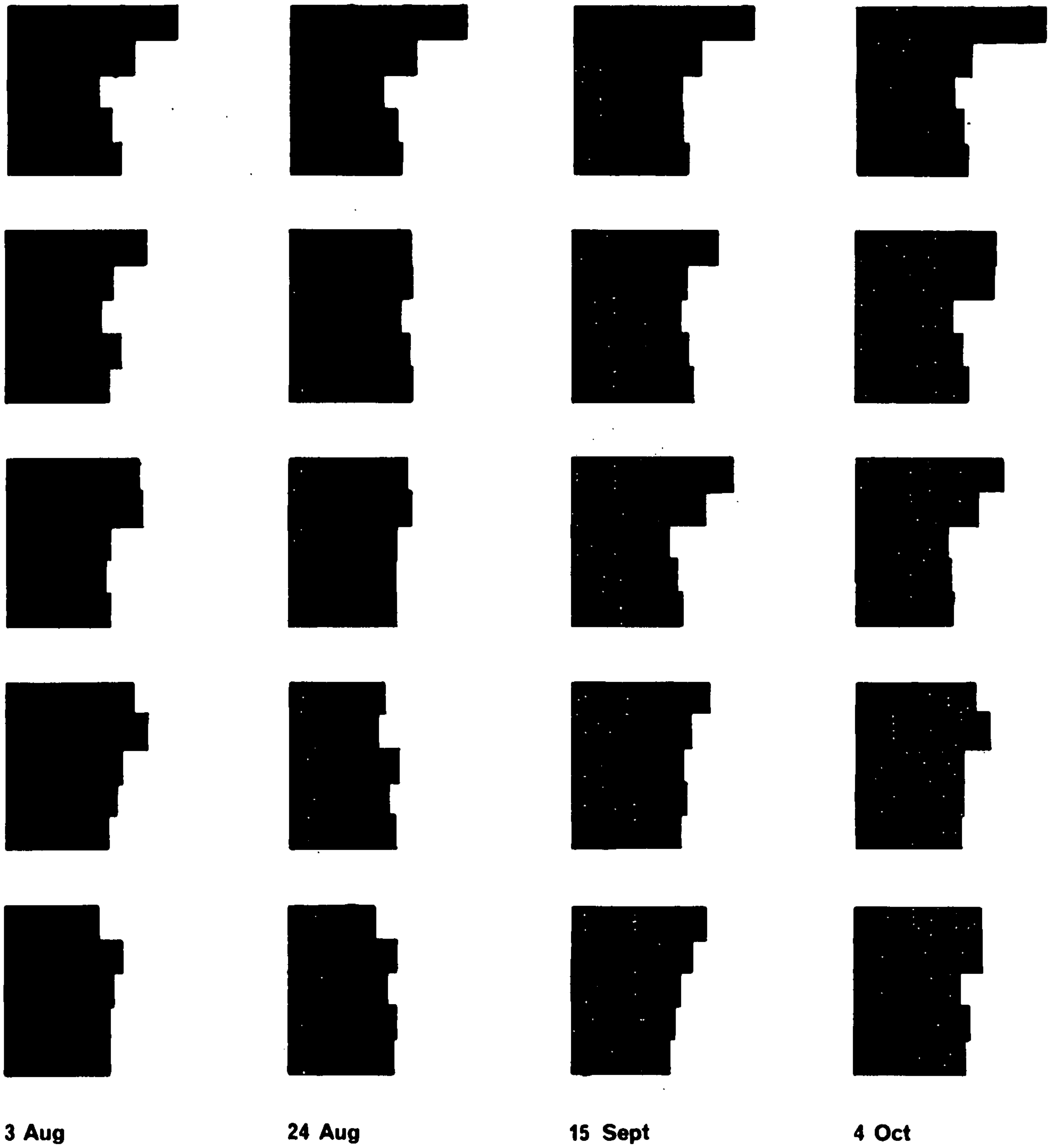
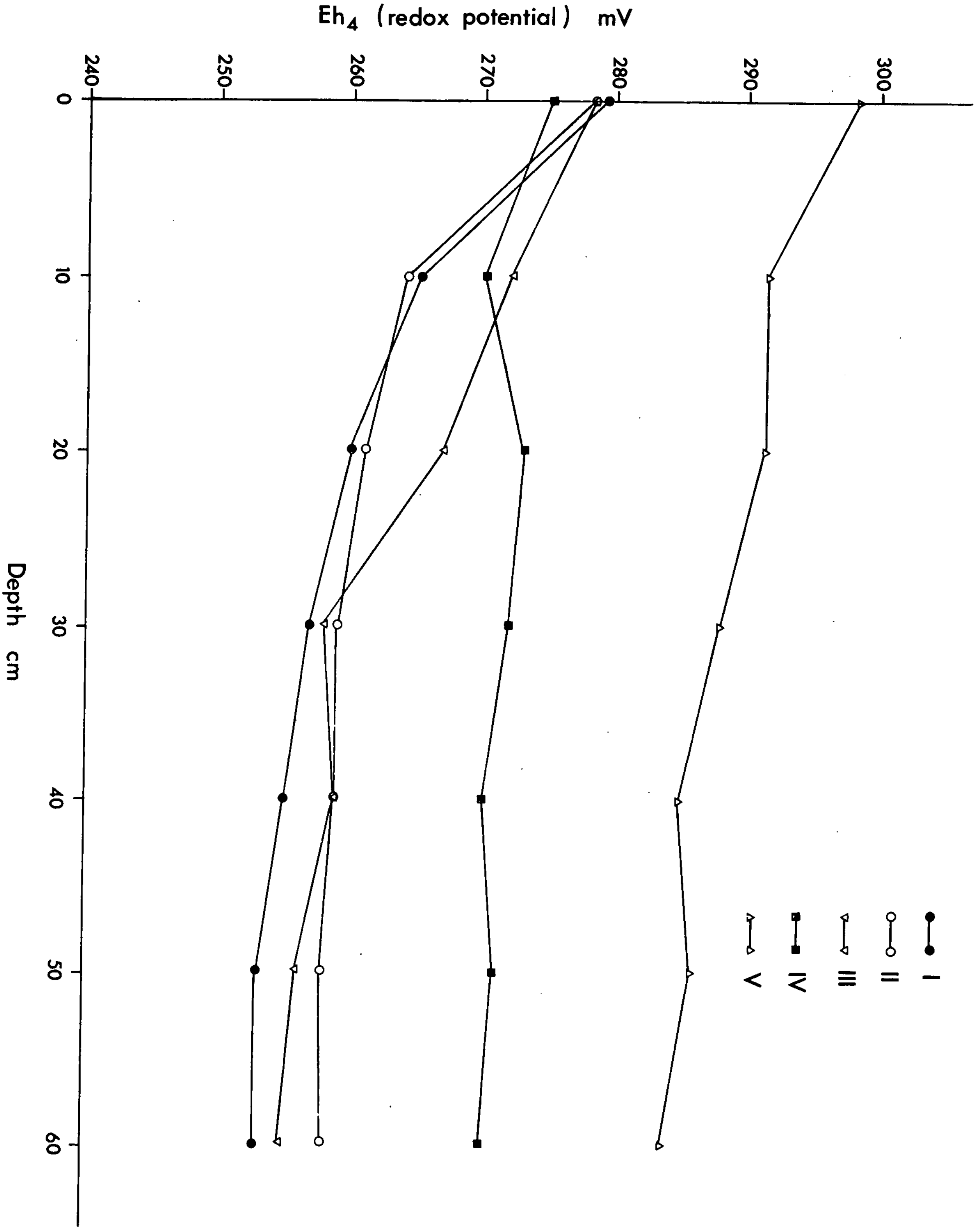


Fig. 4. Redox potential measurements at different depths in plots I-V. Means of four readings taken on 5 July, 1968.



similar and hence moisture contents at these depths are comparable.

Redox potential measurements were made periodically in all plots at depths down to 60 cm. This was done using a portable pH meter calibrated in mV, in conjunction with a platinum electrode and a saturated KCl calomel reference electrode. Although the values obtained varied according to the time of sampling, the overall pattern between plots remained constant. Mean values (corrected to the hydrogen scale at pH 4.0 - Eh_4) recorded on 5th July 1968 are shown in Figure 4. In so far as redox potential measurements indicate oxidation-reduction conditions in the peat, the improvements effected by lowering the water table are clearly demonstrated.

DISCUSSION

Although growth of the trees shows a marked response to the height of the water table in the peat, the reason for this is not entirely clear. Many observations have been made of the chemical and physical characteristics of the peat profiles under treatment but, in general, many of the results have shown that there are greater similarities between treatments than there are differences. The small effect of the treatments on moisture content of the peat was unexpected and it seems possible that the better growth conditions in those plots with lower water levels may have been due to some downward movement of water following rain. This movement may carry with it dissolved oxygen and nutrients and also serve to remove toxic substances formed under anaerobic conditions. It is possible, therefore, that the advantage of drainage is not so much in reducing the water content of the peat as in promoting a "flushing" with fresh rain water. There is some evidence that a downward movement of water does take place under these experimental conditions and this aspect is being investigated further.

HYDROLOGY IN RELATION TO PEAT SITES

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The basic relation between hydrology and peat is a relatively simple one, but it is important to express it as clearly as possible, to look at its implications, and see how circumstances complicate it.

Expressed in terms almost to the point of naiveté, it is that peat develops where the rate of evaporation of water never exceeds the rate of precipitation. No one would apply this to the length of absurdity in the case of a hot, dry desert, where, for instance, for years on end it never rains at all and there is nothing to evaporate; there might be one fall of rain, of perhaps one inch, in ten years, and this is not enough water, whatever the rate at which it evaporates, to enable a vegetation cover to develop. Yet even this case is covered if we restate the relationship by substituting for "evaporation" the words "potential evaporation" (P.E.); in a warm desert of course the potential evaporation will exceed precipitation except during the short period when the downpour is actually occurring.

Now let us look at the opposite extreme. Is there in fact a single place on earth where potential evaporation never exceeds precipitation? There probably is not. In the very rainiest places known - up to 600 inches per year - there are sunny intervals when P.E. exceeds rainfall. So we need to take such intervals into account. P.E. and air temperature both vary in direct relation to net solar radiation. Where this is low, short dry intervals will be of negligible significance; where it is high, they may be significant. In fact, we need to attempt to determine what length of dry interval begins to be significant. One cannot precisely state what it is, in respect of any one locality, but in the Scottish summer, we would not be far wrong if we said 4 or 5 days.

A map based on monthly intervals - because the data is most readily available for calendar months - shows that in considerable areas in the British Isles P.E. never exceeds precipitation over periods of one month. Such conditions are almost peculiar to parts of the British Isles. Attempts to redraw the map on a basis of "pentades" (five-day periods) show that most years have short significant dry spells even in these exceptionally wet areas. Exploiting to the full the possibilities presented by the short dry periods is what we need to concentrate effort on.

Now what about the actual distribution of peat, past and present, in this country? It is immediately apparent that at the present time, and much more so in the past (both historic and pre-historic), peat is, and was, extensively distributed over large areas where P.E. certainly exceeds rainfall each year even over periods of much longer than a calendar month. The Fen District of East Anglia, and the upper Forth Valley, were very extensive areas of peat in well documented historic time, and we know how they were artificially drained. Why were they peat-covered, in spite of a considerable excess of P.E. over rainfall in most summer months? The answer lies of course in a supply of water to these localities by other than direct rainfall. Water flowed in from other areas faster than it was removed by either outflow or evaporation. It became technically, and economically, possible to reduce inflow and/or expedite outflow, such that the latter exceeded the former. Immediately the effects of P.E. exceeding the local rainfall became apparent. But it would be fruitless to apply the same methods to peaty flats in Kintail! There are intermediate situations where P.E. does exceed precipitation in the summer, where it would be technically possible to drain, but the economics extremely doubtful! Such an area is mid-Strathspey, which has been surveyed for drainage schemes, but it has been concluded that the cost of continuous pumping could not be repaid by the returns off the land - so different from the East Anglian Fens or the Carse of Stirling.

In mountainous topography, there are of course areas devoid of peat cover even in wet places like the West Highlands. Steep slopes will often ensure that, except actually during downpours, flow off exceeds flow on. It is a matter of common observation that there are trees, and other non-peaty vegetation, in such sites. There are of course places where the angle of slope is such that almost no soil or vegetation can maintain its grip, and there is bare rock.

It is not so very difficult to estimate whether (a) flat areas, or (b) steep slopes, can be effectively drained. But there are also vast areas of intermediate slope, covered with blanket peat. It is in these that variables, which can be neglected in considering the extreme cases, come into their own, and must be considered by the forester, or by any one else who is considering any change of land use. These too include many parts where the vegetation cover has changed, through causes which are in part natural, and in part man-induced - one often does not know which.

For some years, the Natural Environment Research Council has had a Peat and Fen Sub-Committee (now re-named "Working Group") of its Hydrology Committee which, among other things, has tried to assemble and reconcile the apparently conflicting views of the hydrological effects of peat cover, and of changes in treatment of this peat cover. A good deal of effort was given to collecting the views of many people whose experience of peaty catchment areas lent authority to their opinions, but it was found that "even where there is firm evidence, or well-based opinion, it seems to be conflicting, even to the point where different people describe the same evidence in different terms". "The inescapable conclusion, if the evidence is accepted, is that different things can happen in different circumstances, and that these circumstances have not been recognised and reported upon quantitatively".

One of the few generalisations that is widely - if not universally - accepted is that the drainage of peat alters the catchment characteristics at least temporarily in the direction of a sharper response to rainfall, even in a catchment where the response is already sharp. Thus it is advised - and the Forestry Commission itself accepts this advice - that drainage works should always be initiated in gradual stages to avoid floods.

A small bog in the Beinn Eighe Nature Reserve was drained by hand-dug ditches several years ago. Shrinkage was clearly seen, but measurements of water levels, as well as the observed run-off from the ditches, showed that this shrinkage, accompanied by lowering of the water level, took place mostly in the first season, after which a new "base state" seemed to have been established. From the point of view of run-off, the net result was little change, but the - at least temporary - increase in unevenness of the surface meant that the hummocks were better aerated, and self-sown tree growth on them was visibly encouraged. It remains to be seen whether this small flat bog in a distinctly humid area will gradually revert to its former condition, or whether it is just sufficiently dry (or rather "not too wet") for the tree cover to be maintained.

In trying to assess what will happen in treating blanket peat in these areas of intermediate degree of slope, it is most important to compare like with like, and many workers have failed to do this. Questions such as the following need to be clearly enunciated, and considered separately:-

i Is run off more flashy from peat-covered (drained or undrained) areas than from non-peat covered areas?

ii Is run off more flashy from drained peat-covered areas than from undrained?

iii Is the degree of flashiness from undisturbed peat areas significantly different from different kinds of peat?

iv Does burning (or other kinds of treatment) have analogous effects to drainage?

v What are the differences in run-off from peat in dry weather as compared with wet weather?

vi Does degree of slope affect the degree of flashiness in run-off from peat areas in a different way from non-peat areas?

Too often they have not been separated, and, for example, the answer to question (i) has been invalidated because it was mixed up with question (vi), and question (v) was studied in dry weather conditions and the answer applied to wet weather conditions.

Question (iii) involves some classification of peat after the fashion of Von Post, who postulated ten grades from "completely undecayed and slime-free peat" to "completely decayed or almost completely slime-like peat". The flow of water through the first is very much faster than through the latter, but, beyond this, the question of the rate, and manner, of actual flow through peat, as distinct from off it, is extremely complicated. The paper by Miller, Robertson and Williams suggests an extremely useful method of classification. Being dynamic, rather than static, it is a more useful guide to ameliorative action than the Von Post type of classification. Two points worthy of emphasis are (i) that water does flow through any kind of peat if any kind of pressure is applied to it - and this includes the natural pressure of steady rain, (ii) that a very thin surface layer of peat can become desiccated in warm dry weather, and then, paradoxically, often forms a dry skin which defies penetration by rainfall for some time after the dry spell has ended.

Mr. O'Hare says that the "overground" conditions are more important than any others, and this is the justification for the emphasis in this brief paper on hydrometeorology rather than strictly to the subject of "The Water Relations of Trees on Peat". It is necessary to emphasise that in the west of the British Isles we are dealing with quite exceptionally wet areas, the wettest in Europe in the sense of P.E./rainfall relationships; blanket peat is ineradicable from much of this territory, and the problem is how to alter and make use of a medium which cannot permanently be removed, as can "non-climatic" peat. The alteration of the flow pattern of water - in the general direction of increasing rate of flow - seems to be the fundamental desideratum.

DISCUSSION OF SECTION II

Seal: Could Professor Heikurainen tell us what species were used in his trials?

Heikurainen: We concentrated on domestic species; Norway spruce and Scots pine are very suitable for our conditions. Some exotic species have been tried and P. contorta seems promising. In more recent trials larch species and Sitka spruce have been used but no results are available yet.

Parkin: There seems to be a difference in the results reported by Professor Heikurainen and other speakers who suggested that the drainage effect of trees went to greater depths.

Heikurainen: There is a difference of opinion even in Finland; deeper rooting is reported in the south than the north. For instance the average rooting depth for pine is c. 8 cm in the south while it is 4-5 cm in the north. It is possible that your rooting systems are deeper. The formula that I gave in my talk relating depth of drains and rooting depth is true for Finland.

Binns: There seem to be important species differences in rooting depth. In the experiment that I mentioned P. contorta rooted to much greater depths than Scots pine and Seal's paper gives similar results.

O'Hare: I would like to ask Dr. Burke if the water table depth in his better drained plots was 33 in?

Burke: No, it was 33 cm.

O'Hare: In 1967 data from four lines of boreholes under a P. contorta shelter-belt showed the water table to be at 33 in while the roots only reached 18 in. We found that there was only 56-65% throughfall beneath this canopy and this together with the better rooting seems to have brought this about.

Green: Part of this result was probably due to the greater transpiration from the exposed shelter-belt.

Barry: Mr. Green in his paper referred to climatic peat and raised bogs, yet Seal in his talk stated that no classification suitable for afforestation purposes had been devised. However, Fraser's classification is very useful especially for Scotland. Climatic peats are the upper parts of all our bogs. However, this is psychologically a bad name as one tends to have less hope of reclaiming them and this is not necessarily true. It is unlikely that we shall ever have a perfect classification as our requirements are always changing. In fact it seems necessary that we may have to classify according to our own particular requirements.

Gorrie: In a recent article in Forestry on the drainage of peats and tree growth in Finland, Hinson reported Heikurainen to have said that their old trees are less able to benefit from drainage.

Heikurainen: The younger the trees are at the time of drainage the more they are able to respond. In older trees the rooting systems do not seem to respond to the new growing conditions while young root systems can. There are a few results from fertilizer experiments which seem to show that old big trees can react to this. It is not known if there is a correlation between age and fertilizer response, but there is between age and drainage response.

Gloyne: Dr. Boggie suggested that there was no difference in the moisture contents of his peat profiles even after rain. This seems to suggest that the classical model for soil wetting does not apply - is this so?

Boggie: We found in our experiment with a fixed water table that profile moisture contents taken every three weeks were practically the same and have little relation to the preceding rainfall.

Youngs: It seems probable that as the water table is high, the soil moisture tension is low, and so little change in moisture content will occur.

Binns: In the dry summer of 1955 , we found that the peat around plants was very dry and surface cracking occurred.

Green: I think we are fairly confident that water will move through peats under a pressure difference, but with high water tables no great pressure differences can occur.

Gloyne: In fact, I am used to ordinary agricultural land problems where the effect of very high water tables does not normally occur.

Robertson: The last paper referred to the work of the Hydrology Committee and seems to assume that, if drained, peat gives a higher peak discharge. The only work I know by Bidell, and by Burke, seems to show the opposite, i.e. lower peak discharge and more sustained flow from drained peat. This seems very important hydrologically.

Green: I was quoting replies to questionnaires sent out by the Committee. The answers were very inconsistent and not all the factors operating were stated.

O'Hare: I showed similar results to the peat power station authorities who had been paying compensation for flooding following their drainage of peatland.

Burke: I think in the case of the power station it was a milled peat area with a road-like surface and hence surface run-off occurred. In 1959 we put in drains at a depth of 2½ ft, 9-10 ft apart. After a long period of rainfall the undrained area was practically covered with water while the drained area was not. However, in the undrained area there was a vegetative cover and undulating surface so that the water drained through the peat.

Heikurainen: I am very interested in the influence of draining on run-off. The results of drainage are a fall in the water table and decreased transpiration, so drainage must increase run-off. However, forest cover changes this. It takes part of the rainfall as interception (about 95% in Finland) so that a forest planted after drainage will result in decreased run-off.

Burke: In our experiment we sampled the water table and moisture content at 3 in intervals every month. On the drained plot the water table fell to 18-20 in and stayed there over summer while the water table fluctuated at 0-10 in on the undrained plot. The moisture contents were less in the drained plot but the patterns converged at about 2 ft.

Haigh: We have all noticed in peats evidence of previous tree crops. Thus on Dartmoor we find very large tree stumps on the mineral soil surface. Does this mean that by carrying out drainage and placing mineral soil on the surface we can improve on the artificial methods suggested in today's papers? Also, how has the bog formed on an area carrying trees, and can it be made to revert?

Green: Frequently we do not know why the trees failed in the past. It could be a climatic or a drainage change or some other cause.

Rutter: It is also relevant that some trees found in bogs are not useful crop species, e.g. alder. Also, we often find self-sown trees growing on a number of raised bogs; again these are generally not suitable as a tree crop.

Haigh: But on Sedgemoor we find oak tree remains. In fact, I was mainly interested in the effect of bringing the mineral soil to the surface.

Binns: Yes, I agree that we see quite large individual trees, but in fact the total volume produced may well have been very small.

O'Hare: In support of this, a survey in 1911 of a preserved forest of Scots pine from about 400 B.C. showed a mean height of 40 ft. By counting the annual rings it was found that the trunk diameter growth over 150 years had been 9 in.

PREPARATIONS FOR TREE PLANTING ON PEATLAND IN NORTHERN IRELAND

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INTRODUCTION

Government policy in Northern Ireland decrees that afforestation is virtually confined to marginal agricultural land, much of which lies above the 600 ft contour. In Northern Ireland a high proportion of land above this altitude is covered with a blanket of peat, varying widely in depth but averaging about 4 ft deep. This fact means that much of the 4000-acre annual programme of new planting carried out by the State is on peat of over 2 ft in depth and the relative importance of the problems associated with this has meant that experimental and research efforts have been concentrated on this field for many years.

This paper summarises the current techniques of fertiliser application, ploughing and drainage layout on blanket peat and gives the basic reasoning behind these. At the same time it must be emphasised that techniques are constantly being modified as experimental results throw new light on the many aspects of tree growth on peat and as new materials and machines are produced to provide more effective ways of tackling problems.

Another important point to be kept in mind when considering the techniques in use in Northern Ireland is the fact that for a variety of reasons it was decided some time ago to concentrate on the growing of pure Sitka spruce on these peat areas. The techniques in use may not always be equally effective if other tree species were employed.

FERTILISER APPLICATION

Apart from occasional "pre-draining" of particularly waterlogged areas of blanket bog, or the "chopping" (by rotovator or swipe) of dense heather vegetation cover which might seriously impede ploughing, the broadcast application of fertiliser is the first operation employed in preparation of peatlands for afforestation

The standard treatment currently employed in Northern Ireland State afforestation is an initial broadcast application of 4 cwt of coarse rock phosphate per acre immediately prior to ploughing. There are indications that a small amount of Potash might profitably be applied in certain western peatland areas, but this has not yet been accepted as standard practice.

The policy of broadcast application immediately prior to ploughing was generally introduced in 1964 following a number of years of experimental trials. Previous to this the standard system was hand application of 2 oz of fertiliser to the roots of each tree at the time of planting. In the trials the broadcast application proved so consistently superior to the various alternatives compared with it, that a complete change-over to this practice was introduced. The reasons for the effectiveness of broadcast application are not fully understood but it is probably associated with the rapid development of adventitious roots by the newly-planted Sitka spruce which exploit the entire surface peat in the first few years after planting.

A recognised disadvantage of broadcast application just prior to planting is the loss of fertiliser in the rapid run-off of excess water immediately after ploughing and draining. Experiments are proceeding to ascertain the effectiveness of applying fertiliser some time prior to ploughing, thereby using the surface peat and its vegetation as a fertiliser reservoir.

The choice of Ground Mineral Phosphate as the fertiliser to be applied on the normal blanket peat resulted from trials of many phosphates and combinations of fertilisers, which consistently failed to produce a more effective and economic alternative.

The "coarse ground" type of mineral phosphate was selected as being more easily broadcast from the type of distributor in use.

Various types of fertiliser distributor have been used over the years but the current and most effective is the "Metsa Viska" mounted on a "Muskeg" low ground pressure vehicle.

With the introduction of broadcast application of fertiliser the rate was increased to 4 cwt per acre of Ground Mineral Phosphate. Once again this decision was based on comparative trials designed to provide the minimum amount of fertiliser needed to get Sitka spruce through its initial establishment period on typical blanket bog without the need for further treatment.

It is generally accepted that, if reasonable yields of Sitka spruce are to be obtained on the extremely infertile conditions of typical Northern Ireland blanket peat, then subsequent applications of fertiliser will be required. The frequency, type and amounts of fertiliser to be applied are the subject of intense experimental investigation at present but early indications are that a carefully calculated fertiliser regime is a practical and economic proposition. The plantation layout is designed to facilitate this periodical fertiliser treatment.

PLOUGHING TECHNIQUES

A small amount of afforestation of typical blanket peat had taken place in Northern Ireland prior to the 1939-45 war, but the technique of hand drainage and turf planting employed resulted in poor growth of both Sitka spruce and Contorta pine and this discouraged any extensive planting of peatland. The availability of low ground pressure tractors and special ploughs shortly after the war led to renewed interest in peatland afforestation and from 1950 onwards ploughing has remained the standard ground preparation procedure.

The type of plough used, and the intensity of ploughing employed, have varied a good deal since 1950 as knowledge and experience have increased and it appears likely that there is still a good deal to be learned before a confidently accepted optimum technique will be evolved.

In order to provide a rational basis for decisions on the intensity of ploughing and drainage on typical blanket bog, it was necessary to select an hypothetical ideal for tree growth. Careful studies were made of tree rooting and peat changes - both chemical and physical - on existing peatland plantations and on early experimental areas of different drainage intensities. At the same time estimations were carried out of nutrient availability in the peat and the requirements of the trees growing on it. From all these studies it was decided that, in order to produce a satisfactory pioneer crop of Sitka spruce on typical blanket bog, it was necessary to ensure the drainage - and hence aeration - of a layer of peat equivalent to the top 18 ins. of the bog.

Further studies suggested that this could be achieved by initial ploughing of an 18 in. deep furrow at 10 to 12 ft intervals plus a main drainage system of a somewhat greater depth to permit rapid run-off of surface water from the plough furrows. It was assumed that the main drainage system would be periodically deepened, by machine but that the 18 in. deep plough furrows would have no further treatment.

The assumption that sufficient fertiliser would be applied from time to time, to ensure that a vigorously growing tree crop was maintained to play its part in the water extraction andhence aeration of the peat, was an essential condition of this hypothesis.

Problems were encountered in efficiently achieving the 18 in. deep furrow at 10 to 12 ft intervals and at the same time maintaining a satisfactory basis for a tree planting spacing of 5½ ft by 5½ ft. The Cuthbertson "P" type plough was not capable of providing the necessary furrow under all conditions and, although the later "S" type plough had no difficulty giving the 18 in. furrow, the ridges were rarely suitable for planting on without expensive "stepping" or straightening.

Accordingly, the standard practice accepted for the past eight years has been a combination of alternate "F" type and "P" type Cuthbertson ploughing, the former providing a 24 in. deep furrow every 15 ft. and the latter a 12 in. deep double furrow every 15 ft. While this system provided approximately the equivalent drainage intensity to the accepted requirement, it had the disadvantage that the "F" type ridge had to be "stepped" before planting and the fact that two ploughs had to be used over any section of ground; accordingly, it has always been looked upon as a temporary system pending replacement by a more efficient one.

Over the past few years, trials with the Clark Double Throw plough have been carried out under a variety of peat conditions and the general success of this system - which provides the required 18 in. deep furrows at 12 ft. centres with acceptable planting ridges on either side - had led to a decision to accept this as the standard system in future.

The Clark Double Throw ploughs are mounted on hydraulically operated frames with double rubber-tyred wheels and are towed by Fordson County Swamp model Crawler tractors.

PLOUGHING AND DRAINAGE LAYOUT

During the early years of afforestation of peatlands and the development of ploughing and drainage techniques, efforts were concentrated on finding the most efficient way of establishing tree plantations and little thought was given to the subsequent problems of maintenance and extraction of the timber crop. The short-sightedness of this policy was quickly realised, however, and in the late 1950's a number of discussion meetings were held within the Northern Ireland Forestry Division in order to formulate a peatland plantation layout policy which was most likely to facilitate future forest operations as far as they could be assessed at that time.

This exercise brought to light the need to make a number of very far-reaching and important decisions and yet at the same time emphasised the need for the retention of flexibility in the light of the multiplicity of possibly divergent future developments in techniques and economic policies.

The main factors taken into consideration were as follows:-

1. The well-planned layout of a main drainage system of a peatland area was considered essential. This should be of sufficient intensity to rapidly remove surface water from the plough furrows and at the same time provide the possibility of a water table sufficiently low to permit root penetration down to 18 in below the peat surface. The drains must also be capable of mechanical maintenance and deepening where necessary.

2. In order to facilitate periodical fertiliser treatment of plantations from the ground, an intense system of

racking must be provided.

3. Although the economics of afforestation on infertile peatlands suggests that only limited capital expenditure on roads can be justified, it is appreciated that timber extraction problems on deep peat may be intense and unless extended cableways, hovercraft or other revolutionary means of timber movement are evolved then roadmaking may be inevitable at timber harvesting.

4. Extraction problems, windthrow risk and marketing, are all factors which influence the decision as to whether a peatland forest plantation will be thinned or not. The current assumption in the Northern Ireland forest planning programme is that thinning will not take place. It is appreciated that this present decision is one that could be influenced by many factors and any plantation layout policy should be sufficiently flexible as to allow for a change to a thinning regime.

5. Extraction of timber from the stump to the main roadway system - whether as thinnings or final crop - must inevitably be difficult, due to fragility of the peat surface and the obstacles created by ploughing and drainage. Hence an intense rackway system designed to bring timber by the shortest route to the roadways - by low ground pressure machines or cableways - seems essential.

Based on the above main considerations - plus many other less important ones - the standard plantation layout for peatland afforestation areas in Northern Ireland State forests was evolved. This is summarised below in the normal order of application:-

(1) The main drainage system for the whole peatland afforestation area is laid out on the ground in accordance with the considerations mentioned in 1 above. Mechanical maintenance is assumed and access routes are left alongside the drains (see (2) and (3) below).

(2) A maximum roadway system is marked out on the ground and sufficient width (minimum 35 ft) is left to permit eventual road construction - or hovercraft route. Wherever possible the roadway is tied in with the main drainage system.

(3) A network of 35 ft wide rides is then laid down to form boundaries of compartments which are from 15 to 40 acres in size. As far as possible the rides should be negotiable and should be tied in with the main drainage layout.

(4) Having laid out all the above then the compartments are ploughed with planting ridges running as near as possible at right angles to the roadways, leaving 15 ft wide racks parallel to the ploughing every 72 ft.

Having completed these preparations then the area is ready for the planting of Sitka spruce at a spacing of 8 ft apart along the plough ridges which have been left at 6 ft apart. The planting is left until late in the season (March/April), whenever possible, to avoid a period of dry north-easterly winds which is a frequent feature of the January and February period in Northern Ireland.

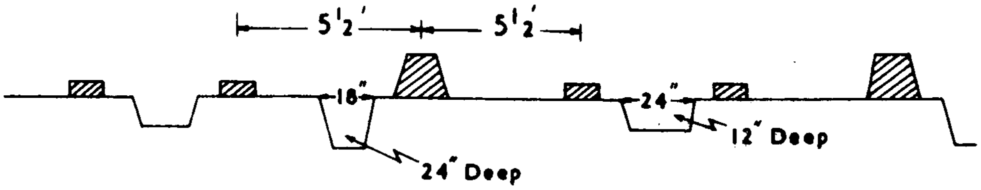
CONCLUSIONS

Foresters in Northern Ireland are very much aware of the considerable problems associated with the pioneer planting of the inhospitable areas of blanket bog which clothe much of the country's hill land. The progress of older plantations on peat, together with encouraging experimental results, however, indicate beyond reasonable doubt that a tree crop can be produced on these agriculturally unproductive areas. Some doubts still exist as to the economics of the enterprise in pure compound interest returns on investment capital, but as more sophisticated techniques become involved - and research and mechanical trends suggest that this is a probability - then even these doubts may be removed.

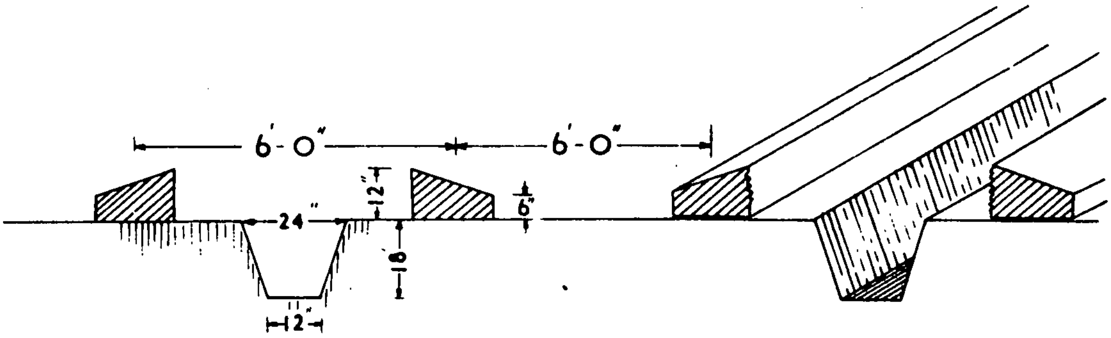
It is emphasised once again that the procedures outlined in this paper are strongly influenced by policies and conditions which may be peculiar to Northern Ireland.

PLOUGHING TECHNIQUE

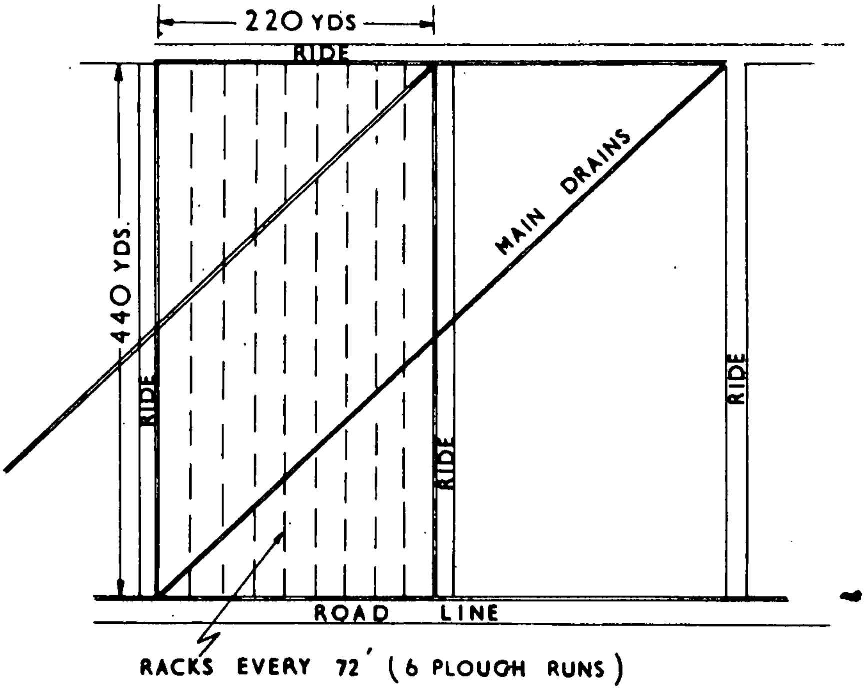
(a) STANDARD SYSTEM (Pre 1968) ALTERNATE 'P' AND 'F' TYPE



(b) STANDARD SYSTEM (From 1968) CLARK DOUBLE THROW PLOUGH



LAYOUT



A REVIEW OF SITE PREPARATION AND PLANTING TECHNIQUES ON PEAT IN THE FORESTRY COMMISSION

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HISTORICAL REVIEW

For the purposes of this paper, peatland is defined as being of such a depth that neither current nor foreseeable equipment will penetrate into the mineral soil below. It is also assumed that tree roots irrespective of treatment will not be expected to utilise the mineral layers. Hence I exclude peaty gleys and peaty podsols with or without pan, and avoid the difficulties of specifying exact peat depths and extending the paper's coverage into areas where indurated or compacted subsoils require cultivation and/or drainage.

The distinction between cultivation (the artificial increase of pore space) and drainage (the removal of water from existing or newly created pores and fissures), which was highlighted by Henman (1963), is less readily applicable to entirely organic soils as these are almost invariably associated with waterlogged conditions and any disturbance results in important changes in the local moisture regime. It is however, convenient to think in terms of short and long term drainage results from any site disturbance under these conditions.

The history of afforestation of oligotrophic peats is virtually confined to this century and Zehetmayr (1954) provides a complete review of developments up to that date. It is noteworthy that the progression from very shallow hand-dug turfs, succeeded by the deeper and heavier Belgian turf which was itself subsequently superseded by the thinner vertical slice turf, (linked with the provision of drainage channels) affords a very close parallel with the sequence of later ploughing development.

Ploughing began experimentally in 1927 with horse drawn equipment and by 1938 quite extensive areas were shallow-ploughed with the Begg and Solotrac ploughs. Ploughing subsequently became deeper with the advent of the single mouldboard Cuthbertson plough and tracked tractor, and also became shallow again when, associated with the additional provision of drainage, the use of the double mouldboard Cuthbertson plough and deep cross-drainer became popular.

In 1965 it was estimated (Neustein 1966) that approximately 37% of peatland afforestation was on relatively shallow turfs. Until the mid 1950's it was widely assumed that ploughing at 5' to 6' spacing ipso facto would provide adequate drainage for establishment and early growth, and that later growth would be maintained by transpiration of the crop, and by deepening occasional ploughed furrows. This assumption and the pressure of a massive afforestation programme often led to a ploughing pattern which maximised provision of turfs at the expense of long term drainage requirements. Large areas were ploughed at or near the contour and only when the stage of pre-thicket drain maintenance was reached was it appreciated that such a layout rendered the provision of effective long term drainage channels virtually impossible. The advent of the deep drainer (originally Cuthbertson type D Mark V, VI or S) which could traverse standard plough furrows, led to a clearer distinction between short and long-term drainage needs. By the late 1950's up-and-down turf ploughing, often with mixed single and double mouldboard ploughs, with near contour cross ploughing of deep drains was increasingly used. Now we see once more a trend towards deeper and closer plough furrows which combine growth aspirations with drainage requirements.

The double mouldboard Cuthbertson plough providing two shallow turfs on each pass was not only more productive but also avoided the necessity of step planting to get tree roots into the vegetational sandwich - a specification which most Scottish Conservators regarded as necessary (Neustein ibid). In North East England and Northern Ireland foresters preferred the higher productivity of notch planted trees, often using a semi-circular spade.

Deeper single mouldboard turf ploughs remained in favour where uneven peat surfaces needed a deeper furrow for a continuous turf and minimised consequent "sorting up" and because faster early growth was obtained. Binns (1962) attributed this enhanced growth to better nitrogen mineralization under the heavier moister turf. The third year result of an experiment at Achray Forest, in which, incidentally, three turf depths are compared, reinforces this conclusion (Taylor 1968) and indicates that growth differences at this stage are not correlated with drainage intensity.

Unfortunately double mouldboard ploughing was almost invariably used in mixture with single mouldboard ploughing and comparisons of deep and shallow turfs were neither carried out by Research Branch, nor on a field scale by Conservators. Therefore it has been impossible to elucidate the mechanism of the decrease in the difference in tree height between trees on deep and shallow turves which normally takes place by the thicket stage (Neustein 1966). Are the biological advantages of deep turves exhausted, or were the shorter trees on shallow turves responding to the shelter provided by adjacent taller ones on deep turves? Foliage analysis showed that phosphate and potassium concentrations in the taller trees at ten years were lower and therefore with timeous top dressing faster growth of the trees on deep turves might have been maintained. At this stage roots will have extended far from the original turf and hence, if there is a genuine continuing growth advantage from single mouldboard ploughing, it is probably associated with the better local drainage associated with deep furrows rather than the deep turf.

In 1964 a plough "sock" with an angle cutter designed to remove a continuous step from a deep turf was developed in Northern Ireland and subsequently introduced into Scotland as a means of reducing planting costs. Neither it nor the various shapes of "boxed" or angled spades (Neustein 1963) and (Ramsay 1964) have as yet gained widespread acceptance, but results of the first Work Study comparisons of planting methods, which are now becoming available and which are described in this paper, may reduce the general reliance on the garden spade as the standard tool.

RECENT WORK STUDY INVESTIGATIONS

A series of comparative trials were carried out in 1967 and 1968 to test the combined effects of different planting and ploughing methods, in terms of establishment cost, survival, and subsequent growth. Planting methods selected for study were:-

(a)	Semi-circular spade	- removing a plug from the top of the turf ridge.
(b)	Garden spade	- making a single vertical notch on top of the turf ridge.
(c)	Garden spade	- making an L-shaped notch in the turf side, cutting a 'step' where necessary to get the roots into the sandwich layer of vegetation.
(d)	Glendaruel spade	- an angled spade giving an L-shaped cut - used as for (c).

Ploughing methods on which these planting methods were tried were:-

(a) Single mouldboard Cuthbertson
(b) Double mouldboard Cuthbertson
(c) Single mouldboard tine
(d) Double mouldboard tine
(e) Single mouldboard tine, complete ploughing

(d) and (e) were omitted from the 1967 trials.

First assessments of growth and survival in the P.67 plots, at Glenorchy, Leanachan and Torrachilty forests, show no appreciable differences between planting treatments. A full analysis of results of time studies carried out during planting has still to be completed, but the highest outputs are associated with semi-circular spade planting, followed by garden spade/vertical notch. The advantages of the semi-circular spade are greatest on the thick turf produced by single mouldboard Cuthbertson ploughing particularly on non-fibrous peat. On the most difficult conditions, (stony mineral soil, complete ploughing) differences between methods become much less pronounced.

This set of trials was intended to demonstrate whether there are any particular drawbacks with the faster methods on any of the ploughing types. The sites were selected so that exposure and soil were not advantageous, to prevent uniform good 'take' on lush conditions masking differences between treatments. Some indication of the importance of getting the roots into the "sandwich" of vegetation should also be obtained. This may be much less important now than in the days of hand turfing, and in the case of deeper peats it can be argued that the most suitable planting position is right on top of a large peat ridge, with the roots in a truly vertical position.

Within the area of NE(E) where the semi-circular spade is in general use, certain workers have produced outputs of 3,500-4,000 plants per 8-hour day compared with the general level of 2,500-3,000. Work Study staff carried out a micro-motion study of the methods of these skilled men, using 8 mm photography and simo charts. From these, a planting method has been evolved which combines the best features of several individual methods, and which has the advantage that it can be easily taught to untrained workers. Though the exact place of semi-circular spade planting is still to be determined, it is obviously a most attractive alternative to garden-spade methods where output ranges generally from 1,500 to 2,000 plants per day.

Satisfactory planting costs are not determined by method alone; planting investigation brought to light several ancient faults, such as:-

(a) Ordering too many plants per acre, because insufficient allowance had been made for roads, rides, and the sides of main drains.

(b) Too close spacing; either deliberately done because there are too many plants, or because the men are on a piecework price per hundred, i.e. paid according to plant disposal. Work Study strongly recommend piecework planting on an acreage basis.

(c) Using too large plants; plants over 9" from collar to shoot tip are unnecessarily expensive to handle at every stage, however beautiful they look.

Failure to guard against these and other elementary faults (adequate and intelligent spacing of plant dumps, for instance) can raise planting costs per acre by anything up to 50% more than they need be.

Work is now in progress and will continue into 1969 to investigate further the effect of terrain characteristics, peat type, etc., on planting outputs. Also the first set of provisional Standard Time Tables for semi-circular spade planting is under preparation. Similar investigations are being made on factors affecting ploughing output. The main points which emerge so far are:

(1) The terrain characteristics which appear to have the greatest influence on output are slope, which determines whether ploughing can be done one way or two; and hardness

(usually associated with rocks), which may cause a driver to go slack because of fear of breakages. Much of the ground ploughed in the north and west of Scotland is a mixture of hard knolls and slopes and varying amounts of soft "shelves" or "saucers". An attempt has been made to express these conditions quantitatively, i.e. a "Hardness percentage", given by $\frac{\text{Area of 'hard' ground}}{\text{Total area}}$ %. 'Hard' and 'soft' being assessed visually according to certain broad criteria, analogous to the method of assessing density of weed growth in weeding Standard Time Tables. A set of provisional Standard Time Tables for ploughing, based on the above ratio, is now under test.

(2) Usage of ploughing machinery is currently around 60-70%, although this varies considerably between areas and outfits. Time spent under repair can be as much as 20%, and in the short term, better machine use offers the most promising scope for improved productivity.

(3) The acknowledged superiority of an hydraulically-controlled plough mounted directly on the rear of the tractor is confirmed, particularly on the steeper broken ground.

(4) Outputs vary a good deal between operators and it is essential that operators receive clear, unambiguous job specifications. There is a distinct tendency on the part of operators not on piecework to plough too close, or one-way when they could plough both ways.

These points lead to the conclusion that ploughing requires special supervisory skills, which the ordinary best forester who "has the ploughs in" for a couple of months each year cannot be expected to acquire. Ploughing supervisors must be competent to direct and - most important - recruit and adequately train operators. Several Conservancies operate systems of specialist ploughing supervisors, and this is likely to be extended to other areas.

FUTURE DEVELOPMENTS

Obviously, in an imperfect world, there are continual amendments to standard practices which improve out-turn but do not significantly alter basic practice. Among these may be numbered the fertiliser spreading attachment which laid manure beneath the turf while ploughing. It was introduced at a time when finely ground mineral phosphate was generally used and with such material it was insufficiently reliable to gain wide usage. Granulated manure increased the overall cost slightly and the advent of more coarsely ground mineral phosphate has coincided with increasing use of broadcast applications for which mechanical spreaders are being developed. At present three machines are competing in the field of broadcast application before ploughing (viz. the Vicon, a modified lime spreader and the Finnish Metsa-Visko). Atterson and

Davies (1967) described their scope and foresee extensive use for their type. As yet none has been satisfactorily attached to the ploughing outfit but even as independent machines they will reduce manurial application costs to an important degree.

It has been found that deep draining outfits can spend as little as 30 per cent of their time actually draining because of their inability to reverse their mouldboard. This means that the spoil on alternate runs not only blocks the topside furrows, but more importantly frequently rolls into the drain and can lead to excessive labour charges. Hence there is an obvious need for reversible mouldboards.

The first prototype of a powered plough carriage has been built in which each carriage wheel has a hydraulic motor with pressure provided by the tractor. There are clearly several defects still to be overcome, but when successful it should facilitate the choice of an optimum tractor of appropriate power, draw bar pull and bearing pressure for ploughing deep drains. The search for an optimum tractor has mainly arisen and been accelerated due to the demise of Ford County Crawlers which, for many years, were the mainstay of the peatland ploughing programme.

Although several types of tractor are available which can produce planting turfs none can, singly or in tandem, tow a deep draining plough over as wide a range of conditions as the Long Wide County tractor. It is not yet clear whether a single tractor (which might be capable of towing two or a battery of turfing ploughs, and markedly increase productivity with uphill ploughing) or a combination of two smaller tractors is the better solution. The latter does have practical advantages where bogging is an ever-present hazard. Winch ploughing of drains on bare ground has not yet been shown to be economically competitive.

More basic changes in peatland afforestation techniques than those briefly described above are foreseen in the following developments:-

Firstly and possibly nearest fruition is the design of a deep double mouldboard turfing plough which would combine the advantages of the present single and double mouldboard models. In addition, windthrow hazard may be diminished by the widening of deep furrow spacing.

Secondly, the use of rotary trenchers (e.g. the Finnish Oja-Visko Ditch Digger) may offer not only a more economic means of achieving deep drainage, but also be the basis of the much sought after tool for drain maintenance. Equipment of this type minimises flotation problems and produces a wide angled ditch which is less susceptible than conventional cross sections to shrinkage and slumping. Consideration is also being given to creating a system of "riggs and furrs" in which peat thrown up from appropriately spaced ditches provides a raised deep mulch between them and thereby influences the water shedding capacity of the site and hence the longer term need for drain maintenance. In addition, important nutritional effects in terms of peat aeration, breakdown, vegetation suppression and release of nitrogen may result.

Thirdly, a novel technique of establishment which appears to be particularly relevant to peatland afforestation is the use of tubed planting stock. Seeds are sown in small polystyrene tubes filled with a suitable rooting medium and grown in controlled conditions (under polythene) until 6 to 8 weeks of age when, after a two week period of hardening off, they are transported in trays to the planting site and inserted into dibbled holes on the turf ribbon. Although costs of such stock are not expected to be drastically lower than conventional plants, there are obvious potential economies to be gained from extending the planting season to perhaps six or seven months and reducing the need for forward planning of plant requirements to as many months as now are required in years. Mechanisation of planting which has not as yet been possible may become feasible as tubed stock is not only very uniform but is also in a biologically safe condition for transport and handling.

Low (1968) describes preliminary studies into the influence of rooting medium, level of nutrition, depth of seed cover and tube dimensions. The earliest results of survival in the field are promising and suggest that frost lift is a greater hazard on mineral soils than on peat and that the seedlings in exposed situations respond to the shelter of the step position on deep turf.

Afforestation of peatland is at this time at an important cross-roads. The potential of standard methods is well established by experience though improved training and management could still yield important dividends. Advances in herbicidal and nutritional knowledge now present the forester with two alternatives. Should he continue to establish low input/low yielding crops of Lodgepole pine or should he change massively to a high input/high yield regime based on Sitka spruce. Although this is essentially dependent on nutritional aspects, a move towards the latter alternative will doubtless react importantly in all aspects of establishment.

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DISCUSSION OF SECTION III

Dr. Binns asked Mr. Parkin how long before draining the broadcasting of fertilizer was carried out in Northern Ireland. Mr. Parkin replied that current practice was to apply it immediately before ploughing, but that experiments have been laid down to test the effect of application 5 years, 3 years and 1 year ahead of ploughing.

Mr. Neustein confirmed a suggestion by Dr. Binns that the normal ploughing pattern was ploughing for turf up and down the slope with cross-draining across the slope just off the contour.

In a suggestion concerning planting methods Mr. Innes pointed out that in the North Scotland Conservancy, when planting Lodgepole pine, L - notching with a garden spade is preferred to the semi-circular spade, because it is felt that the roots are not in contact with the sandwich-layer when using the latter method.

Mr. Parkin was of the opinion that Sitka spruce derived no immediate benefit from fertilizer in the sandwich layer because early root development is in the surface of the turf and the adjacent fertilized ground surface, and not in the sandwich layer.

PEAT NUTRIENTS AND TREE REQUIREMENTS IN FORESTRY COMMISSION PLANTATIONS

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INTRODUCTION

There is no need to remind foresters that most of the peat generally available for afforestation is very infertile, as well as being waterlogged most of the year, and that much of the research on planting peat in Britain has been concerned with fertilizers (e.g. Zehetmayr 1954). The present state of practice is described by Seal in another paper at this Symposium, and this has told how the use of phosphatic fertilizers has become almost the rule on peat soils (and we suspect that even where its use is not yet general, worthwhile improvements would be obtained in the long run). The use of potassic fertilizers has so far been virtually restricted to top-dressings, but there is evidence that on some poorer peats potassium deficiency, as detected by poor growth, frost susceptibility, colour, and foliage analysis, sets in within two or three years of planting (Binns and Atterson 1967) and potassium may be necessary on such sites at planting. There is at present no regular use of nitrogen fertilizers on peat soils, except on an experimental and pilot scale.

RESERVES OF NUTRIENTS IN PEAT

We shall say something here about the total reserves of nutrients in peat in this country; other papers at this Symposium, by members of the Macaulay Institute, deal with nutrient availability and the evaluation of peatland sites according to their physical and chemical characteristics.

Peat, being partly decomposed organic matter, has a relatively high total nitrogen content but low total phosphorus and potassium contents when compared with mineral soils. To a depth of 30 cm, a hectare of peat can contain between 2,000 and 10,000 kg nitrogen, 40 to 300 kg phosphorus, and 30 to 350 kg potassium; the range is from half to one order of magnitude. The low values are usually found in peat derived from a high percentage of *Sphagnum* moss while the high values are found in basin peats.

The bulk of the nitrogen in peat occurs in organic compounds, and is unavailable for plant growth until these compounds are broken down. Frequently trees can be severely deficient in nitrogen even though they are rooted into peat containing very high amounts of nitrogen. We shall have more to say on this problem later.

The amounts of phosphorus in peat are never sufficiently high to prevent a response being obtained in trees given a phosphate fertilizer. The rate of phosphorus necessary and the duration of a response to any given dressing differs between peat types, but we know little about the long-term aspects of this as yet.

Potassium levels, while similar to those of phosphorus, are usually adequate for tree growth for at least a few years after planting, although on the poorest peat, i.e. very deep, raised bogs, responses have been obtained from applications at planting. In an experiment at Shin on deep blanket peat (developed over hornblende and granitic rocks), which contains about 240 kg K/ha in the top 30 cm, there was no response in Lodgepole pine after three growing seasons to an application of 100 kg K/ha at planting; whereas at Racks Moss, a raised bog, where peat to the same depth contains about 30 kg K/ha, an identical dressingof potassium resulted in a very significant increase in mean height of 15 cm after three growing seasons. The peat at both sites has a low phosphorus level, about 82 kg P/ha and both trials included phosphorus; however, a most marked response to phosphorus was seen at Shin where an area adjacent to the experiment was left unphosphated.

The <u>total</u> contents of P and K have roughly the same ranges, but P is always deficient, K only on the poorer peats. Phosphorus is well known for its limited availability, so this difference in the available supplies of phosphorus and potassium is probably largely due to chemical causes. However, the difference between the phosphorus and potassium contents of rainfall is considerable, the second being often five or more times greater than the first, and this difference may be responsible in part for the apparently better supply of K. Over a period of 50 years, rainfall may supply 100 kg K/ha, but less than 20 kg P/ha. The earlier paper by Boggie and Miller showed that lowering the water table on a peat site does not by itself affect the moisture content of the peat very much, but will allow fresh water to penetrate the peat. As well as carrying oxygen with it, this water will also carry the nutrients, notably potassium, supplied by the rainfall and hence these nutrients will stand a better chance of being absorbed by the peat and the plant and tree roots growing in it.

NUTRIENT UPTAKE FROM PEAT

Estimates of the total uptake and retention in the tree crop of major nutrients have been made by many people, but the trees from which the data have been obtained have seldom been grown on peat. The amounts of the three major nutrients contained in a tree crop are likely to be 250-600 kg N/ha, 25-90 kg P/ha, and 130-330 kg K/ha (e.g. Meshechok 1957, Binns 1962).

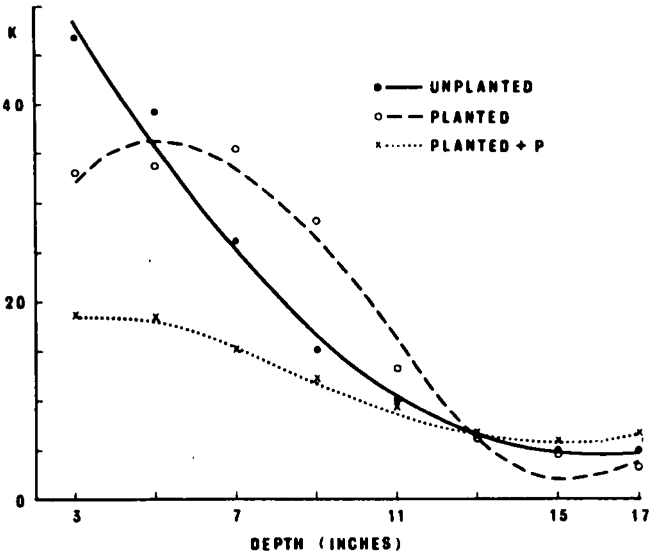
Taking even the lowest estimates of the uptake of potassium by trees, the reserves of K in very many peats are obviously inadequate to raise a healthy crop of trees, and the addition of potassic fertilizers will be necessary at some time in the life of the majority of crops on deep peat. It is more difficult to compare a tree's requirement for phosphorus with the phosphorus contents of peat, due to the small proportion available to the trees.

With the very low levels of total P and K in peat soils, looked at on a volume basis, it would seem reasonable to expect withdrawal of these nutrients by trees to be detectable. Two plantations of Scots pine and Lodgepole pine (at Inchnacardoch Forest), planted in 1926 and 1928 respectively, were studied in 1955-58 (Binns, 1970).

Peat was analysed in two-inch (5 cm) layers from unplanted ground and from planted ground with and without phosphatic fertilizer down to 18 inches (45 cm). The profiles were then compared, for each variable analysed, by fitting regression equations using the technique of orthogonal polynomials (Fisher and Yates 1953). The terms of the equations were then compared by an analysis of variance, and tests made of the significance of the differences between the effects of the different treatments on the shape of curves of contents down the profiles, for the many physical and chemical variables which were determined.

The results obtained suggested very strongly that the trees had removed substantial amounts of potassium from the upper layers of the peat. The observed points and fitted curves for total potassium for the Lodgepole pine experiment (Inchnacardoch 47/28) are shown in Figure 1.

Fig. 1. Total K, as mg/100 g oven dry peat, under Lodgepole pine (from Binns, 1970).



The effects on the other nutrients were absent or less marked; only for phosphorus and manganese was there any suggestion that the trees had removed detectable amounts of nutrients, and for manganese the differences were not significant.

We know that we have to add P and K to peat plantations: these results serve to underline the inadequacy of the peat as a growing medium in the absence of applied nutrients. The suggestion of manganese withdrawal is a reminder that trace element deficiencies are possible; copper deficiency has been found on some of the peats in W. Ireland.

NUTRIENT REQUIREMENTS

Trees obviously need nutrients, but to determine the optimum nutrient requirement of a particular species would necessitate a great deal of experimentation; as trees can take up more of any nutrient than they require for optimum growth ("luxury" uptake), response curves for all nutrients likely to influence growth would have to be worked out in factorial combination (work along these lines has produced some conflicting results). Observations on the few field experiments to date, however, suggest that so-called "luxury" uptake does not occur on peat soils.

In spite of the lack of precise information on nutrient requirements, and responses to added nutrients, it is possible by analysing tree foliage over a wide range of site types and climates to gain some idea of what optimum levels in the foliage are likely to be and the levels associated with moderate and severe deficiencies. However, the levels of nutrients in foliage, although they can indicate possible deficiencies in the plant, need not necessarily be due to low levels of the nutrient in the rooting medium, e.g. poor drainage can cause nutrient deficiencies in plants. Many other factors can also influence nutrient levels in trees, such as:

tree species
provenance of any species
date of sampling
age of tree
position of the foliage in the crown
leaf size
age of needle
availability of other nutrients
ground vegetation
cultivation
soil type
growing season's weather
previous growing season's weather.

To give some examples of these differences, Sitka spruce generally has higher foliage nutrient levels than Lodgepole pine where both are growing well; inland provenances of

Lodgepole pine have higher nitrogen levels but lower potassium levels on similar sites than coastal provenances; spruce on heather sites generally has lower nitrogen levels in its needles than on grass sites; and trees on peat sites growing on plough ridges have higher nitrogen levels than those on turves, and those adjacent to ridges from deep drains have higher nitrogen levels than those on normal plough ridges. The effect of larger ridges can be seen at the Twiglees Section of Castle O'er Forest in South Scotland where, three growing seasons after deep draining was done through $1\frac{1}{2}$ m high, 13 year old Sitka spruce, the spruce adjacent to the ridge from the deep drain had a foliage nitrogen concentration of 1.3% compared with 0.85% in the spruce away from the ridge. It is important to note that in cases where rapid improvement in growth follows deep draining on peaty sites it is the trees on the ridge-side of the drain which are improved and not those on the side away from the ridge, indicating that it is not drainage as such which is causing the immediate improvement, but the provision of a large quantity of aerated peat, which results in more nitrogen becoming available.

The need to add phosphorus is recognised and accepted, and the use of foliage analysis to confirm deficiencies can aid practice considerably. The total internal requirements of a crop for phosphorus can be stated, as mentioned above, but the complications due to fixation and availability of phosphorus do not allow us to state with any precision how much must be added for a crop on any particular peat.

Potassium deficiency, as mentioned above, is likely to become widespread, and all the raised peats will need additional potassium. The cases from Shin and Racks Moss suggest that peat analysis may help to pick out in advance the peats which are relatively rich in K and those where deficiencies are likely to be severe.

Widespread K deficiency has also been diagnosed in plantations of Sitka spruce on deep peats in Wales (Binns 1965), and treatment with potassium fertilizers increases the K contents of the needles from extremely low levels of 0.2% to around 0.6%. A consistent feature of the stands examined has been the high nitrogen concentrations in the needles, compared with Sitka spruce in Scotland, indeed often high by any standards (though the N concentration in the peat is not notably high). Unfortunately the addition of K as well as P, and the naturally high N levels, do not seem to produce the rates of growth which had been hoped for; the reasons for this are not known.

NITROGEN MOBILISATION

As we mentioned in the section on nutrient reserves in peat, most of the nitrogen in peat occurs in organic compounds which must be broken down (presumably by bacterial action) before the nitrogen becomes available for plant growth. An illustration of the unavailability of nitrogen on acid peat can be seen in an experiment on Sooke and Langley provenances of Lodgepole pine (Lulu Island types) on Cardross Moss, Achray Forest. Here in May, 1966, P, PK, and NPK fertilizers were applied to the six and ten year old pine which changed within two months of treatment from yellow to dark green where NPK was applied. At the end of 1966 the nitrogen concentration in the needles was 1.0% in the untreated and P plots, 1.4% in the PK plots and 1.8% in the NPK plots. This response was obtained by applying 90 kg N/ha on peat where the total nitrogen content of the top 30 cm is about 2,500 kg/ha, which though large in comparison with the applied amount, is at the lower end of the range for peats.

Obviously, if a cheap and simple method of releasing some of this nitrogen could be found then potentially high yielding species such as Sitka spruce and Western hemlock could be grown economically on such sites. As we mentioned earlier, some nitrogen becomes available from acid peat following cultivation and the greater the volume of peat disturbed, the greater the quantity of nitrogen that is available for plant growth. This available nitrogen could be from increased fixation of atmospheric nitrogen or from bacterial breakdown of organic compounds containing nitrogen.

As bacteria prefer a non-acid environment, one would expect lime to increase nitrogen availability on acid peats by stimulating bacteria. A few liming experiments were established with rates of up to 10,000 kg lime/ha. Surprisingly, no obvious improvement resulted from these dressings and this line of approach was not continued. However, what was not realised at the time was that phosphate fertilizers contained calcium so that there was no control plot with no calcium, as the whole experiment was treated with phosphate fertilizer. Also it is likely that the micro-organisms, like other forms of life, prefer a balanced diet, and if lime is going to have an effect, other nutrients in short supply may have to be applied before or with the lime - the obvious ones would be phosphorus and potassium, but it is possible some trace elements may be required as well.

At Arecleoch Forest in Ayrshire an experiment was established in 1964 on an area of peat more than four metres deep carrying checked Sitka spruce and poor Lulu Island Lodgepole pine planted in mixture in 1960. This experiment was designed to compare potassic superphosphate and potassium metaphosphate applied at equivalent rates of potassium. Some rock phosphate was applied to the superphosphate plots to bring up the rate of phosphate equivalent to that applied as metaphosphate. The differences between these treatments are that the superphosphate contains calcium and sulphur and is highly soluble in water, the metaphosphate contains no calcium or sulphur and is relatively insoluble in water. With Sitka spruce, the nitrogen percentage in the foliage increased equally following equivalent top-dressings of potassic superphosphate and rock phosphate, but did not increase after top-dressing with potassium metaphosphate.

Table I gives the results of these analyses.

TABLE I

Nitrogen Concentration in Sitka Spruce Needles, Arecleoch Experiment 3/64

	per cent oven-dry weight needles collected at end of			
	1964	1965	1966	1967
Mean of potassic superphosphate and rock phosphate plots	1.6	1.3	1.0	0.9
Potassium metaphosphate	1.0	1.0	0.8	0.7

It is also notable that the nitrogen percentage has decreased steadily, and by the end of 1967 is very low in all treatments indicating that the spruce even in the initially good treatments is again going into 'check'. TableII shows the decrease in annual shoot growth in 1967 in the potassic superphosphate and rock phosphate plots, and also shows that the metaphosphate plots became steadily poorer since the start of the experiment. This experiment has shown that on the peat at Arecleoch it is possible to stimulate tree growth with the addition of phosphorus plus calcium as these are the only major nutrients common to potassic superphosphate and rock phosphate.

TABLE II

Annual Shoot Growth of Sitka Spruce, Arecleoch Experiment 3/64

	centimetres			
	1964	1965	1966	1967
Mean of potassic superphosphate and rock phosphate plots	24	28	30	23
Potassium metaphosphate	24	16	14	11

The results obtained with potassium metaphosphate in Scotland have been confirmed in the only fully valid comparison in Wales, where plots treated with orthodox PK fertilizer have shown higher N concentrations than plots treated with potassium metaphosphate (see TableIII)

TABLE III

Nitrogen Concentration in Sitka Spruce Needles
Clocaenog Experiment 53/65, in 1967

Rate of nutrients kg element/ha		N concentration as % oven dry weight	
P	K	Potassic superphosphate	Potassium metaphosphate
41.5	47	1.64	1.54
83	94	1.89	1.64
166	188	1.88	1.70
332	376	1.93	1.62

Difference between forms significant at 5%

There is also a strong suggestion that the higher rates of potassic superphosphate increase the N concentration in the needles more than the low rate, and this difference was significant at 5% in the previous year.

Rock phosphate, however, will not always increase nitrogen availability sufficiently on poor deep peat. An experiment similar to the one at Arecleoch, but at Cardross Moss, Achray Forest, Stirlingshire, on Lulu Island type Lodgepole pine shows that, on this raised bog, potassium is required in addition to phosphorus and calcium to cause an increase in nitrogen concentration in tree foliage (see Table IV). This effect of potassium may be because the trees were deficient in potassium, the foliage potassium level in trees which did not receive potassium being 0.35%. The effect of calcium on nitrogen uptake is definitely not through increasing tree foliage calcium levels.

TABLE IV

Nitrogen Concentration in Lodgepole Pine Needles
Achray Experiment 4/66

Year	Potassic Superphosphate	Rock Phosphate	No Fertilizer	Fertilizer Containing N,P,K, Ca	S.E.
1966	1.4	1.0	1.0	1.8	± 0.06
1967	1.3	1.1	1.1	1.4	± 0.08

If the effect of calcium plus phosphorus on peat sites is to stimulate bacteria, then it is likely that broadcasting calcium phosphate would release more nitrogen in the long run than by applying the same quantity in localised spots around each tree, as has been the practice until now. Experiments have been started to examine this question, but as yet they are not old enough to give long term results. However, one of these experiments started in 1966 at Shin Forest, Sutherland, on Lodgepole pine has yielded some interesting interim results. In this experiment four rates of rock phosphate were either broadcast or 'spot' applied after planting. Foliage analyses done on samples collected after the 1967 growing season show that the nitrogen concentration was 1.8% (oven-dry weight) where 17 kg P/ha were broadcast, but where the rate was increased to 67 kg P/ha the nitrogen level rose to 2.1%, the difference being significant. With 'spot' applications, the nitrogen levels were higher at low rates, but lower at high rates probably because of the methods by which the 'spot' applications were done. At the low rates the phosphate was thrown at the young trees, but at the high rates to avoid the risk of damaging the young trees the phosphate was placed in two or four spots near but not immediately around the trees; hence more nitrogen would be released immediately around the trees given the lower rates. Also, in these same analyses, potassium levels in the foliage seem to follow a similar pattern to the nitrogen levels suggesting that if the peat is being broken down to release nitrogen then potassium is being released at the same time.

The effect of the spoil from drains on nitrogen uptake and tree growth has been mentioned above. In an experiment at Wauchope Forest, Roxburghshire, planted in 1953, both deep single and shallow double mouldboard ploughing were used. It was noticed very soon that several species showed much more rapid early growth on the deep ridges, and at first this was thought to be due to shelter. Analysis of the needles showed however that Sitka spruce and Lodgepole pine on deep ridges had higher N concentrations than shallow ridge trees, and this difference was present every year from 19 7 to 1961, being statistically significant on two occasions. The peat in the region of the junction between ridge and ground was analysed on seven occasions between April and October 1958, and showed consistently higher NH_3-nitrogen concentrations associated with the deep ridges, significant on four occasions (Binns 1962). Further studies of growth were complicated by potassium deficiency, but the N effect was decreasing from about 1957, and had virtually disappeared by 1960.

LONG TERM CHANGES AND REQUIREMENTS

Nothing in this paper so far has been said about the physical effects of tree growth on peat, though an earlier session discussed water relations. However, since the availability of nutrients is controlled by physical factors as well as purely chemical ones, the permanent changes in peat which follow drainage and the growth of a tree crop are likely to affect the nutrient supply. The effect is likely to be least for potassium which is present largely in exchangeable form (e.g. Gore and Allen 1956) and greatest for nitrogen.

The amount of phosphorus removed in timber is small, but, even in relation to the low phosphorus content of acid peat, is important. It has been suggested (Binns 1962) that if the working capital of deficient nutrients in peat is increased sufficiently, only small additions of nutrients might be needed thereafter: this is probably an unrealistic view, and it may well be necessary to go on applying P and K for a long time.

The practice towards which foresters in Scotland are now moving is to apply 3 cwt rock phosphate per acre at planting, which is about 50 kg P/ha, or about 4½ oz per tree at 6 x 6 foot spacing. Further applications of P will be affected by the need for K, since it is difficult to apply the small amounts needed of a fertilizer supplying K only; on the poorer sites it will probably be necessary to repeat the phosphate application every ten to twelve years. The rate usually used for potassium is 95 kg K/ha, or 1½ cwt of potassium chloride (muriate of potash) per acre, and, to maintain growth rates, this may need repeating every six years or so. Attempts to grow Sitka spruce on poor deep peat are now being made, using four-yearly applications of nitrogen at 170 kg N/ha, or about 3 cwt of urea per acre.

Very little is known about nitrogen build-up and release in peats. As the figures quoted above show, the total amounts present are very large, and we know that mobilisation takes place more readily under some drainage and fertilizer regimes than under others, but the mechanisms are still unknown, and will remain unknown until a great deal of microbiological work has been done on such sites. If the very large reserves of nitrogen in peat could economically be made available for tree growth then high-yielding species such as Sitka spruce could be grown in place of pine. It must be obvious, therefore, that microbiological research on nitrogen mobilisation could alter foresters' outlook on peat forestry in Scotland. The anomalous results from Welsh sites, where the foliage N concentrations are very high, although peat N concentrations are similar to those in Scotland, only underline the challenge to foresters, soil scientists, and microbiologists.

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UTILISATION OF NUTRIENTS BY TREES AND VEGETATION ON DEEP PEAT IN NORTHERN IRELAND

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INTRODUCTION

Extensive areas of ombrogenous hill blanket peat at elevations of 600-1,000 ft O.D. have been planted with Sitka spruce (*Picea sitchensis* Carr.) in Northern Ireland. The peat is generally about 5-7 ft deep and the vegetation, although varying somewhat in detail throughout the Province, is of the general *Scirpus*/*Calluna*/*Sphagnum* type, the subsidiary species being *Eriophorum vaginatum*, E. *angustifolium*, *Erica tetralix* and *Narthecium ossifragum*. *Cladonia* spp. and hummocks of *Rhacomitrium* are common on the poorest sites.

Until 1963, plantations on this peat were established with 2 oz basic slag per tree (corresponding to approximately 2 cwt per acre) as the only form of fertiliser. At this low level of phosphate, the drainage carried out at planting has resulted in rapid and vigorous growth of *Calluna* and after about five years the growth of Sitka spruce in many such plantations is severely checked (McConaghy, 1962). Although additional phosphate application increases tree growth, the improvement is only temporary (Dickson, 1965).

In the years following planting there is considerable competition for nutrients between the trees and the native vegetation. Until closure of the crop canopy, therefore, the uptake and retention of nutrients by the vegetation must be considered in any analysis of nutrient utilisation by a tree crop. This paper describes three nutritional aspects of the tree - vegetation - peat ecosystem. Firstly, the distribution of nutrients between the components of the ecosystem is discussed. Secondly, the effect of herbicide treatment on the uptake and utilisation of applied nutrients by the vegetation is studied. Finally, the results of an experiment testing the response of checked Sitka spruce to herbicide and fertilisers are presented.

NUTRIENT CONTENT OF A 5 YEAR OLD SPRUCE CROP IN RELATION TO NUTRIENTS CONTAINED IN ECOSYSTEM

To estimate the maximum nutrient content of a 5 year old Sitka spruce crop on deep peat, two of the largest trees (each about 6 ft high) growing on peat which had received a high rate of phosphate (300 lb/acre P as Basic slag) were removed, complete with the greater part of the major root system, for chemical analysis. Table I shows that the total nutrient content of the crop was equivalent to approximately 16 lb nitrogen, 4 lb phosphorus, 5 lb potassium and 4 lb calcium per acre.

TABLE I

Total Nutrient Content and Dry Weight of Heavily Fertilised Five Year Old Sitka Spruce on Deep Peat

Component	Dry wt. (g)	Total Nutrient Content N (g)	P (mg)	K (mg)	Ca (mg)
Roots	135	0.82	274	320	148
Wood	407	2.85	951	845	733
Needles	242	3.63	419	1005	968
Total/tree (g)	784	7.30	1.64	2.17	1.85
Total Crop Content (lb/acre) (Based on 1000 trees per acre)	1723	16.05	3.60	4.77	4.07

In Table II these quantities are compared with the total quantities of nutrients contained in the top 5 cm of peat, in the vegetation and supplied as fertiliser under current practice in Northern Ireland.

TABLE II

Nutrient Content of Five Year Old Spruce Crop in Relation to Total Quantities of Nutrients in Peat Ecosystem

Nutrient	Quantities (lb/acre) contained in:-					$\frac{\text{Crop}}{\text{Total}}$ %
	Vegtn.	Peat	Fertiliser (4 cwt/acre G.R.P.)	Total Ecosystem	Total Crop	
N	38	640	-	678	16	2.4
P	2	15	64	81	4	4.9
K	18	18	-	36	5	13.9
Ca	5	55	156	216	4	1.8

Table II shows that even a heavily fertilised spruce crop of this age contains only a small proportion of the total quantity of nutrients in the ecosystem. Potassium is the only element of those shown for which the quantity in the crop represents an appreciable (14%) fraction of the quantity in the peat and vegetation. The phosphorus contained in the crop corresponds to only about 5% of the total in the ecosystem.

UTILISATION OF NUTRIENTS BY CALLUNA DOMINATED VEGETATION FOLLOWING HERBICIDE AND FERTILISER APPLICATION

There is considerable discussion at present concerning the relative values of herbicide and fertiliser in the treatment of checked Sitka spruce on deep peat. The present feeling in Northern Ireland is that since the majority of checked areas were established with a minimum quantity of phosphorus this element, at least, will have to be applied. The point in question, then, is whether there is any value in applying herbicide with fertiliser treatment.

In an experiment at Beaghs Forest, Co. Antrim (Beaghs 25/67) to test this, an area of badly checked Sitka spruce with very vigorous Calluna dominated vegetation was treated in 1967 with a factorial combination of N, P and K, each at three levels. Herbicide was applied to half of the area at time of fertilising. Samples of the vegetation were collected for analysis from selected plots during summer 1968. The total nutrient content and dry matter production of the standing crop of vegetation is shown in Table III.

TABLE III

Effect of Fertiliser at Herbicide Application on Total Nutrient Content of Calluna Dominated Vegetation

Treatment	Total Dry Matter Content (lb/acre)	Total Nutrient Content (lb/acre) N	P	K	Ca	Mg
$N_oP_oK_o$	6 918	56.8	4.4	16.9	18.2	7.4
$N_2P_oK_o$	8 811	70.7	5.2	17.2	22.0	10.2
$N_oP_2K_o$	7 665	64.0	10.4	15.7	20.9	9.8
$N_oP_oK_2$	8 375	68.7	6.1	28.3	22.5	8.8
$N_1P_1K_1$	7 494	63.9	8.4	20.6	20.3	8.9
$N_2P_2K_2$	7 405	71.5	10.0	23.8	23.0	8.0
Herbicide + $N_2P_2K_2$	7 218	51.8	4.5	6.2	13.3	2.6

Treatments	Fertiliser	Rate of Application cwt/acre	lb element / acre
N_1	Sulphate of ammonia	2	48
N_2	Sulphate of ammonia	4	96
P_1	Coarse rock phosphate	4	64
P_2	Coarse rock phosphate	8	128
K_1	Muriate of potash	1	56
K_2	Muriate of potash	2	112

Without herbicide, the highest rate of fertiliser increased the nutrient content of the vegetation by 14.7 lb N, 5.5 lb P and 6.9 lb K per acre. This difference corresponds to 0.61 cwt sulphate of ammonia, 0.34 cwt rock phosphate and 0.12 cwt muriate of potash. The vegetation has thus utilised 51.2% of the N, 4.2% of the P and 6.0% of the K added as fertiliser in the year before sampling.

The effect of herbicide application on the nutrient content of fertilised vegetation is also shown in Table III. Because of the high proportion of the total dry matter content attributable to the stems of Calluna, there is little difference in dry matter content between herbicide treated and non-treated plots. Differences in nutrient content are, however, appreciable and reflect the relatively high nutrient content of the leaves and flowers of the living vegetation. The vegetation which received fertiliser only contains 19.7 lb more N, 5.5 lb more P and 17.6 lb more K per acre than remains in the dead vegetation in the herbicide treated plots. These differences correspond to 0.8 cwt sulphate of ammonia, 0.3 cwt rock phosphate and 0.3 cwt muriate of potash per acre. In view of the high rate of leaching of nutrients from ombrogenous peat (Gore and Allen, 1956), it must be expected that quantities of applied nutrients corresponding to these differences may be lost from the site following herbicide application.

EFFECT OF HERBICIDE AND FERTILISERS ON GROWTH AND NUTRIENT UPTAKE OF CHECKED SITKA SPRUCE

Until the crop closes canopy, the trees must compete with the native vegetation. Removal of the vegetation might improve tree growth in one or more of three distinct ways. Firstly, the direct competition of the vegetation for nutrients would be eliminated. Secondly, some of the nutrients in the vegetation would, in time, become available to the trees. Lastly, any substance toxic either to tree roots or mycorrhizae produced by a component of the vegetation e.g. Calluna (Handley, 1963) would no longer be produced.

In 1965, another experiment at Beaghs (Beaghs 14/65) was laid down to test the effect of herbicide and fertilisers on the growth and nutrient uptake of checked Sitka spruce. The trees had received 2 oz basic slag per tree at time of planting (1960) (corresponding to approximately 20 oz P/acre applied broadcast). The trees showed the typical yellowing of foliage associated with check in Sitka spruce and the average leader growth was less than 10 cm (4 in).

Two levels of nitrogen (as sulphate of ammonia) were tested in combination with two rates of phosphorus (as superphosphate) and potassium (as muriate of potash). The fertilisers were broadcast in April 1965 both with and without herbicide. The herbicide (a 'paraquat' based compound) was applied at 8 pints/acre in mid-July 1965 with a further application in mid-October to ensure a complete kill.

Growth response is shown in Table IV.

TABLE IV

Effect of Herbicide and Fertiliser Treatment on Growth of Checked Sitka Spruce

Season	Herbicide	Nil	$N_1P_1K_1$	$N_1P_2K_2$	$N_2P_1K_1$	$N_2P_2K_2$
		Annual Leader Growth (cms)				
1965	+	9.6	16.0	14.5	13.5	18.8
	-	9.6	11.4	14.7	14.0	15.2
1966	+	15.5	24.6	24.1	22.6	26.7
	-	9.4	17.0	21.8	19.0	25.9
1967	+	24.1	27.9	28.7	28.9	30.5
	-	9.9	20.1	24.9	21.8	30.5
1968	+	22.6	27.4	29.5	29.5	30.0
	-	9.6	17.5	23.1	18.5	27.9

(Column heads $N_1P_1K_1$ to $N_2P_2K_2$ stand under the spanning heading "Fertiliser Treatment".)

<u>Treatments</u>

<u>Herbicide</u> Gramoxone W. (Paraquat) 8 pts/acre
applied twice - mid July and mid October 1965

<u>Fertilisers</u> Applied April 1965

Treatments	Fertiliser	Rate of Application cwt/acre	lb element/ acre
N_1	Sulphate of ammonia	1	24
N_2	Sulphate of ammonia	2	48
P_1	Superphosphate	3	30
P_2	Superphosphate	6	60
K_1	Muriate of potash	½	28
K_2	Muriate of potash	1	56

Annual leader growth of the untreated trees has remained below 10 cm over the four year period of the experiment. Herbicide alone has markedly increased growth, the average leader length in the fourth year being over twice that in the control plot. Without herbicide, there has been a progressive increase in growth with increase in rate of fertilisers applied. Where herbicide was applied there has been a slight response to fertiliser application but little difference due to rate or composition of the fertiliser.

Thus, when the competition of the vegetation is removed, initial tree response is not closely correlated with the quantity of nutrients added. Without herbicide, however, the vegetation utilises some of the applied nutrients (cf. Table III) and tree growth is clearly related to rate of fertiliser application.

The course of nutrient uptake by the trees in this experiment is shown in Table V.

TABLE V

Effect of Herbicide and Fertiliser Treatment on Nutrient Uptake by Checked Sitka Spruce

		Fertiliser Treatment					
Season	Herbicide	Nil	$N_1P_1K_1$	$N_1P_2K_2$	$N_2P_1K_1$	$N_2P_2K_2$	Mean
		Average foliar N concentration - % D.M.					
1965	+	1.56	1.89	1.97	1.94	2.08	1.89
	-	1.06	1.53	1.51	1.57	1.68	1.47
1966	+	1.65	1.67	1.76	1.63	1.88	1.72
	-	1.21	1.56	1.40	1.38	1.53	1.42
1967	+	1.50	1.48	1.27	1.77	1.72	1.55
	-	0.94	1.09	1.12	1.07	1.20	1.08
		Average foliar P concentration - % D.M.					
1965	+	0.13	.17	.18	.17	.20	.17
	-	0.11	.18	.17	.17	.19	.16
1966	+	0.15	.17	.16	.17	.18	.17
	-	0.13	.16	.17	.16	.18	.16
1967	+	0.14	.15	.18	.17	.20	.17
	-	0.11	.19	.21	.19	.19	.18
		Average foliar K concentration - % D.M.					
1965	+	0.52	.49	.47	.45	.47	.48
	-	0.45	.55	.53	.51	.52	.51
1966	+	0.50	.51	.52	.53	.52	.52
	-	0.52	.56	.58	.55	.56	.55
1967	+	0.52	.46	.50	.48	.57	.51
	-	0.47	.63	.68	.64	.63	.61

Treatments as for Table IV

Herbicide treatment produced a very rapid and highly significant increase in foliar nitrogen concentration. Although the herbicide was not applied until mid July 1965, by the end of the season weed killing alone had increased the foliar nitrogen concentration from 1.06% to 1.56%. Herbicide treatment, averaged over all fertiliser levels, increased the foliar nitrogen concentration from 1.47% to 1.89%. Differences between treatments were less marked during the second year but, in the third season following treatment, weed killing produced an overall 50% increase in foliar nitrogen concentration. Indeed in the absence of weed killing, the foliar nitrogen levels at the end of the third season after application of even the higher rate of nitrogen were again below the generally accepted 'optimum' level of

1.5% (Leyton, 1958), at 1.07% and 1.20% at the lower and higher rates of phosphorus and potassium respectively.

Foliar phosphorus concentration is increased very slightly by herbicide treatment alone. This is not unexpected in view of the low total phosphorus content of the native vegetation. Fertiliser application has increased foliar phosphorus concentration but there is little difference between treatments.

Foliar potassium concentration is increased slightly by herbicide treatment alone, but in the presence of fertilisers there is a decided decrease in levels of foliar potassium where the vegetation has been killed. In the third season, for instance, the foliar potassium concentration (averaged over all fertiliser treatments) was 0.51% with herbicide and 0.61% without herbicide treatment. The rate of applied potash has had no effect on foliar potassium uptake.

DISCUSSION

The phosphatic fertilisers commonly used in forestry practice on peatland (ground rock phosphate and superphosphate) are soluble at the low pH values of ombrogenous peat. It is surprising, then, that recently planted Sitka spruce, which shows a positive growth response to increase in rate of applied phosphate up to 160 lb P/acre as ground rock phosphate (Dickson 1969), contains only a small portion (approximately 5%) of the available phosphorus. This suggests that the better growth at the higher rates of application is due to a factor or factors other than the quantity of phosphorus applied. Even a five year old spruce crop on deep peat can contain 14% of the total potassium in the peat ecosystem. Although it has recently been shown (Atterson 1967, Dickson 1966) that the growth of spruce on peat is improved by potash application, this is only slowly being accepted in field practice.

The nutrient content of Calluna dominated vegetation is increased considerably by fertiliser application. The increase in nitrogen content corresponds to 0.61 cwt/acre sulphate of ammonia. Since it appears that Calluna can utilise applied nutrients more efficiently than spruce (Weatherall, 1953), it follows that unless the competition of the vegetation is removed the tree crop will only benefit from rates of applied nitrogen which exceed this figure. This is illustrated by the response of checked Sitka spruce to fertiliser and herbicide application. Thus, spruce growth is increased either by fertilisers or herbicide alone. At a low rate of fertiliser application growth is improved by herbicide treatment, but no such improvement occurs at higher rates when sufficient nutrients are added to satisfy the requirements of both trees and vegetation.

Since the poorer peat types do not contain sufficient nutrients to meet the demands of a mature tree crop (Binns,

1962) considerable fertiliser input will be needed to allow a tree crop on these types to reach the end of the rotation. Herbicide treatment allows a re-distribution of nutrients already in the ecosystem. It does not add to the nutrient capital of the site and hence cannot overcome the long term nutritional problems involved in growing trees on deep peat. Indeed the capacity of living vegetation to accumulate some of the applied nutrients until the crop canopy closes (when the crop demand for nutrients increases towards a maximum, Ovington 1959) may be a valuable asset.

A noticeable feature of the effect of herbicide on the nutrient uptake of checked Sitka spruce is the rapidity with which foliar nitrogen concentration increases. Even when herbicide was not applied until after the main growing period, nitrogen uptake had increased by over 50% due to weed killing only by the end of the same growing season. This suggests that there is a pool of relatively easily available nitrogen in the peat and that on removal of the competing vegetation the trees can exploit this source. The fact that phosphorus uptake by spruce is little changed and potassium uptake if anything decreased suggests that the initial benefit from weed killing is due to greater nitrogen availability. This agrees with the findings of Weatherall (1953).

SUMMARY

The paper deals with various aspects of the growth of recently planted Sitka spruce on deep ombrogenous peat in Northern Ireland. An analysis of the distribution of nutrients in the tree-peat-vegetation ecosystem shows that a five year old Sitka spruce crop contains only a small proportion of the total nutrients in the ecosystem. The natural vegetation in a checked peatland plantation utilises a considerable proportion of nutrients added as fertiliser. Herbicide treatment eliminates this competition for nutrients and considerably improves the growth of the trees. At relatively high rates of fertiliser application, however, the growth of checked Sitka spruce is not improved by herbicide treatment. It is considered unlikely that herbicide treatment will solve the nutritional problems of spruce established on deep peat with small quantities of phosphate. The increased tree growth following herbicide treatment is associated with an increase in nitrogen uptake by the trees.

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NATURE CONSERVANCY RESEARCH ON THE NUTRITION OF PINES ON HIGH ELEVATION PEAT

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INTRODUCTION

The Nature Conservancy has within its series of Reserves areas of both upland and lowland peat. Work with trees on such areas is on a small scale and attempts to complement, rather than duplicate, the numerous experiments of the Forestry Commission who are concerned with establishment of trees for timber production. The studies on lowland peat have been concerned with the interactions between aeration and nutrition in wet peat-bogs (Brown et al, 1966) and will not be further considered here.

Upland work has been concentrated at the 10,000 acre Moor House National Nature Reserve. This area, a portion of the main ridge of the Northern Pennines, lies just south of Cross Fell - the highest point of the Pennines - and ranges from 1000 ft O.D. in the western side rising up the escarpment to 2780 ft O.D. on Great Dun Fell and falling more gradually eastwards along the dip slope to 1575 ft. A range of upland habitats is represented, but with blanket bog as the predominant type, covering most of the gently sloping dip slope. The Reserve was not acquired for its rare species or exceptional character, but rather as an open-air laboratory in which a study could be made of blanket bog and the problems of land-use associated with it.

The climate has been described fully elsewhere by Manley (1936, 1943), who has likened it to that of the coastal regions of Iceland. Briefly, it is wet, cold and exposed, providing a very short growing season.

Thus the Reserve in many ways is well suited to studying different forms of land-use and management techniques for peatland areas under severe climatic conditions. A variety of such studies have been made - sheep-grazing, moor-burning and catchment work amongst others. At the same time it was appreciated that the re-establishment of a woodland cover was likely to play an increasingly important part in the future use of these upland areas - though not necessarily always for timber production. A tree cover will create diversity in the habitat and increased conservation and amenity value, in addition to providing shelter and stabilization of eroding areas.

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In connection with establishing and growing trees in the uplands, research into the relative importance of and interactions between the inhibitory climatic and edaphic factors was needed, i.e. studies of the inter-relations between tree-growth, nutrition and climate.

Species trials started in 1954 soon showed that of the species tried only the pines P. sylvestris, P. contorta, P. mugo could survive on the blanket peat, and that Scots pine grows adequately only in the more sheltered sites and on shallow or redistributed peat. Nutritional studies at Moor House were initiated with the latter species, planted at 1875 feet and dressed with Ground Mineral Phosphate (G.M.P.). The results reported in an earlier paper (Brown et al, 1964) indicated that a potassium deficiency was severely limiting tree growth. It was suggested that this deficiency was aggravated by the severe climate of the Reserve, reducing either the availability of the potassium in the peat, or the trees' ability to take up the element. There is experimental evidence from other fields that absorption of nutrients by plants is directly related to temperature (Robertson, 1958; Sutcliffe, 1962).

As it was evident that the production of a woodland cover of any scale on the exposed blanket bog would be most readily accomplished using Pinus contorta, studies were extended to this species.

NUTRITION OF LODGEPOLE PINE ON UPLAND PEAT

A lodgepole pine fertilizer trial was established in the spring of 1962 on an exposed 2 acre plot of blanket peat at 1825 ft. The vegetation is dominated by Calluna vulgaris with Eriophorum vaginatum, Sphagnum spp. of the acutifolia group, and Rubus chamaemorus, (i.e. the Sphagna-rich facies of McVean and Ratcliffe's (1962) Calluna-Eriophoretum which is widespread in northern and western Britain). The peat varies from 3-7 feet (c. 1-2.2 metres) and analyses made on samples collected in the June before ploughing are given in Table I. It may be seen that in several respects the peat is not especially infertile compared with some other peats, judging from analytical data given, e.g. by Binns (1962). Neither phosphorus nor potassium is particularly low, although the latter falls off rapidly with depth. Calcium content of the Moor House peat is quite high. On the other hand the total nitrogen content is low compared with many other peats.

The site was ploughed early in 1962 to 18 in depth, using a Cuthbertson single mouldboard plough at 6 ft spacing. The trees were step-planted at 5 ft spacings in the rows using 1 + 1 trees of Long Beach, Washington provenance.

METHOD

Three fertilizer elements were added: nitrogen, phosphorus and potassium. The aim of the experiment was to study the effects of adding these in soluble and insoluble forms and in different combinations, upon the height growth of the pine, and to find out how long the effects upon growth and nutrient levels in the leaves persisted. The nitrogen was added in a highly soluble form (N_1) as ammonium nitrate (2 oz per plant) or in a relatively insoluble form (N_2) as urea formaldehyde (4 oz per plant). The phosphorus was added as the soluble, and calcium free, sodium orthophosphate (P_1) ($1\frac{1}{2}$ oz per plant) or as the relatively insoluble ground mineral phosphate (P_2) (2 oz per plant). Potassium was added as soluble potassium sulphate (K) (2 oz per plant).

A randomized block experimental design was used, with four blocks and twelve treatments (one treatment per plot). There were 45 trees in each plot which, allowing for guard rows, left 21 trees per plot for sampling.

The twelve treatments consisted firstly of the soluble N_1, P_1 and K added singly and as all possible combinations; secondly the relatively insoluble N_2 was added with and without phosphorus (as P_1); thirdly the relatively insoluble, calcium-containing, P_2 was added with and without potassium; and finally there was an unfertilized control (see Table II). The fertilizers were placed on the steps around trees, the soluble fertilizers being added over 2 seasons, part of the prescribed quantity in each case in late spring 1962, the balance in the following year.

Early in October of each year since planting, measurements of leader increments and tree height have been made. In addition height at planting was obtained. At the same times, samples of the current year's needles were taken for chemical analysis. Subsequently, analyses of variance have been carried out on the data.

The present paper is essentially an interim report on a long term experiment.

RESULTS

TREE GROWTH (Figs. 1 and 2)

As was to be expected there was no effect of treatment during the first season. By the end of the second year, however, statistically significant differences ($p <.05$) were apparent, which by the following year had become very highly significant ($p <.001$). Largest increments were associated with treatments containing both P and K (i.e. P_1K, P_2K and N_1P_1K). Adding K on its own had an increasingly marked effect both on overall height and on increment which by 1967 was statistically highly significant and had become second only to P_2K in effect on increment. This is difficult to explain because, as will be seen later, foliar potassium by 1967 was as low in the K treatments as in the control and indeed lower than in several treatments.

Beneficial results from the use of nitrogenous fertilizers have been reported from a variety of experimental sites (e.g. Forestry Commission Research Reports), and Heilman (1968) quotes a level of 1.5% for peat nitrogen content, below which nitrogenous fertilizers are usually beneficial. As the N content of the peat at Moor House is only 1.3-1.4% and thus at the lower end of the range usually associated with acid peats, a positive response to added nitrogen had been expected here. In fact, the reverse was the case. The addition of N_2 (urea formaldehyde) had no significant effect on growth; the treatments containing the more soluble N_1 (ammonium nitrate) actually reduced growth (statistically significant) compared with those without this fertilizer. Whether this was a reaction to the addition of nitrogen per se or to the particular compound NH_4NO_3 is not clear. The lack of response to N_2 may be due to delayed breakdown. There was certainly no evidence of the harmful formation of biuret.

Similar responses to nitrogenous fertilizers have been reported previously, e.g. Jack (1965) found nitrogen applied to Sitka spruce was either not beneficial or actually deleterious; and Dickson (1966) reported the response to nitrogen of both Sitka spruce and *P. contorta* as minimal.

Other than a direct toxic effect of ammonium nitrate, two further hypotheses can be put forward to account for the deleterious response to the N_1 treatment:

(a) A stimulation of microbial activity, the organsisms then competing with the trees for nutrients. There is, however, no consistent reduction in foliar concentrations of P and K associated with the N_1 treatment.

(b) Mineralization of nitrogen in the peat following ploughing has been sufficient to provide a high enough level of N, or at least, high enough in relation to other elements. The ratio of N to other elements may have been markedly upset by further additions. Of the treatments containing N_1 only the triple-element fertilizer N_1P_1K produced a better response - at least initially - than the corresponding treatment without N_1.

As has been emphasized by other contributors to the Symposium, the nitrogen status of a peat may be less related to total N content than to other factors, either introduced by treatments - ploughing, fertilizer applications - or possibly inherent. In the present case, the relatively high calcium content of the Moor House peat may account for the presumed adequate N mineralization.

Adding phosphorus either on its own or in combination with other elements greatly improved height growth (significant at $p < .05$). Leader increment was greater in treatments with P_2 (G.M.P.) than with P_1 (sodium orthophosphate) but only significantly so in 1967. Needle weight on the other hand was significantly increased by P_2 over P_1 in several years (1964-66).

The annual height increment increased in all treatments up to the end of the 1965 growing season (i.e. for the first 4 years). Subsequently leader lengths have tended to level off (e.g. P_2K, N_1K) or decreased (e.g. control, P_1, N_1P_1K). The best treatment P_2K levelled off with a height increment of 21-22 cm.

FOLIAR ANALYSES

The chemical analyses made annually on needle samples from all plots enable the patterns of nutrient uptake to be followed. In the control plots the effect of ploughing only can be seen, whereas in the treated plot the way this pattern is modified by fertilizer additions is demonstrated. In the untreated controls (Fig. 3), after a general initial fall in the concentrations of all elements following planting there was a temporary increase for a year or two starting in 1963 for N, K and Ca and in the following year (1964) in the case of phosphorus. This rise in foliar concentrations is possibly associated with the mineralization of nutrients following the ploughing early in 1962. During 1963, a marked development of basidiomycete fruiting-bodies (mainly Hypholoma uda) along the exposed edges of the sandwiched vegetation layer, suggested that breakdown was by then active. It is also perhaps of relevance that in the case of potassium - an element normally thought to be released readily in ionic form from decomposing vegetation - the rise in needle concentration occurred immediately and only in 1963, followed by a marked and continuing fall. The nitrogen and phosphorus show a more prolonged rise - in fact delayed by a year for P - before falling off again, which accords more with their known conditions of being normally much more closely bound organically.

The three other elements behave rather differently. Magnesium varied over the years between .065 and .082 and followed inversely the levels of N, P and K; Ca and Na after a very marked initial drop showed the subsequent rise but have tended not to fall off again like N, P and K. In fact with Na a further rise has occurred in the last 2 years, possibly associated with the weather. Rainfall, and therefore probably sodium income, was greater in both 1966 and 1967 than during each of the previous 4 years.

The individual elements and the effects of the fertilizers are now considered in more detail:-

NITROGEN (Fig. 4)

The overall patterns of foliar N during the course of the experiment were similar in most treatments.

The levels of these foliar concentrations support the view that mineralization of nitrogen has been adequate following ploughing. The control plots showed the initial drop after planting to a level of 1.2% N but then rose to a peak of 1.9% in the 3rd season, i.e. a little higher than the level in the planting stock, figures which cannot be considered particularly low for lodgepole pine.

On the other hand initially greater uptake of N, possibly following increased mineralization, is associated with the P additions, especially G.M.P. + K, but not by adding K alone. These effects are quite short-lived.

Although the addition of ammonium nitrate in any treatment was associated with a highly significant ($p < .005$) increase in foliar N concentration at the end of the first season, this increase was short-lived. By 1965, and subsequently, N concentrations in N_1 treatments did not differ from those without N_1. With the addition of relatively insoluble N_2 (urea formaldehyde) alone, foliar nitrogen concentrations were only slightly and not significantly above those of the control and followed the pattern of the latter closely. In some years the addition of ammonium nitrate (N_1) increased the levels of both phosphorus and potassium in the leaves (significant at $p < .10$).

PHOSPHORUS (Fig. 5)

The annual pattern of phosphorus in the leaves was more influenced by treatment than was the case with nitrogen. The P level was related ($p < .005$) to whether or not this element was added as soluble orthophosphate or as ground mineral phosphate. In the first year the phosphorus level was higher in the orthophosphate treatment (P_1) but later it was higher with the ground mineral phosphate (P_2) illustrating the delayed action of the latter. In both cases, the initial gain in leaf phosphorus was followed by a steep decline. The benefit of the P_2 was that this decline was less rapid than with P_1 and may even be levelling off. By 1967 the leaf phosphorus levels with the soluble orthophosphate (P_1) were the same as that of the untreated control, (.10%). The addition of phosphorus had no effect on foliar levels of other elements, except in the case of K where in some years the foliar levels of this element were lower where phosphorus (P_1) had not been added than where it was included. These increases in foliar phosphate concentrations are, as has been seen, associated with significant increases in height growth.

The calcium levels in the ground mineral phosphate (containing Ca) treatments did not differ significantly from those with calcium-free sodium orthophosphate.

POTASSIUM (Fig. 6)

The general pattern in all treatments was that from 1962-63 there was a rise in foliar K, followed by a sharp fall in succeeding years. Where potassium sulphate alone was added, this rise was maintained into 1964, but levels then declined sharply to the control level (.36%) by 1967. The effect upon foliar concentration of the potassium containing treatments in general was short-lived and there was no evidence of any benefit from potassium recycled from the decaying tree leaf litter. The leaf K is consistently low with G.M.P. and lowest in this treatment, in the last three years (1965-67). In some years there were highly significant relationships ($p < .005$) between presence and absence of potassium and levels of N and Ca in the tree leaves, but these were not consistent.

By 1967 all the K levels were low (.28-.40%) including the levels in the treatments P_2K (.36%), K (.36%), P_1K (.41%) and particularly P_2 (.28%), but in spite of this the height increment was either maintained or (in the case of the N_1 and K treatments) slightly increased. It is well known that Lodgepole pine can tolerate relatively low potassium levels, but the level of .28% associated with G.M.P. alone must be markedly sub-optimal. These data suggest that the tree can maintain quite reasonable height growth (for these adverse site conditions at least) of 15-20 cm/year even when levels are only a little above those associated with actual visual deficiency symptoms.

CONCLUSIONS

One of our interests in tree nutrition at Moor House is the question of whether nutrient availability or uptake is influenced to any appreciable extent by the severe environment. As we have not yet made any direct comparisons between Moor House and comparable plantations in more favoured areas, this point must remain inconclusive.

However, in the case of K, there is the very steep decline in foliar concentrations of this element, with all treatments, in trees growing on a peat of relatively high K content. Although this fall may well be due to rapid leaching following the flush of mineralization, the alternative explanation that uptake is reduced by the exposed conditions or low temperatures is also a possibility.

On the other hand, N uptake is somewhat better than might be expected from its levels in the peat. Although this possibly indicates that there is little effect of climate on N uptake, it emphasizes the lack of knowledge of the factors which influence N status and mineralization in peats. The range of studies being initiated at Moor House in connection with the International Biological Programme include some microbiological work on this point, which may help to elucidate this question.

A conclusion which may be drawn with more certainty is that both P and K are needed at Moor House, and that further additions of K will be necessary. The need for slower-acting potassic fertilizers is obviously suggested and the use of potassium meta phosphate as a combined P + K fertilizer would undoubtedly be of interest.

Although the absence of any response to N_2 (urea formaldehyde) either positive or negative, suggests that nutrient release from at least some slow-acting fertilizers may be unduly delayed under the Moor House conditions, the use of soluble fertilizers is certainly not a practical alternative; the benefit from the latter is obviously too short-lived.

There are indications of complex interactions between elements in the concentrations found in the trees, and some of these have been alluded to. It is however, hoped to take this point further by making use of appropriate multivariate techniques which will help to sort out which elements are of primary importance and which are merely dependent on changes in concentration in the former.

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Table I.

MOOR HOUSE EXPERIMENT
PEAT ANALYSES BEFORE PLOUGHING

Depth	pH	% dry weight					
		N	P	K	Ca	Mg	Na
3- 5 in. (7.5-12.5 cm)	3.4	1.26	.066	.051	.190	.057	.017
14-16 in. (35.5-40.5 cm)	3.6	1.37	.039	.013	.263	.047	.011

Table II.

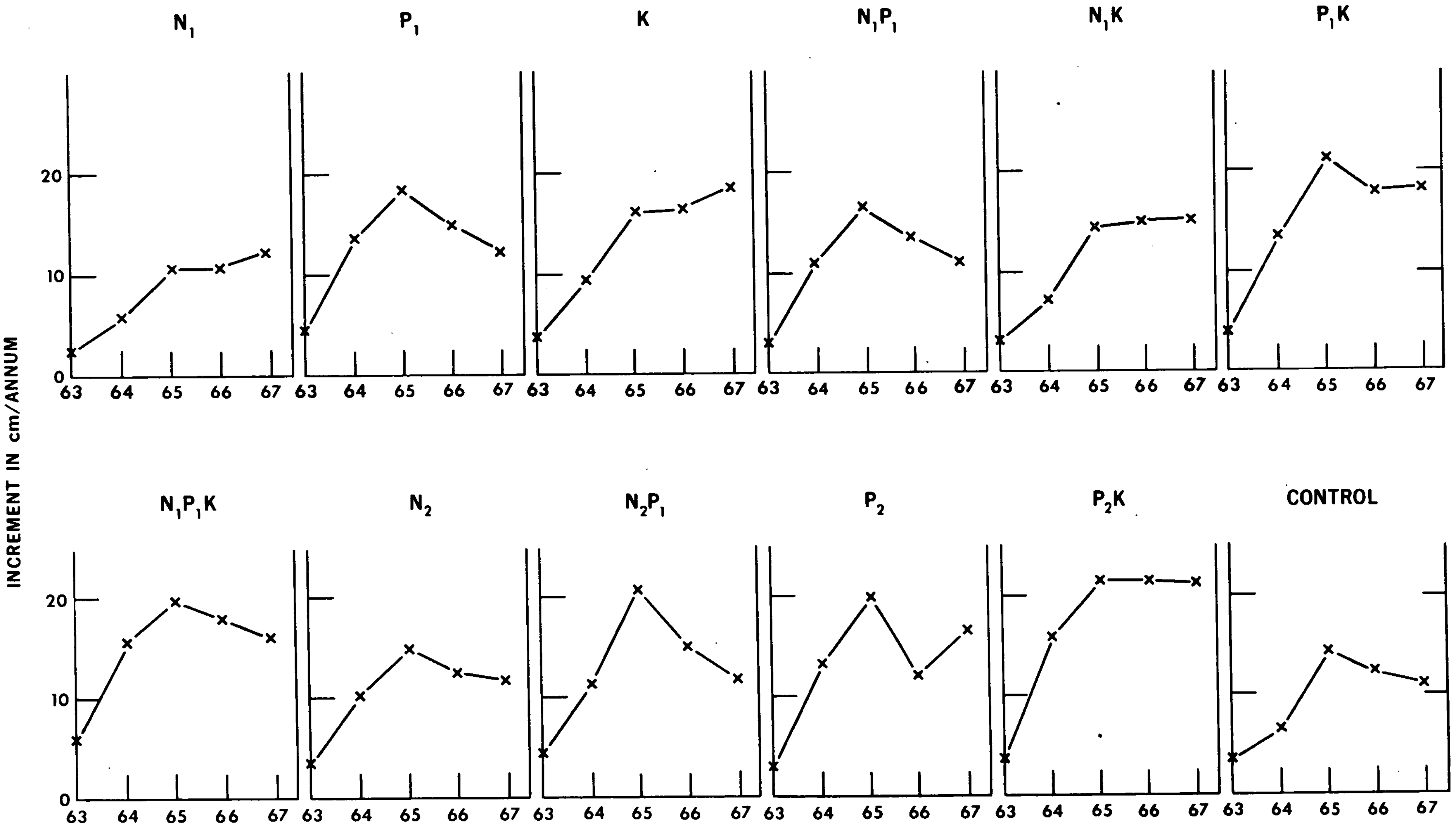
Fertilizers applied to Lodgepole pine at Moor House:

N_1	Ammonium nitrate	2 oz per plant
N_2	Urea formaldehyde "flash"	4 oz per plant
P_1	Sodium orthophosphate	1.5 oz per plant
P_2	Ground mineral phosphate (North African)	2 oz per plant
K	Potassium sulphate	2 oz per plant

Combinations of fertilizers used:

N_1
P_1
K
N_1P
N_1K
P_1K
N_1P_1K
N_2
N_2P_1
P_2
P_2K
Control

Fig. 1. The mean height increment (cm/annum) for different treatments Lodgepole pine: Moor House



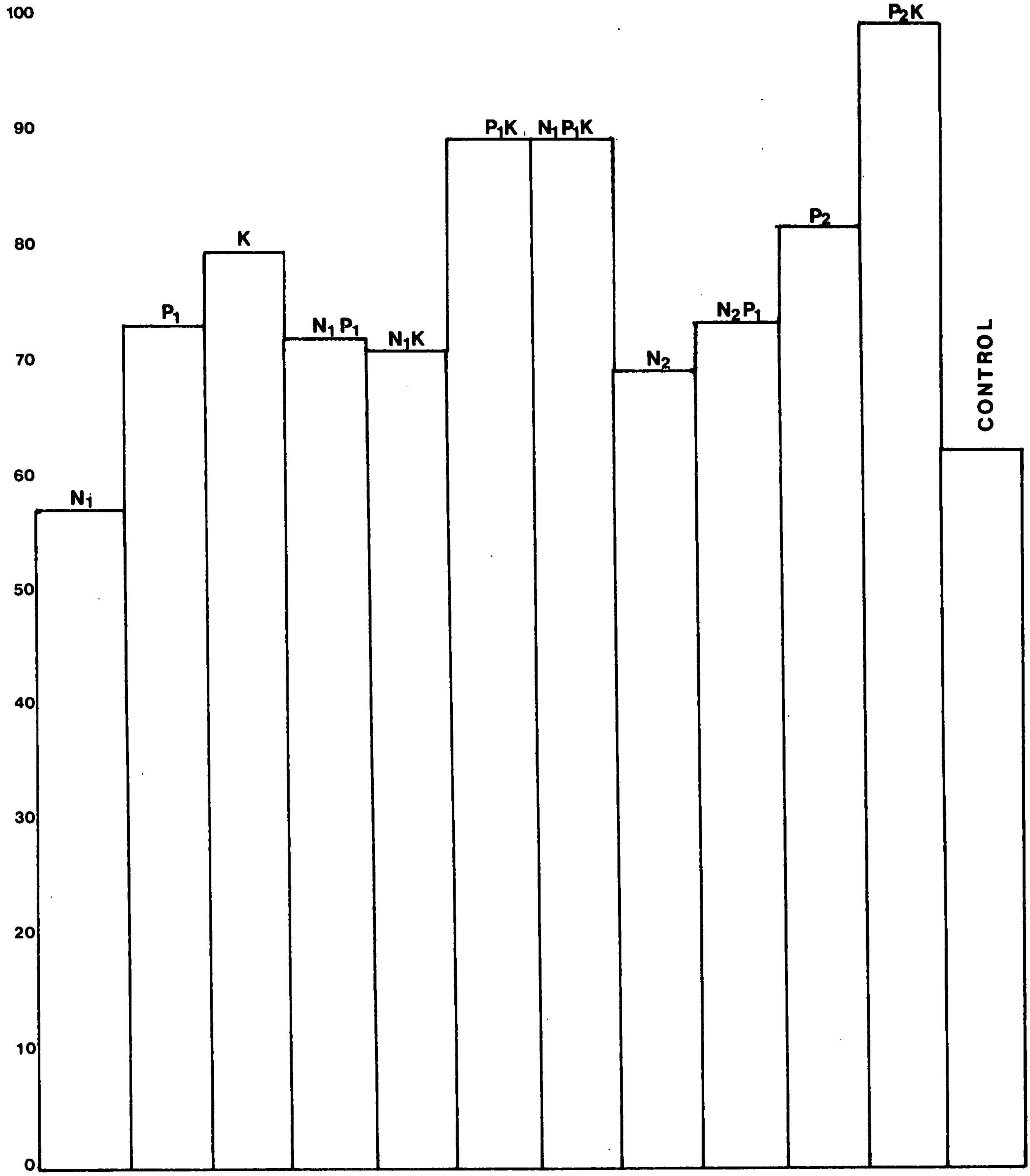


Fig. 2. Mean total height (cm) 1967 for different treatments Lodgepole pine: Moor House

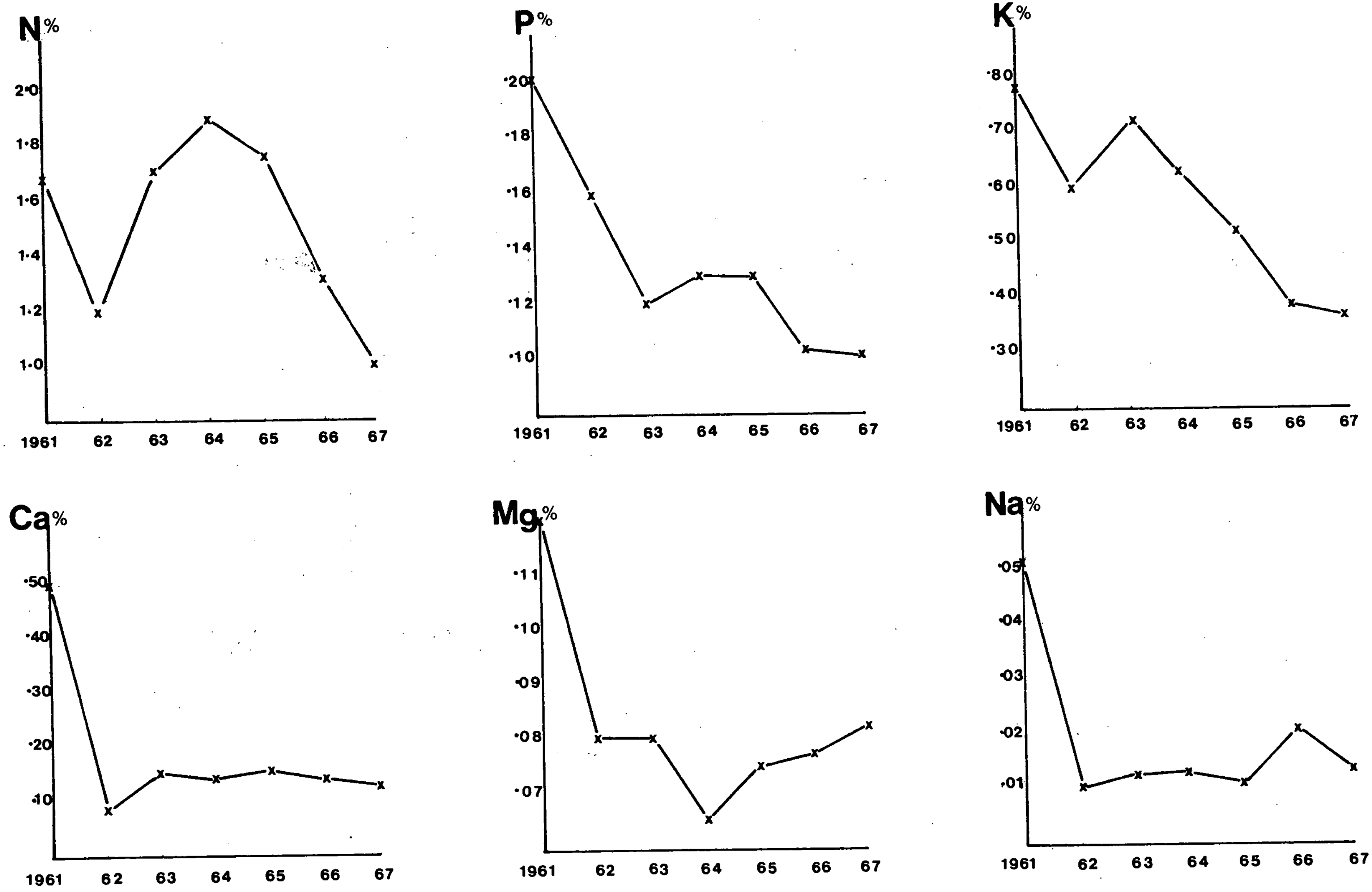


Fig. 3. Annual changes in foliar concentrations in control (unfertilised) plots Lodgepole pine Moor House.

Fig. 4. The mean concentration of nitrogen in current year's leaves for different treatments. Lodgepole pine: Moor House

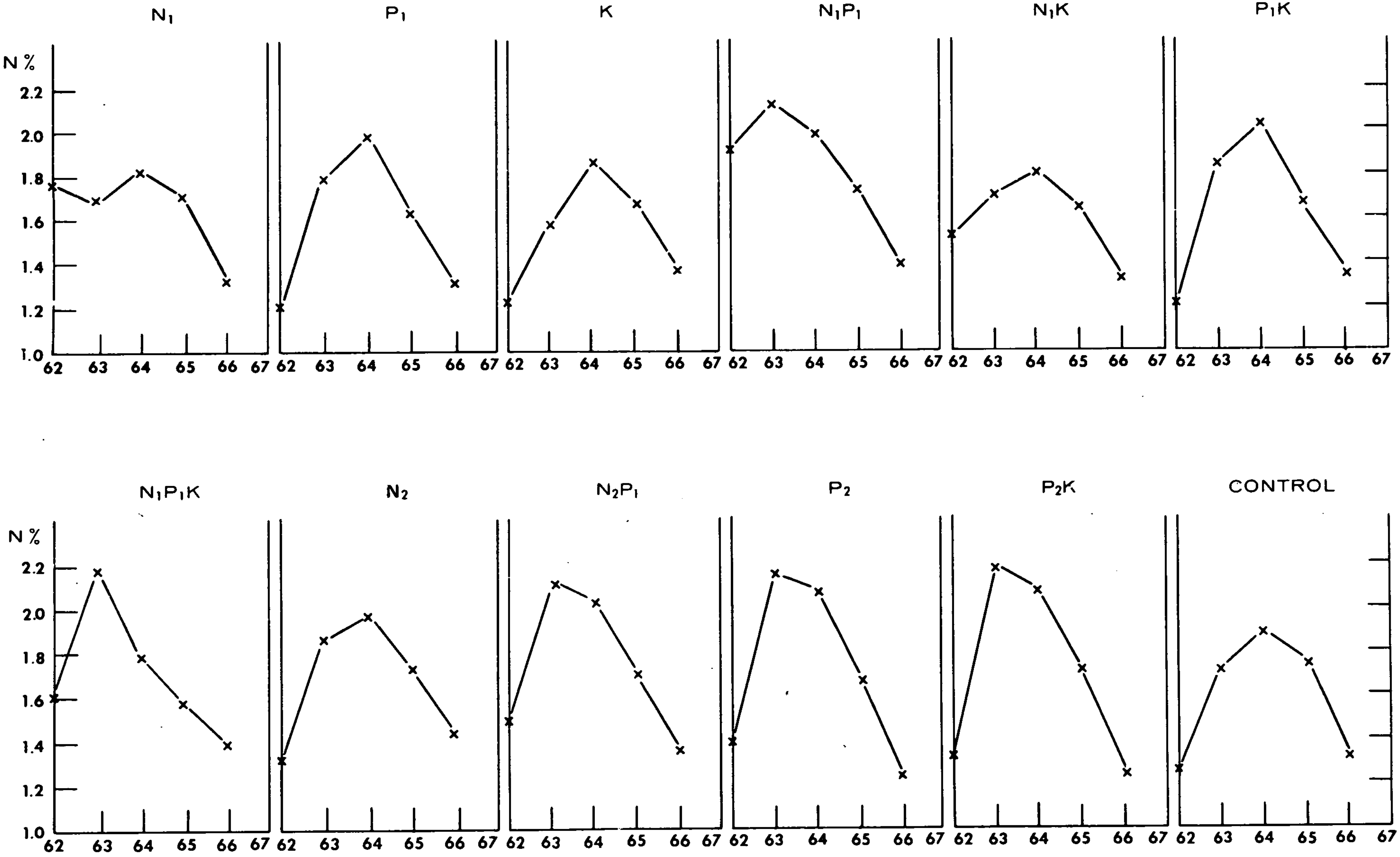


Fig 5. The mean concentration of phosphorus in the current years leaves for different treatments. Lodgepole pine: Moor House

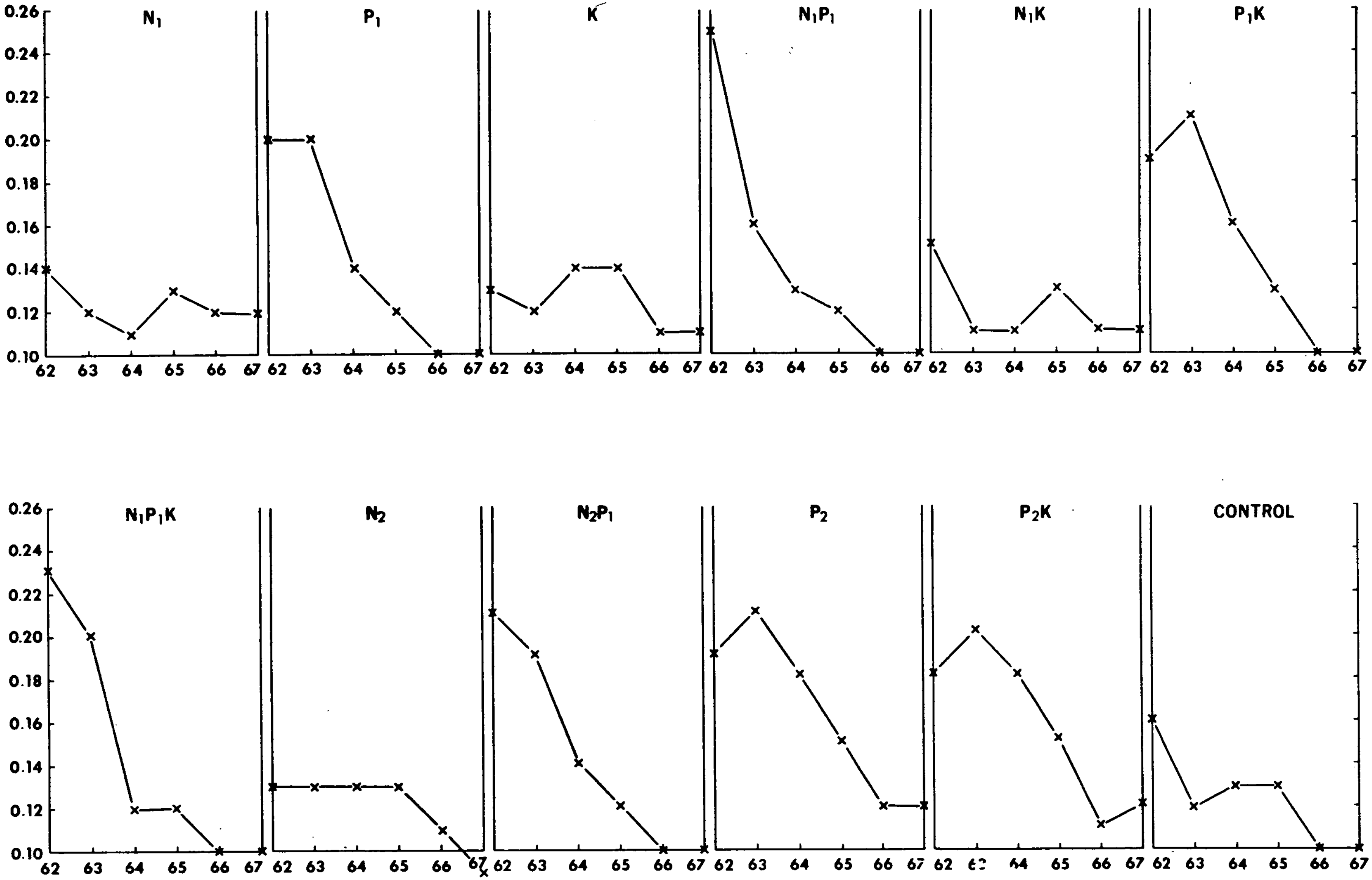
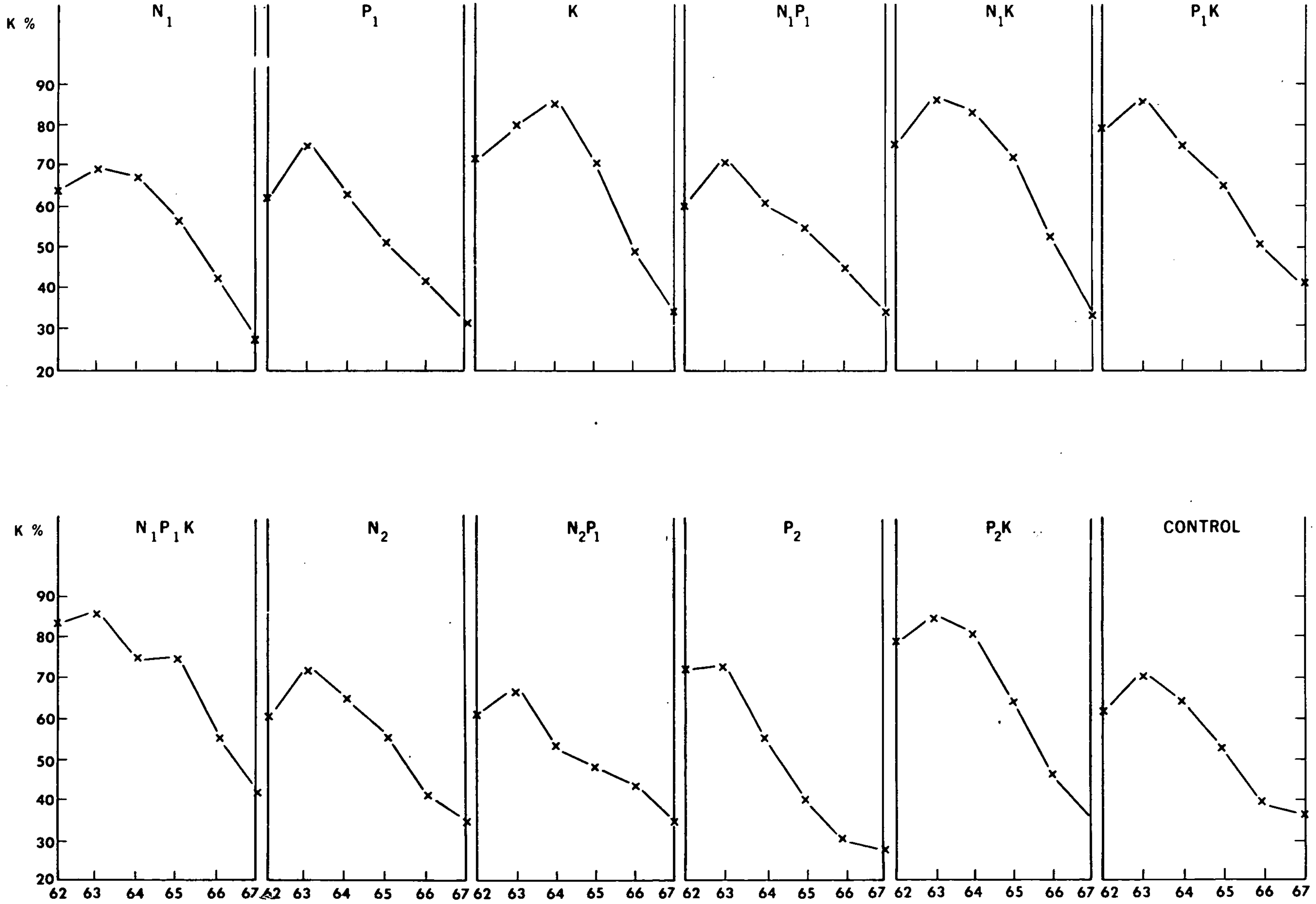


Fig. 6. The mean concentration of potassium in current year's leaves for different treatments. Lodgepole pine: Moor House



EVALUATION OF PEATLAND SITES ACCORDING TO THEIR PHYSICAL AND CHEMICAL CHARACTERISTICS

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INTRODUCTION

Within the broad divisions of blanket, basin and raised bogs the classification of peatland for afforestation is very much a subjective operation. Although it is sometimes argued that detailed sub-division of types is not realistic, there are undoubtedly considerable differences within, for example, an area of blanket bog, and the forester has long recognised the existence of these. The blanket bogs of northern Scotland are particularly variable, both topographically and floristically, and the planting practice in this region has been to change, with improvement in site conditions, from Lodgepole pine to Sitka spruce, planting intermediate sites with a mixture of the two species.

A criticism frequently levelled is that this policy can result in a multiplicity of crops, with all the subsequent managerial complications, and is not always justified by the degree of variation in site characteristics. Furthermore, it is sometimes suggested that apparent site variation on an unplanted bog may be simply a reflection of immediate past treatments, such as burning or grazing, rather than of the condition of the peat itself, i.e. that site differences may be artifacts unrelated to the potential of the land.

From the point of view of forest growth, knowledge of the potential of an area of peat is important quite simply because of the difference in yield between Sitka spruce and Lodgepole pine. Sitka spruce is a relatively demanding species and its use implies a high financial investment, particularly in fertilizers. If investment is adequate, yields may be quite high and more than cover the outlay involved, but if investment is insufficient and not enough care is exercised in selecting sites, Sitka spruce can be a complete failure. Against this is the fact that successful growth of Lodgepole pine is relatively easily obtained, but the yield is always low. A cautious policy of planting a slow-growing species that is certain to form a crop is not to be despised, but it is obviously desirable to use the highest yielding species that any particular site can support. Choice of species is at present based largely on features of the natural vegetation, but this practice is, as yet, unsupported by fundamental data. More information is required on the turn-over of nutrients in coniferous crops and on the environment required for successful root growth - both subjects that are being given considerable attention at the Macaulay Institute. Furthermore, it is desirable to know more about the behaviour of different peats as nutrient-supplying media, in order that site capacity and tree demands can be matched.

The supply of nutrients that trees can obtain from peat will depend partly on the quantities present, although the form in which the nutrients are held is also important and will be discussed elsewhere in this Symposium. The purpose of the present investigation was to determine the extent to which the site types recognisable in the field reflect variations in the nutrient content of the peat.

METHODS

The investigation was carried out in an area of some 200 acres of blanket bog near Lairg in Sutherland (Strath Tirry). This area exhibits a degree of variation typical of other bogs in the region, being characterized by morainic knolls over which the peat cover often decreases to as little as 10 cm thick, as opposed to a depth of more than 3.5 m in some of the hollows. The average depth was found to be around 1.75 m. In some areas input of mineral rich water has resulted in flush conditions, while in others the peat is being eroded: these differences are reflected in the vegetation cover.

Delineation into site types was carried out by members of the Forestry Commission, under the direction of Mr. G. M. Taylor, and the existence of the following types was suggested:

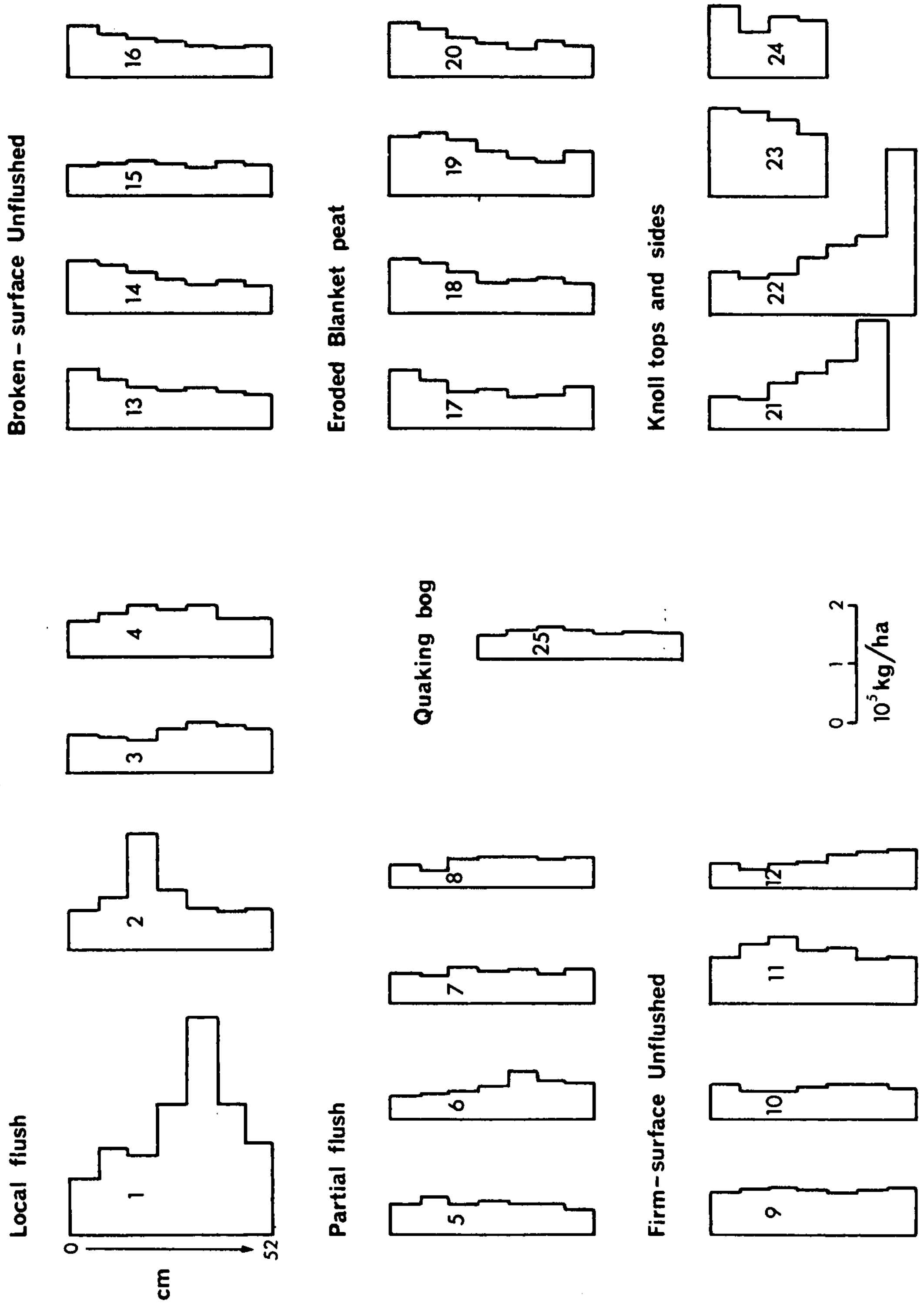
Local flush
Partially flushed blanket bog
Unflushed blanket bog, firm surface
Unflushed blanket bog, broken surface
Eroded blanket bog
Tops and sides of morainic knolls
Quaking bog

Except in the case of the quaking bog, of which there was only one, four examples of each type were located, the vegetation described and the peat sampled down the profile in seven 7.5 cm horizons. All samples were taken on a volume basis, using special stainless steel corers developed at the Macaulay Institute, placed in polyethylene bags and weighed on the site in a mobile field laboratory. The samples were subsequently oven-dried to constant weight and milled prior to analysis for total nitrogen, phosphorus, potassium, calcium and magnesium.

RESULTS

The weight of dry peat material per unit volume, and changes in this with depth, vary considerably between, and even within, types (Figure 1), but in general two distinct patterns are recognisable. For the flush types and the

Fig. 1. Variation in dry weight of peat material per unit volume with depth.



firm-surface unflushed type, the quantity of peat material per unit volume either increases or shows little variation down the profile, whereas for both the broken-surface unflushed type and the eroded type there is a distinct decrease with depth.

Certain anomalies are apparent, as for example the relatively high volume weights of the samples from site 1. Here the vegetation is characterised by a dense growth of Juncus effusus, whereas at the other sites in the local flush category Molinia caerulea is dominant. Again, site 15 appears to be atypical of the broken-surface unflushed types and a close examination of the vegetation suggests that it is in fact more closely related to the Molinia-dominant partial flush type, which differs from the local flush primarily in the absence of Agrostis spp. and associated grasses.

With the exception of site 15, the broken-surface unflushed type, dominated by Trichophorum caespitosum, closely resembles the eroded type, dominated by Rhacomitrium lanuginosum, a common feature being the relative abundance of Rhacomitrium and lichens. Trichophorum is also dominant on the firm-surface unflushed type, but here lichens and Rhacomitrium are absent or rare. Within the firm-surface unflushed type increasing wetness appears to be reflected by replacement of Trichophorum with Eriophorum spp., an extreme example being the quaking bog.

The peat on the morainic knolls varies greatly in density and can be divided into shallow and deep types. Those 30 cm deep or less, represented by sites 23 and 24 - both from the tops of knolls, support a vegetation dominated by Calluna vulgaris with a high proportion of Trichophorum, and may be regarded as extreme versions of the eroded type. Sites 21 and 22, on the other hand, are sufficiently deep for the surface to be relatively unaffected by mineral soil. At site 22, on a knoll top, the vegetation resembles that of the firm-surface unflushed type, whereas site 21, on a knoll side, is dominated by Molinia and somewhat resembles the partial flush type.

Analytical results suggest that nutrient content, in kilograms per hectare per horizon, is strongly dependent on the quantity of dry matter per unit volume of fresh peat. Indeed this appears to be the prime factor governing the nitrogen content in the top 15 cm of all the peat types (Figure 2), although to the total depth sampled (52.5 cm), the flush types do appear to contain a higher quantity of nitrogen per unit of dry weight than the other types. On this basis site 15 is again seen to be more closely related to the partial flush type than to the broken-surface unflushed type into which it was originally placed. The broken-surface unflushed type and the eroded type still appear closely related, although the former has a slightly lower nitrogen concentration.

Fig. 2. Nitrogen content in relation to dry weight of the peat to depths of 15 and 52 cm.

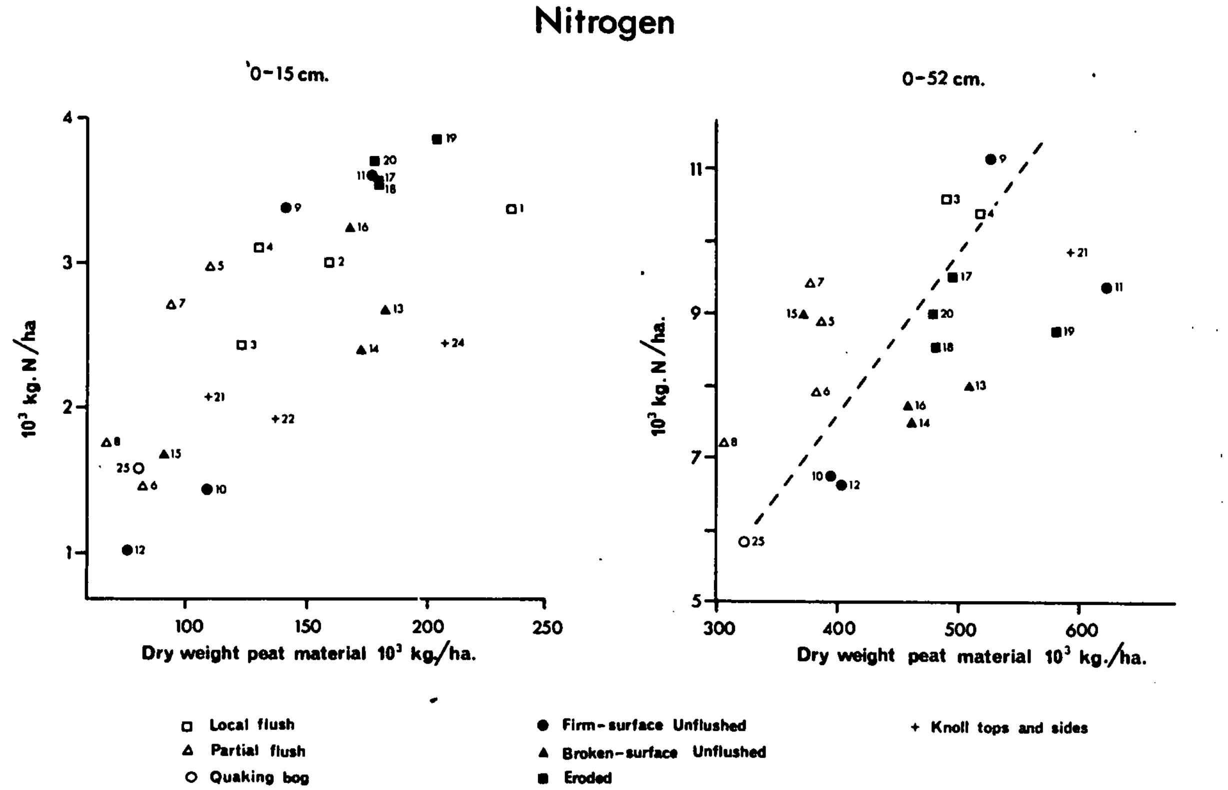


Fig. 3. Phosphorus content in relation to dry weight of the peat to depths of 15 and 52 cm. (key to site types given in Fig. 2).

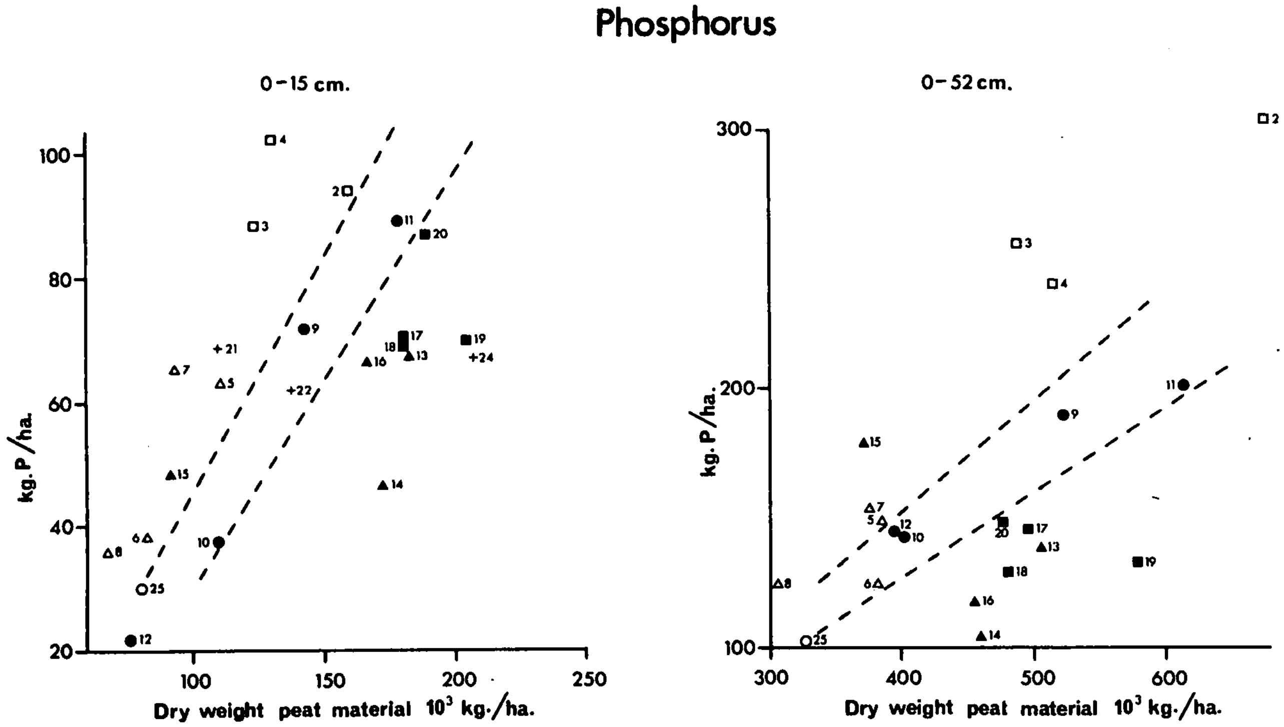


Fig. 4. Potassium content in relation to dry weight of the peat to depths of 15 and 52 cm. (key to site types given in Fig. 2).

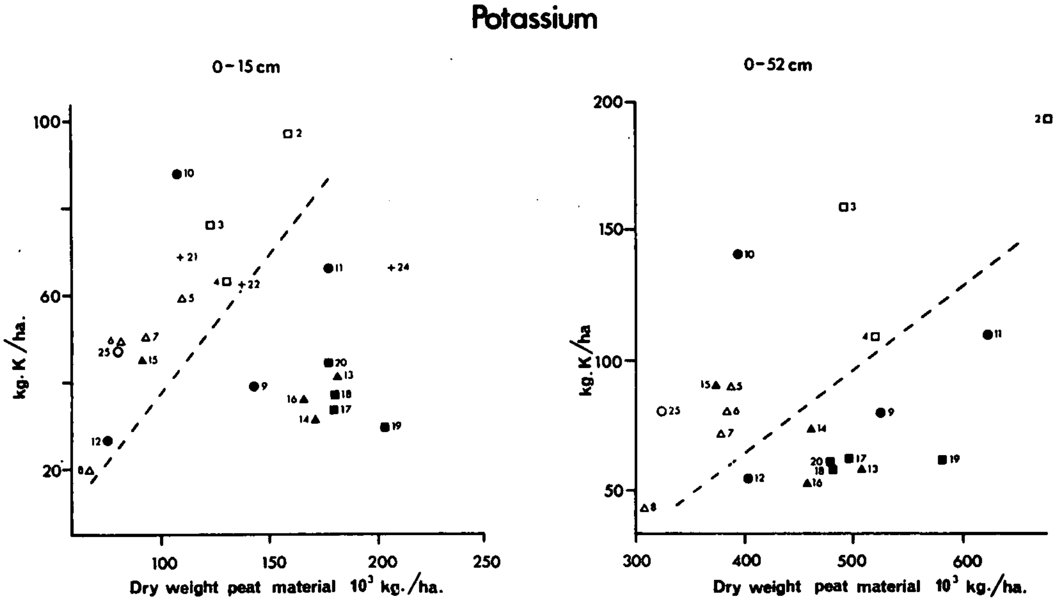


Fig. 5. Calcium content in relation to dry weight of the peat to depths of 15 and 52 cm. (key to site types given in Fig. 2).

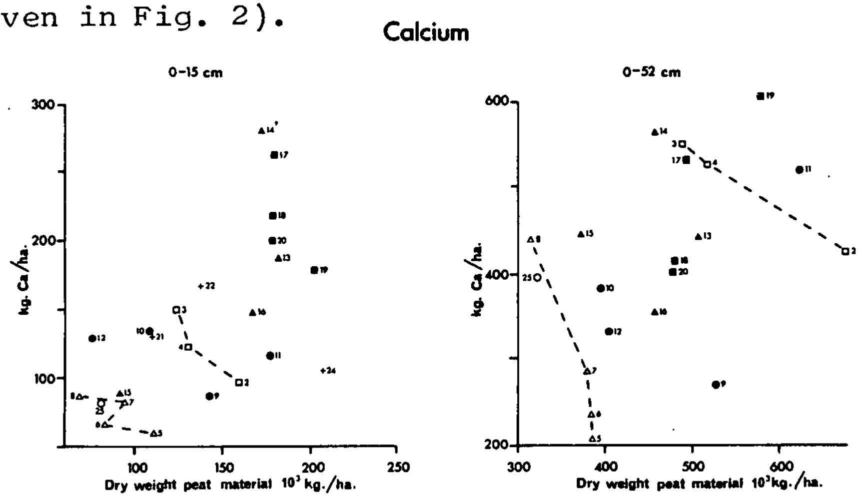
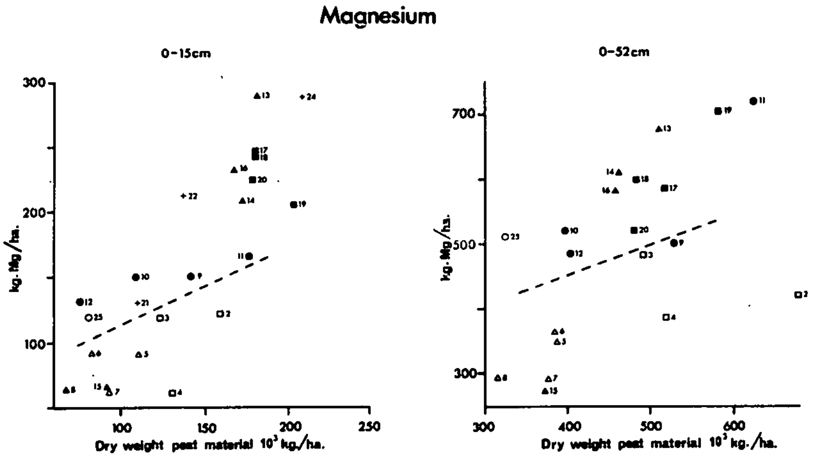


Fig. 6. Magnesium content in relation to dry weight of the peat to depths of 15 and 52 cm. (key to site types given in Fig. 2).



For phosphorus there is a much more definite segregation (Figure 3). In both the top 15 cm and the total profile, the concentration of phosphorus is highest in the flush types; the broken-surface unflushed and the eroded types again form a distinct group, the eroded types usually showing the higher phosphorus concentration. As regards the upper 15 cm of the profile, the Molinia-dominated knoll side, site 21, shows a definite affinity with the Molinia flushes, while the deep Trichophorum-dominated knoll top, site 22, is perhaps more closely related to the firm-surface unflushed type. Also, in terms of phosphorus content, site 24, dominated by Calluna and Trichophorum, appears to be related to the eroded type. Due to the proximity of the mineral soil the relationships of these knoll peats to other types are not apparent when the entire profile is considered. The profiles at sites 1 and 23 are characterised by a large proportion of mineral matter and are so high in nutrient content that they seldom appear in the diagrams.

For potassium the relationships are rather less well defined (Figure 4) and, with the exception of values for the eroded and broken-surface unflushed types, which tend to be low and to fall into a separate group, potassium content appears to be largely an expression of variation in the quantity of peat material. The general pattern for calcium and magnesium (Figures 5 and 6) is similar to that for potassium although the eroded and broken-surface unflushed types contain higher contents of these elements than do the other types. As with potassium, however, the points tend to congregate into a distinct group.

These peats, therefore, can in general be grouped into site types at least not unlike those suggested by the Forestry Commission. However the results indicate that the Juncus flush (site 1) should be regarded as a separate type as should the two shallow knoll tops. Furthermore, the upper horizons of the deeper knoll peats (sites 21 and 22) have strong affinities with those types carrying similar vegetation, namely the partial flush and the firm-surface unflushed types respectively. In Table 1 the sites have been regrouped to take account of these anomalies and the main characteristics summarised. The pattern of change in dry weight suggests that two distinct processes are operating. Taking the quaking bog as the starting point, weight of dry matter per unit volume of fresh peat increases with increasing degrees of flushing and erosion. The results indicate that the top 15 cm reflect fairly closely the conditions in the total profile (to the sampled depth of 52.2 cm), the main exceptions being the knoll types where the lower horizons at the junction with the underlying soil are rich in mineral matter. Although concentrations of phosphorus and potassium are very much lower over the total profile than in the upper 15 cm alone, this does not alter the pattern of variation between types.

The results for the top 15 cm are illustrated in Figure 7. It will be seen that, although the weight of dry

Fig. 7. Changes in dry weight of peat material and in the concentration and content of nutrients (top 15 cm) with increasing degree of flushing and erosion.

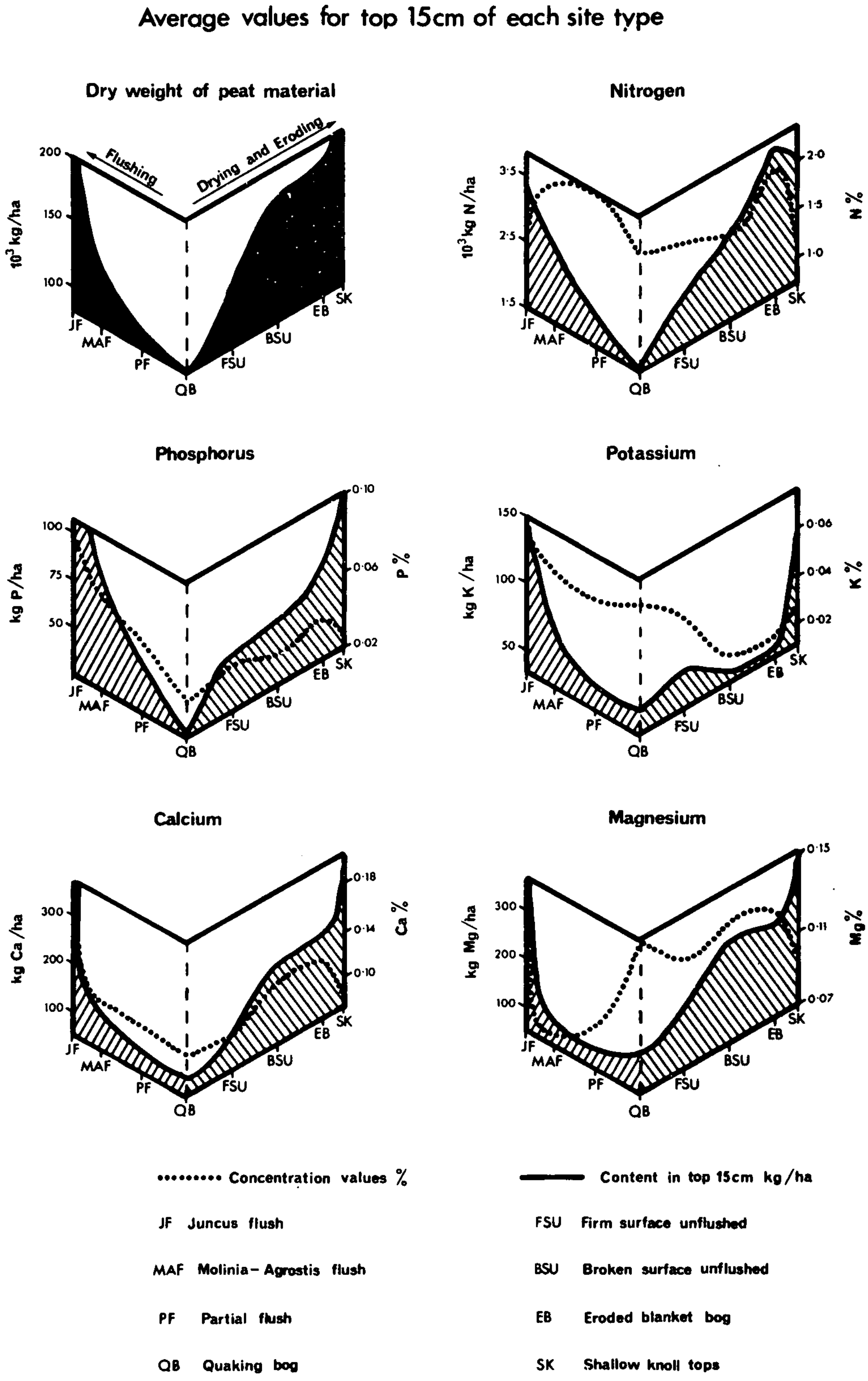


TABLE I

Mean weights of peat material and nutrient concentrations in the regrouped site types

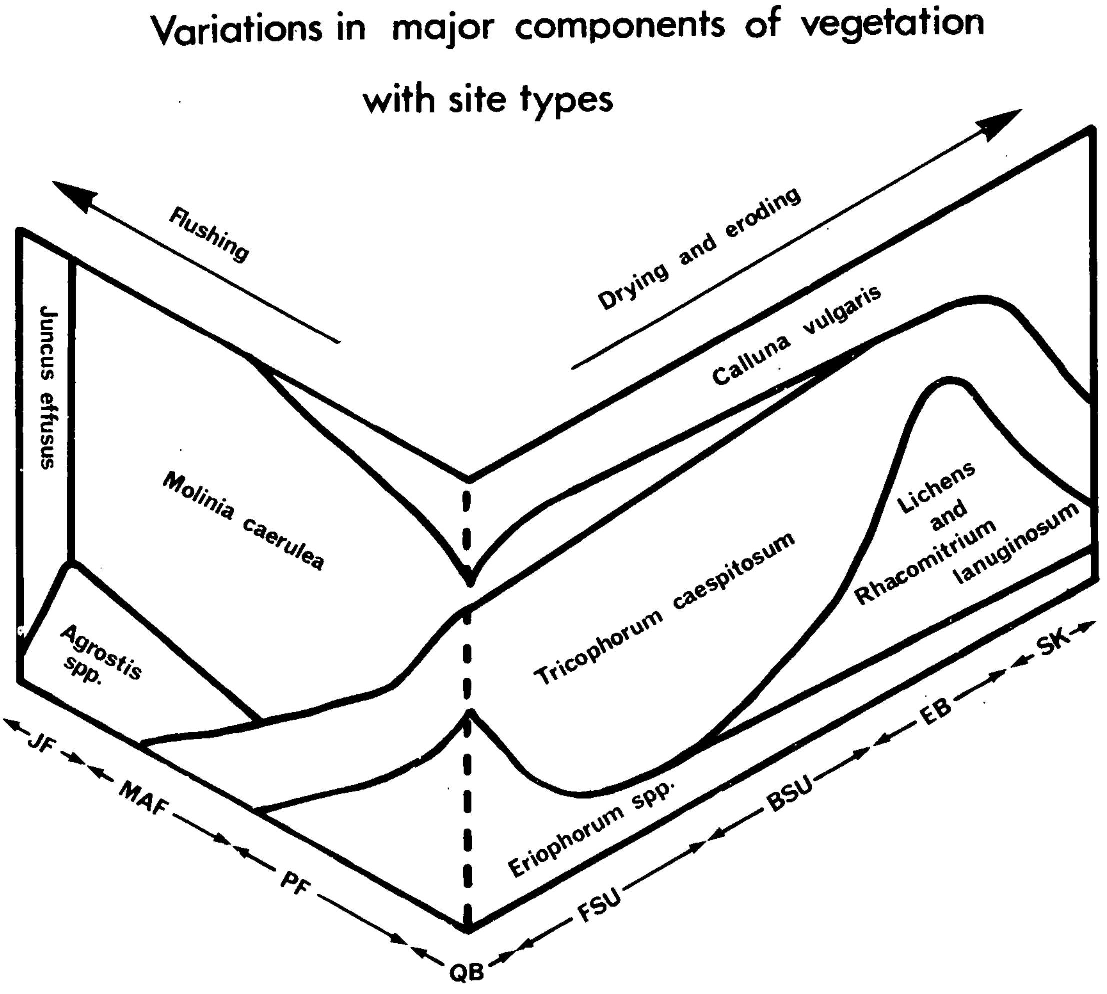
Site type	Site No.	Weight of peat material (10^3 kg/ha)		N%		P%		K%		Ca%		Mg%	
		0-15 cm	0-52 cm	0-15 cm	0.52 cm	0-15 cm	0-52 cm	0-15 cm	0-52 cm	0-15 cm	0-52 cm	0-15 cm	0-52 cm
<u>Juncus</u> flush	1	235	1 357	1.43	1.01	0.091	0.073	0.062	0.036	0.171	0.157	0.345	0.225
<u>Molinia</u>/<u>Agrostis</u> flush	2, 3, 4	138	564	2.05	2.05	0.069	0.047	0.057	0.027	0.089	0.089	0.073	0.076
Partial flush	5, 6, 7, 8, 15 (21)*	94	367	2.23	2.30	0.057	0.039	0.052	0.020	0.087	0.088	0.091	0.086
Quaking bog	25	81	324	1.88	1.80	0.037	0.030	0.060	0.025	0.101	0.122	0.149	0.158
Unflushed, surface firm	9, 10, 11, 12 (22)*	129	488	1.75	1.74	0.044	0.034	0.046	0.020	0.098	0.077	0.127	0.113
Unflushed, surface broken	13, 14, 16	175	534	1.57	1.44	0.034	0.022	0.020	0.011	0.117	0.085	0.138	0.117
Eroded	17, 18, 19, 20	186	510	1.96	1.75	0.040	0.027	0.019	0.011	0.115	0.096	0.124	0.118
Shallow knoll tops	23, 24	425	-	0.88	-	0.024	-	0.027	-	0.071	-	0.091	-

*Only included in top 15 cm.

peat material present is the dominant feature in determining the quantity of nutrients, this relationship can be considerably modified by variations in nutrient concentration. Thus the eroded type contains a greater amount of nitrogen than the broken-surface unflushed type, despite the fact that the quantities of dry peat material are very similar. The contents of phosphorus and potassium are high in the flush types but low in the dry or eroded types, whereas for calcium and magnesium there is a rather striking reversal in this pattern. The extreme types of both the flushing and eroding processes, i.e. the Juncus flush and the shallow knoll tops, are high in all nutrients.

The ground vegetation can be taken as a useful indication of the nutrient status of the peat and Figure 8 illustrates the significant features of the vegetation at the different sites, shown in Table 1. Only those species recorded as at least "occasional" for any one type are included and species that showed no appreciable variation across types have been omitted.

Fig. 8. Changes in major components of the vegetation with increasing degree of flushing and erosion.



CONCLUSIONS

The purpose of this investigation was to ascertain whether variations in vegetation types recognised by field officers are related to the nutrient status of the peat, and the results obtained do indeed suggest that this is the case. The classification, which is largely based on features of the ground vegetation, appears to reflect a progression in two distinct directions - flushing and erosion. Both result in an increase in dry weight of peat material per unit volume and this is the dominant factor in determining the quantity of nutrients present. Flushing is also associated with high concentrations of nitrogen, phosphorus and potassium, whereas erosion is associated with high concentrations of calcium and magnesium. Extreme cases characterised by large amounts of mineral matter and high nutrient content, tend to disturb the general pattern.

Though the site types show appreciable differences, the significance of these with respect to tree growth has still to be determined. Furthermore it should be remembered that cultivation and drainage may well considerably alter the relative standing of the different types. For example, ploughing could turn up mineral matter on the shallow knoll tops and drainage could result in an increased concentration of dry peat material on the extreme wet types.

PHYSICAL AND CHEMICAL FACTORS INFLUENCING THE CATION-EXCHANGE CAPACITY OF PEAT UNDER FIELD CONDITIONS

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INTRODUCTION

In peats of low mineral content the concentration of inorganic cations depends to a large extent on supply from external sources, such as ground water, precipitation, and applied fertilizers, and on subsequent sorption and retention by the peat. Puustjärvi (1956) has shown that the mechanism of cation sorption on peat is an exchange reaction between the hydrogen ions of weakly acidic groups and the cations in the soil solution, and Gore and Allen (1956) have reported that, in peats of low ash content, a large proportion of potassium, calcium, magnesium and sodium are in an exchangeable form. These observations suggest that the cation-exchange capacity is an important factor in relation to the fertility of peat.

Cation sorption is a function of both the concentration of inorganic cations in the external supply and of the concentration within the peat of hydrogen ions with which these cations can exchange. The solid fraction of peat has a high concentration of hydrogen ions but as fresh peat contains a large and variable quantity of water (65-98% by weight) the particles comprising the solid fraction will be more widely separated under field conditions. Furthermore, the variation in moisture content between peat of different types will mean that with increasing moisture content a corresponding smaller number of exchange sites per unit volume can be expected.

Another factor that will influence the concentration of exchangeable hydrogen ions under field conditions is the high acidity characteristic of most peat deposits. It is known (Saric and Schofield, 1946) that the degree of dissociation of the carboxyl groups of polysaccharide molecules varies with the pH of the solution and that dissociation is incomplete at acid-pH values. Should the weakly acidic groups in peat behave similarly, the cation-exchange capacity of this material would be pH-dependent and dissociation may be incomplete under field conditions.

In the present paper a report is given of a laboratory study into the effect of pH on the cation-exchange capacity of peat. The samples used for this were taken from a highly decomposed Trichophorum-Sphagnum hill peat at the Lon Mor, Fort Augustus, Inverness-shire, and from a raised bog comprising relatively undecomposed Sphagnum peat at Red

Moss, Dyce, Aberdeenshire. The effect of moisture and certain other factors on cation sorption in peat are then discussed in the light of preliminary results from a study of the concentration of exchangeable cations in different peatland types sampled at Strath Tirry, near Lairg in Sutherland.

EXPERIMENTAL METHODS

A modified version of the method described by Schofield (1949) was used to study the effect of pH on exchange capacity, the principle being to determine the amount of NH_4^+ sorbed by peat at equilibrium with solutions of ammonium chloride of known concentration and pH. A 5 g sample of fresh peat was washed with 0.1M solutions of NH_4Cl that had been adjusted to various pH values over the pH range 2-7 with either hydrochloric acid or dilute ammonium hydroxide. The peat was washed with 10 ml of this NH_4Cl solution by repeated centrifugation at 2000 r.p.m. for five minutes and resuspension, until the pH of the supernatant liquid was the same as that of the original solution. The number of washings required to attain equilibrium depended on the pH of the solution, as many as 20 being required with solutions of pH greater than 4.0, whereas only 4 or 5 were necessary in the pH range 2-4. Once equilibrium had been attained, the supernatant liquid was decanted off and the remaining wet sample weighed before being rinsed three times with CO_2-free water. The sorbed NH_4^+ in the sample was released by washing with 100 ml 0.2M KNO_3 solution, the washings being collected and subsequently analysed for ammonia in a semi-micro Kjeldahl apparatus. Finally, the samples were dried at 80°C and the weight of oven-dry material determined. Results were initially expressed as m-eq NH_4^+/100 g oven-dry peat but could be converted to values of m-eq NH_4^+/ 100 g wet peat from a knowledge of the weight of wet peat at equilibrium with the NH_4Cl.

The concentration of exchangeable base was derived from the difference between the amounts of exchangeable H^+ measured in fresh and in acid-washed samples, these being determined at pH 7.03 - an arbitrary point chosen to enable the use of 0.5M ammonium acetate as buffer. To determine the amount of exchangeable H^+ in fresh peat a 5 g sample was added to 30 ml ammonium acetate solution, the suspension stirred and allowed to stand for 2 hours. This resulted in a depression of the pH by between a half and one unit and, to measure the acidity of the peat, the suspension was titrated potentiometrically with 0.1N KOH until the original pH of the buffer was attained. Results were expressed as m-eq H^+/100 g oven-dry peat, the oven-dry weight of material being determined separately on a duplicate sample. Knowledge of the bulk density and moisture content, obtained by taking the original samples in the field on a volume basis, enabled conversion of the results to values per unit volume of wet peat (m-eq H^+/litre wet peat).

To determine the exchangeable H^+ in acid-washed samples (cation-exchange capacity), 10 g fresh peat were stirred with 50 ml 0.1N HCl and allowed to stand overnight before being further washed with 50 ml acid. The sample was then washed with distilled water until all the free acid had been removed, i.e. until the leachate gave no precipitate with silver nitrate. The sample was then divided into two, one half being weighed and titrated as described for the fresh peat and the other half used for the determination of moisture content.

RESULTS

An interesting observation from these studies was the effect of adding solutions of 0.1M NH_4Cl of increasing pH to fresh hill peat (Figure 1). Irrespective of the pH of the added solutions, the pH of the suspension remained fairly constant over the pH range studied; this clearly demonstrates the buffering capacity of the peat which is brought about by an increasing dissociation of acid groups at the higher pH values. Despite the fact that the supernatant solution was renewed repeatedly during the experiment a large number of washings was required to raise the pH of the peat suspension above 4.0. Figure 2 shows the sorption of NH_4^+ as a function of pH for two peats of different botanical origin, the raised Sphagnum peat and the Trichophorum-Sphagnum hill peat.

Fig. 1. pH of suspensions of hill peat after addition of 0.1M solutions of NH_4Cl having different pH values

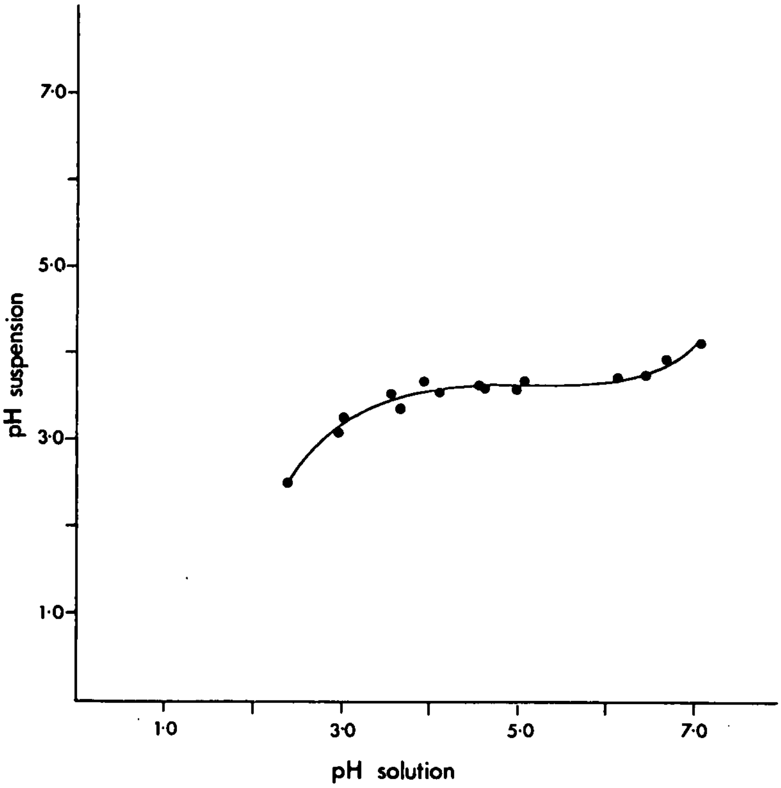


Fig. 2. Sorption of exchangeable NH_4^+ as a function of pH for relatively undecomposed _Sphagnum_ peat and highly decomposed hill peat; results expressed as m-eq NH_4^+/100 g oven-dry peat.

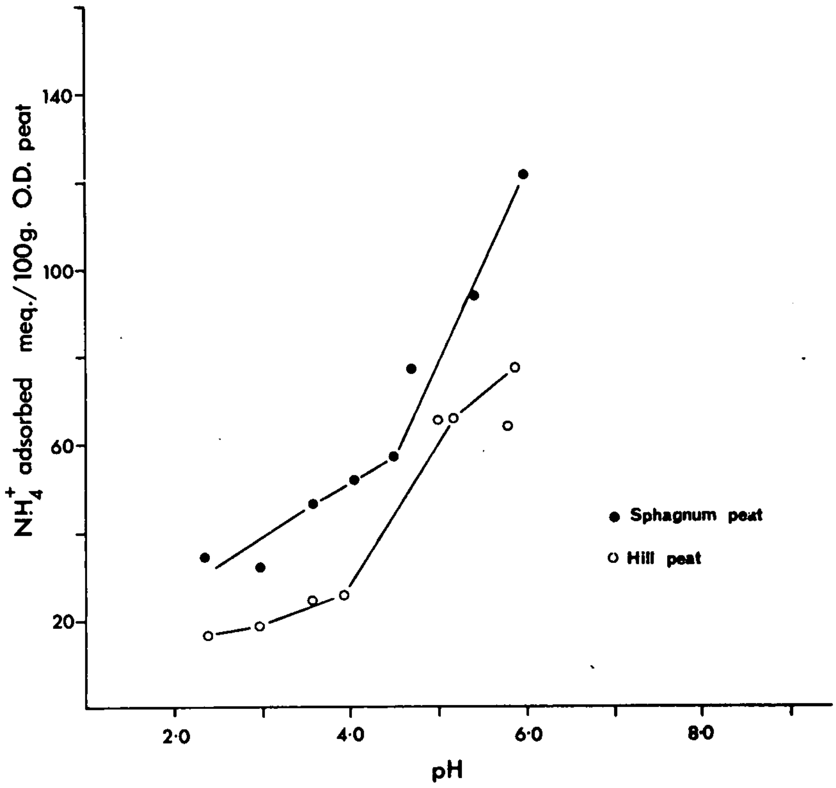
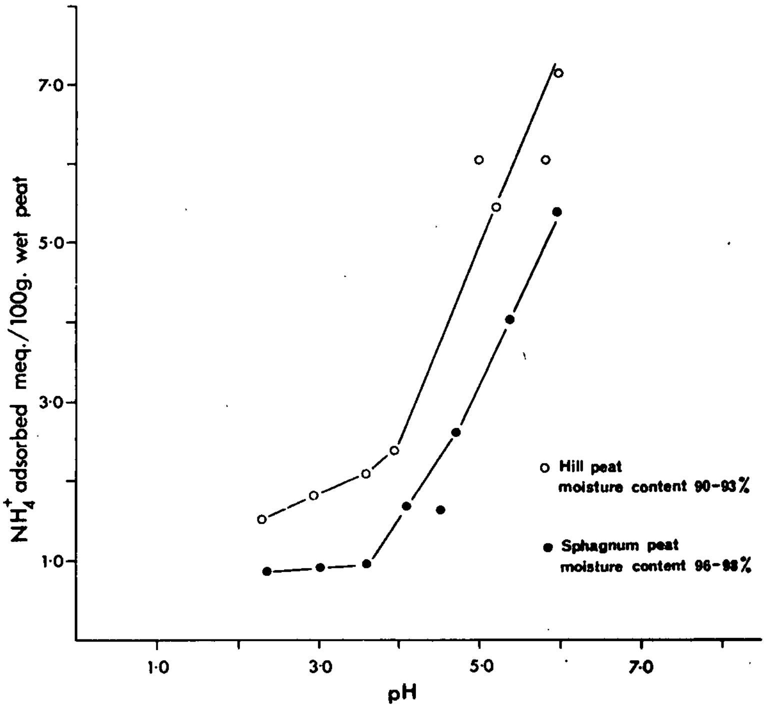


Fig. 3. Sorption of exchangeable NH_4^+ as a function of pH for relatively undecomposed _Sphagnum_ peat and highly decomposed hill peat; results expressed as m-eq NH_4^+/100 g wet peat.



For both peats the amount of NH_4^+ sorbed increases with increasing pH and, on the basis of oven-dry weight, the sample of the raised peat appears to sorb more NH_4^+ than does the hill peat. However, if the wet weight basis is used, the amount of NH_4^+ sorbed increases with pH in the same manner as before but the relative positions of the peats are reversed, (Figure 3), the hill peat apparently sorbing more NH_4^+ than the raised peat. This reversal is due to the greater amount of moisture in the relatively undecomposed raised Sphagnum peat (96-98% by weight) as compared to the highly decomposed hill peat (90-93% weight).

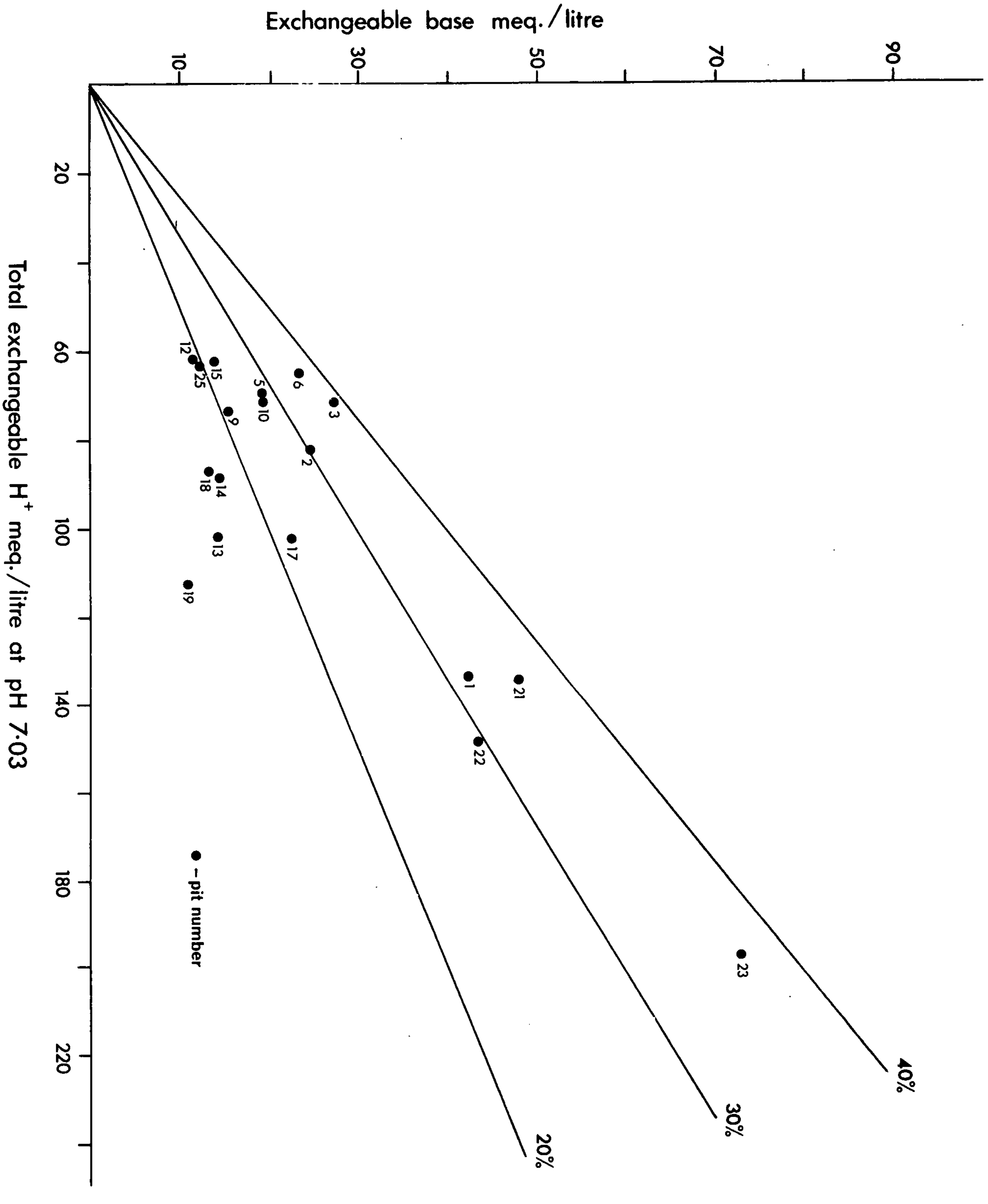
The concentrations of exchangeable cations were determined on samples taken from a series of peatland types which had been classified (see Miller, Robertson and Williams, 1973). as follows:-

(a) local flush, (pits 1, 2 and 3)
(b) partial flush, (pits 5 and 6)
(c) unflushed, unbroken blanket peat, (pits 9, 10 and 12)
(d) unflushed, broken blanket peat, (pits 13, 14 and 15)
(e) quaking bog, (pit 25)
(f) eroded blanket peat, (pits 17, 18 and 19)
(g) knoll tops and sides, (pits 21, 22 and 23)

In Figure 4 the concentrations of exchangeable base (m-eq/l) for the profile to a depth of 0.5 m are plotted against the cation-exchange capacity (m-eq/l) determined at pH 7.03. The main feature of this diagram is the manner in which the values for the different categories are grouped. Because of their low moisture content (ranging from 470 to 790 g H_2O/100 g oven-dry peat), and hence greater weight of dry peat material per unit volume, the knoll tops and sides (pits 21, 22 and 23) contain the highest concentrations of exchangeable base and H^+. This is most marked with the shallow knoll top, pit 23, in which the peat is only 0.3 m deep as against a depth of 0.5-0.6 m in pits 21 and 22. The local flushes, pits 2 and 3, contain lower concentrations of exchangeable base and H^+ as a result of their higher moisture contents (mean values range from 770-1000 g H_2O/100 g oven-dry peat). On the other hand, pit 1, also described as a local flush, has a mean moisture content of only 390 g H_2O/100 g oven-dry peat, which explains its intermediate position between the local flushes, pits 2 and 3, and the knoll tops and sides, pits 21, 22 and 23. The partially flushed areas, pits 5 and 6, contain less exchangeable base and H^+ than the local flushes and have higher moisture contents, mean values ranging from 1240-1300 H_2O/100 g oven-dry peat. These three categories, that is, the knolls, local flushes and partial flushes, have base saturation values ranging from 27 to 38%.

The remaining pits represent categories (c), (d), (e) and (f) and, with the exception of pits 10 and 17, all contain low concentrations of exchangeable cations but cover a wide range of moisture contents - from 840 g H_2O/100 g oven-dry peat in pit 19, which was classified as an eroded blanket peat, to 1530 g H_2O/100 g oven-dry peat in the

Fig. 4. Relationship between concentration of exchangeable base and cation-exchange capacity for samples taken from different peatland types (see text); results expressed as m-eq/litre fresh peat. Lines diverging from origin denote percentage base saturation.



quaking bog, pit 25. For the wetter pits of this group the low concentration of exchangeable cations is a function of the high moisture content but this factor does not explain the low concentration in the drier pits. These results are summarized in Table I in which the pits in categories (c), (d), (e) and (f) have been described according to their moisture contents as wet, medium and eroded (i.e. dry).

TABLE I

Concentrations of exchangeable base, cation-exchange capacity, and base saturation for the various peat types

Peatland type	Moisture content % oven dry peat	Exchange-able base m-eq/l	Cation-exchange capacity m-eq/l	Base saturation %
Local Flush	390-1000	24-43	72-120	30-38
Partial Flush	1240-1300	19-24	65-72	27-36
Blanket peat				
(i) Wet	1300-1530	11-14	60-65	20
(ii) Medium	1000-1220	13-24	72-79	12-25
(iii) Eroded	840-950	10-14	88-113	10-13
Knolls	470-790	43-72	134-198	29-36

DISCUSSION

The results presented here confirm that the exchange capacity of peat depends on the pH of the soil solution and that it is much lower at pH values approaching those observed in the field than at pH 7.0. Even making an allowance for the effect of pH, a precise quantitative estimation of the number of exchange sites in fresh peat at pH values measured under field conditions cannot be obtained from the experiments described here. The pH of peat, like that of soil suspensions, is governed by the composition and concentration of dissolved electrolytes in equilibrium with the peat (Russell, 1961); in the laboratory these were selected and controlled, whereas under field conditions there are several ionic species of differing concentration in equilibrium with the peat.

If one takes moisture content into account and expresses the measurements of exchange capacity on a wet weight basis, these values decrease in proportion to the amount of moisture present. Thus, under field conditions, characterised by low pH and high moisture content, not only is the proportion of exchange sites entering into the exchange reaction (% base saturation) low, but also the number of these sites per unit volume is reduced by the large amount of water present. From Table I it can be seen that the concentrations of exchangeable base and total H^+ per unit volume are lowest in peat with high moisture content, although the lowest value for base saturation is given by the relatively dry eroded peat type.

The base saturation values (Table I) for the unflushed blanket peats range from 10% to 25% whereas for the knolls, the local flushes and the partial flushes these values lie within the range 27-38%. The high base saturation in the flushed types reflects a greater supply of inorganic cations, as these peat types develop on areas that receive a net input of mineral-rich ground water. Similarly, the samples from the sides of knolls had probably received mineral-rich ground water from further up the slope. Thus, as features of the topography control moisture movement and moisture content they also exert considerable influence on the concentration of exchangeable cations in peat.

This is only a preliminary study of some of the factors influencing the mechanism of cation adsorption by peat, which appears, at least in part, to be controlled by acidity and topography. A further factor that has so far not been considered is the influence of the composition and concentration of dissolved electrolytes in the soil solution on the hydrogen ion concentration at the peat-water interface, which in turn will influence the dissociation of acid groups. Further information is required on the composition of the soil solution in different peatland types if the mechanism of cation adsorption under field conditions is to be fully understood.

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SUMMARY OF THE MEETING

J. D. Matthews*
Chairman, Forestry and Woodland Research Committee
Natural Environment Research Council

Figures 1 to 5 show how the many aspects of peatland forestry discussed at the meeting are inter-related. The conclusions that can be drawn from the papers and the discussions include

1. "Peat" is very variable and although the causes of this variation are known in broad outline, more objective basic research is required on the physical conditions, moisture regime, microbiological activity and nutritional status of peat. This work will be aided by a more precise classification of the kinds of peat and a closer definition of the climates associated with peatlands.

2. Experience with drainage and applications of fertiliser suggest that these are the main lines of applied research to follow. Provenance studies have value in identifying those populations within species which are capable of yielding economic quantities of wood on specified kinds of peat.

3. The growth of the extensive plantations of spruces, pines and other species on peat has been promising and the afforestation of peatlands allocated to forestry will continue. Developments in technology - particularly design of machines and tools and the application of work study - will provide practical means for the further amelioration of peatlands and ensure the success of existing and new plantations.

4. Although economic appraisal of the afforestation of peat is always desirable, direct comparisons with other uses such as agriculture, wild life management, horticulture and fuel are difficult. But the rise in population and increasing pressure on reserves of land will make inevitable the orderly development of several kinds in land use on the peatlands of Great Britain and Eire.

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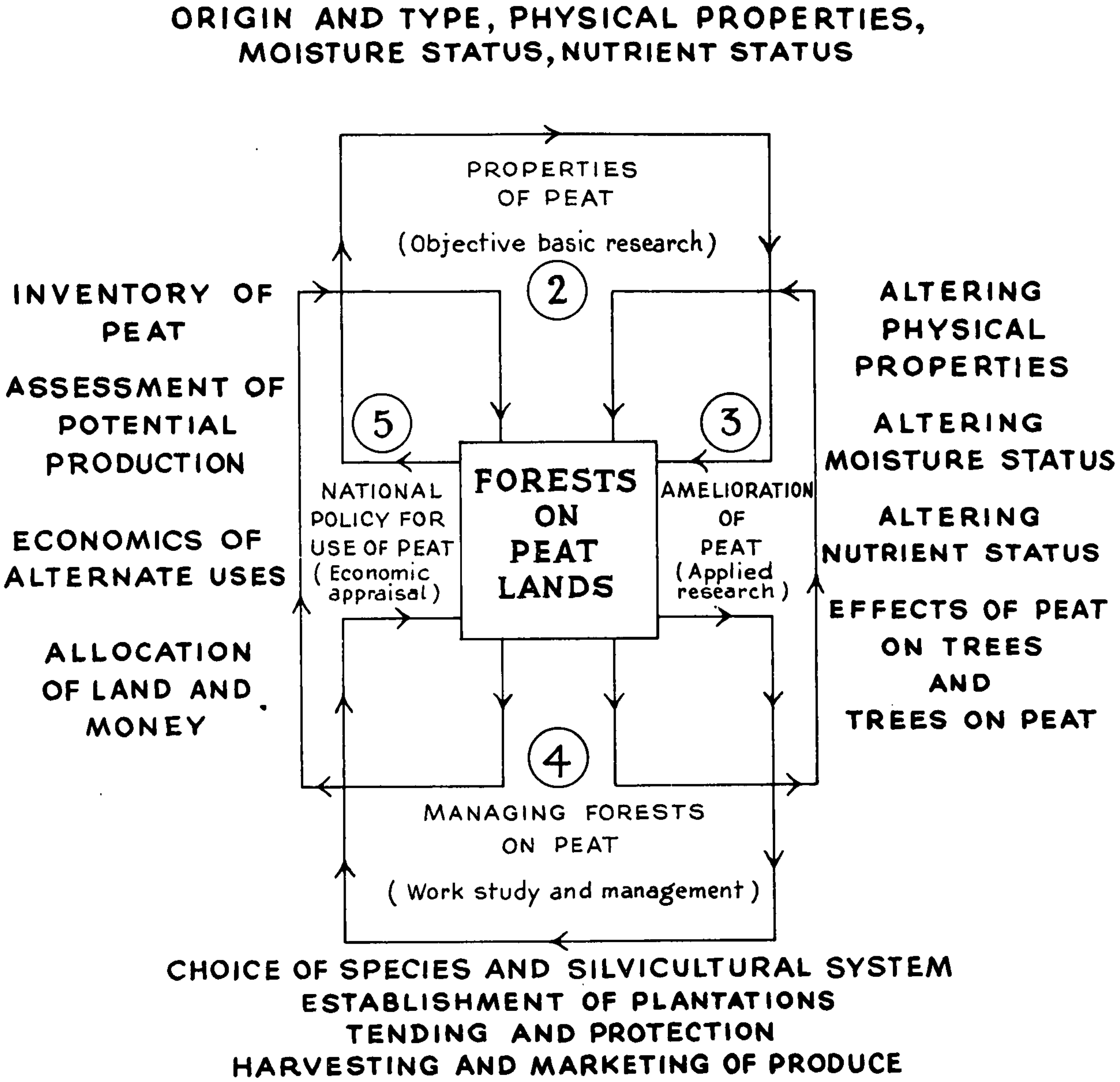
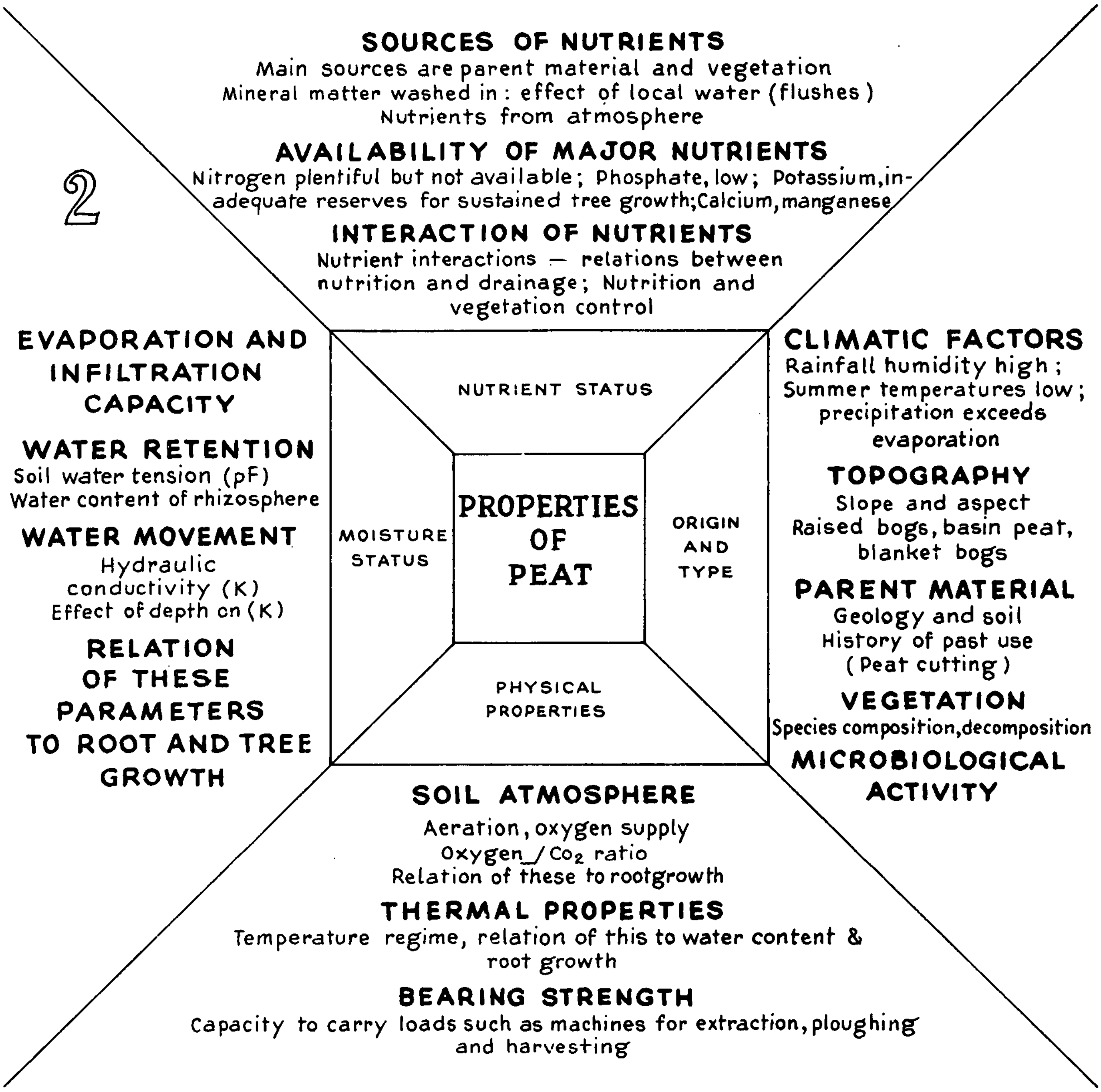

ORIGIN AND TYPE, PHYSICAL PROPERTIES, MOISTURE STATUS, NUTRIENT STATUS
PROPERTIES OF PEAT
(Objective basic research)
2
INVENTORY OF PEAT
ASSESSMENT OF POTENTIAL PRODUCTION
ECONOMICS OF ALTERNATE USES
ALLOCATION OF LAND AND MONEY
5
NATIONAL POLICY FOR USE OF PEAT
(Economic appraisal)
FORESTS ON PEAT LANDS
3
AMELIORATION OF PEAT
(Applied research)
ALTERING PHYSICAL PROPERTIES
ALTERING MOISTURE STATUS
ALTERING NUTRIENT STATUS
EFFECTS OF PEAT ON TREES AND TREES ON PEAT
4
MANAGING FORESTS ON PEAT
(Work study and management)
CHOICE OF SPECIES AND SILVICULTURAL SYSTEM
ESTABLISHMENT OF PLANTATIONS
TENDING AND PROTECTION
HARVESTING AND MARKETING OF PRODUCE



2

SOURCES OF NUTRIENTS

Main sources are parent material and vegetation
Mineral matter washed in : effect of local water (flushes)
Nutrients from atmosphere

AVAILABILITY OF MAJOR NUTRIENTS

Nitrogen plentiful but not available; Phosphate, low; Potassium, inadequate reserves for sustained tree growth; Calcium, manganese

INTERACTION OF NUTRIENTS

Nutrient interactions — relations between nutrition and drainage; Nutrition and vegetation control

EVAPORATION AND INFILTRATION CAPACITY

WATER RETENTION

Soil water tension (pF)
Water content of rhizosphere

WATER MOVEMENT

Hydraulic conductivity (K)
Effect of depth on (K)

RELATION OF THESE PARAMETERS TO ROOT AND TREE GROWTH

CLIMATIC FACTORS

Rainfall humidity high;
Summer temperatures low;
precipitation exceeds evaporation

TOPOGRAPHY

Slope and aspect
Raised bogs, basin peat, blanket bogs

PARENT MATERIAL

Geology and soil
History of past use
(Peat cutting)

VEGETATION

Species composition, decomposition

MICROBIOLOGICAL ACTIVITY

SOIL ATMOSPHERE

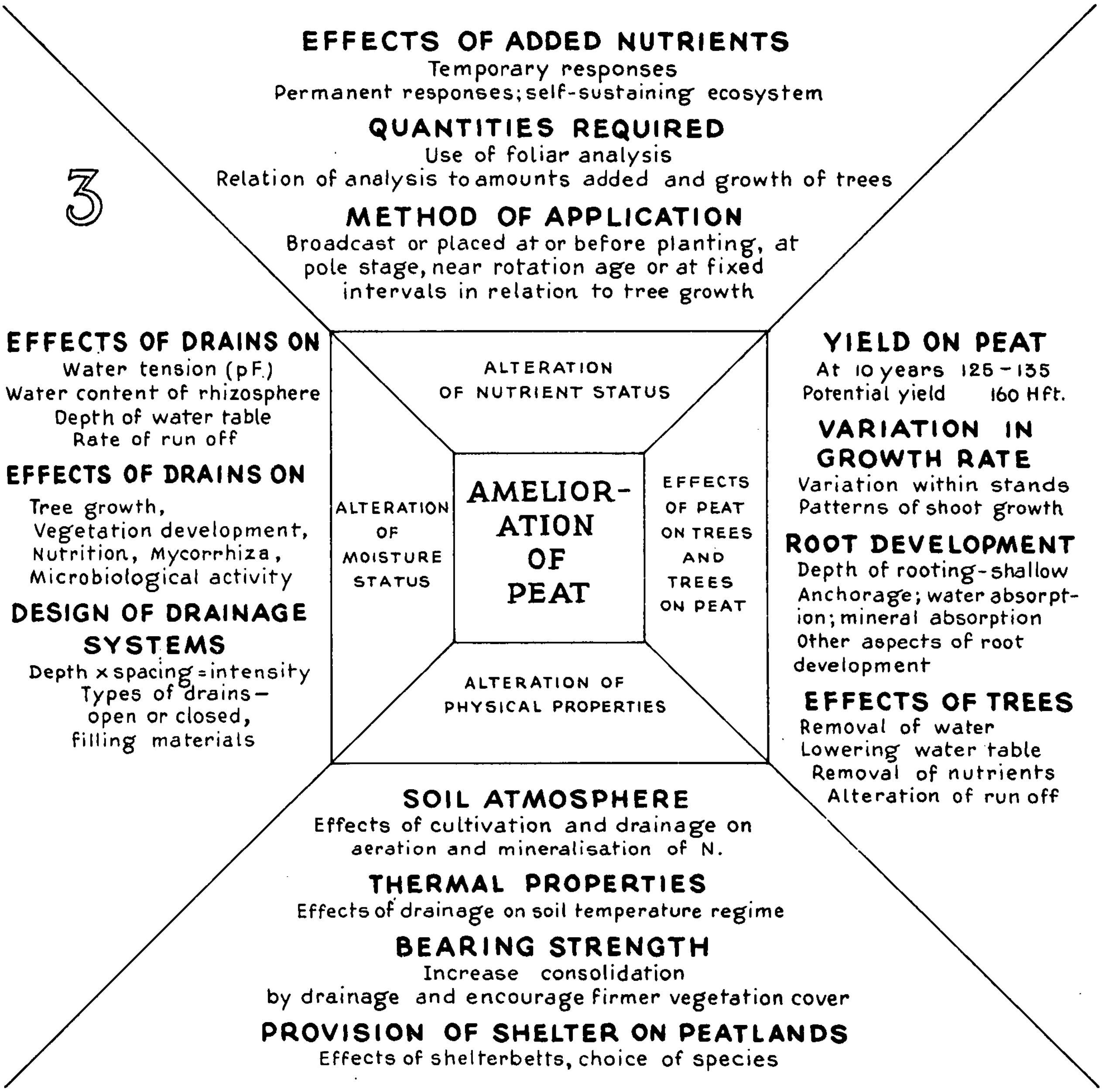
Aeration, oxygen supply
Oxygen / CO_2 ratio
Relation of these to rootgrowth

THERMAL PROPERTIES

Temperature regime, relation of this to water content & root growth

BEARING STRENGTH

Capacity to carry loads such as machines for extraction, ploughing and harvesting



3

EFFECTS OF ADDED NUTRIENTS
Temporary responses
Permanent responses; self-sustaining ecosystem

QUANTITIES REQUIRED
Use of foliar analysis
Relation of analysis to amounts added and growth of trees

METHOD OF APPLICATION
Broadcast or placed at or before planting, at pole stage, near rotation age or at fixed intervals in relation to tree growth

EFFECTS OF DRAINS ON
Water tension (pF.)
Water content of rhizosphere
Depth of water table
Rate of run off

EFFECTS OF DRAINS ON
Tree growth,
Vegetation development,
Nutrition, Mycorrhiza,
Microbiological activity

DESIGN OF DRAINAGE SYSTEMS
Depth x spacing = intensity
Types of drains – open or closed,
filling materials

ALTERATION OF NUTRIENT STATUS

ALTERATION OF MOISTURE STATUS

AMELIORATION OF PEAT

EFFECTS OF PEAT ON TREES AND TREES ON PEAT

ALTERATION OF PHYSICAL PROPERTIES

YIELD ON PEAT
At 10 years 125 – 135
Potential yield 160 Hft.

VARIATION IN GROWTH RATE
Variation within stands
Patterns of shoot growth

ROOT DEVELOPMENT
Depth of rooting - shallow
Anchorage; water absorption; mineral absorption
Other aspects of root development

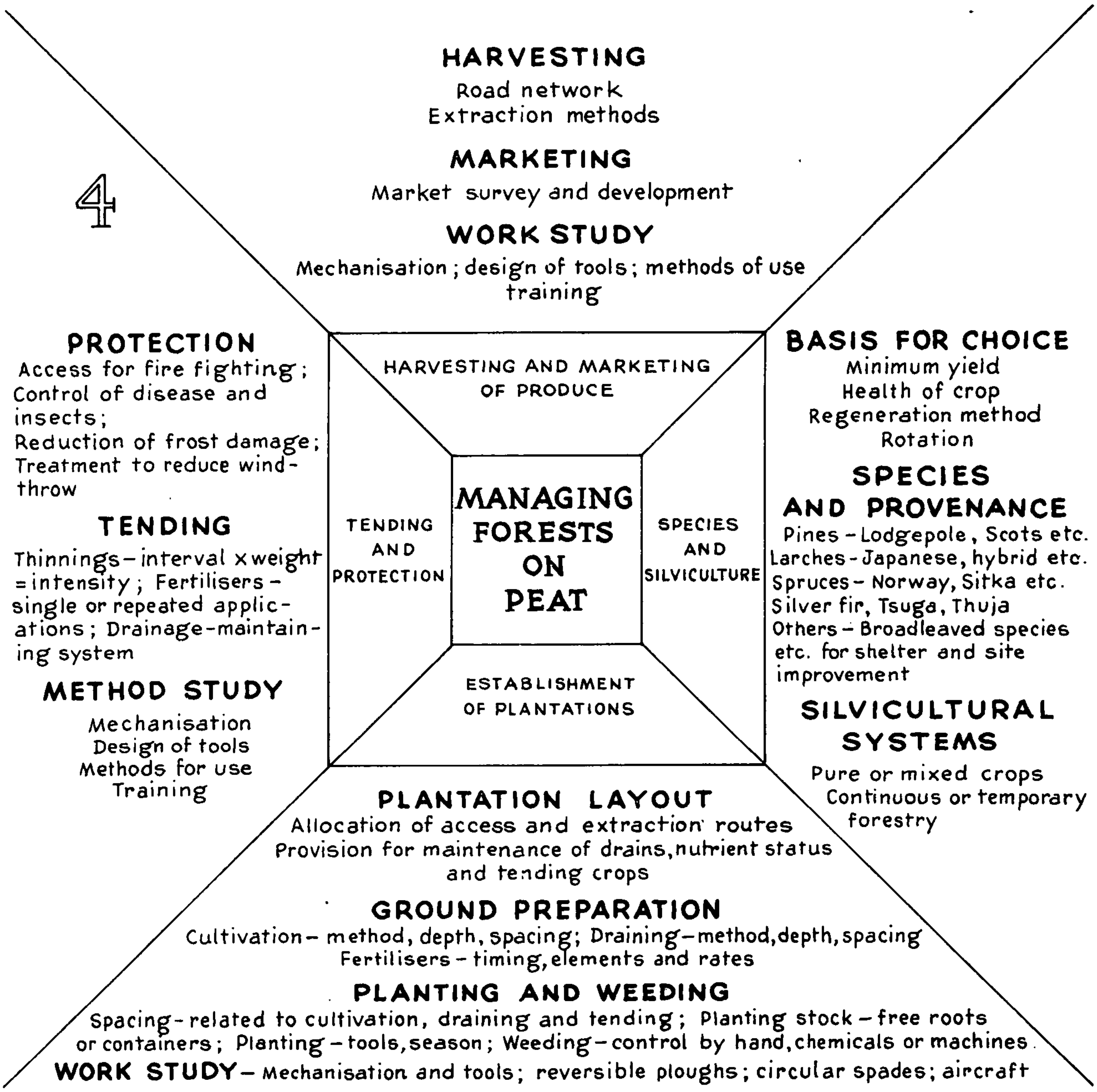
EFFECTS OF TREES
Removal of water
Lowering water table
Removal of nutrients
Alteration of run off

SOIL ATMOSPHERE
Effects of cultivation and drainage on aeration and mineralisation of N.

THERMAL PROPERTIES
Effects of drainage on soil temperature regime

BEARING STRENGTH
Increase consolidation by drainage and encourage firmer vegetation cover

PROVISION OF SHELTER ON PEATLANDS
Effects of shelterbetts, choice of species



4

HARVESTING

Road network
Extraction methods

MARKETING

Market survey and development

WORK STUDY

Mechanisation; design of tools; methods of use training

PROTECTION

Access for fire fighting; Control of disease and insects; Reduction of frost damage; Treatment to reduce windthrow

TENDING

Thinnings – interval x weight = intensity; Fertilisers – single or repeated applications; Drainage – maintaining system

METHOD STUDY

Mechanisation
Design of tools
Methods for use
Training

HARVESTING AND MARKETING OF PRODUCE

TENDING AND PROTECTION

MANAGING FORESTS ON PEAT

SPECIES AND SILVICULTURE

ESTABLISHMENT OF PLANTATIONS

BASIS FOR CHOICE

Minimum yield
Health of crop
Regeneration method
Rotation

SPECIES AND PROVENANCE

Pines – Lodgepole, Scots etc.
Larches – Japanese, hybrid etc.
Spruces – Norway, Sitka etc.
Silver fir, Tsuga, Thuja
Others – Broadleaved species etc. for shelter and site improvement

SILVICULTURAL SYSTEMS

Pure or mixed crops
Continuous or temporary forestry

PLANTATION LAYOUT

Allocation of access and extraction routes
Provision for maintenance of drains, nutrient status and tending crops

GROUND PREPARATION

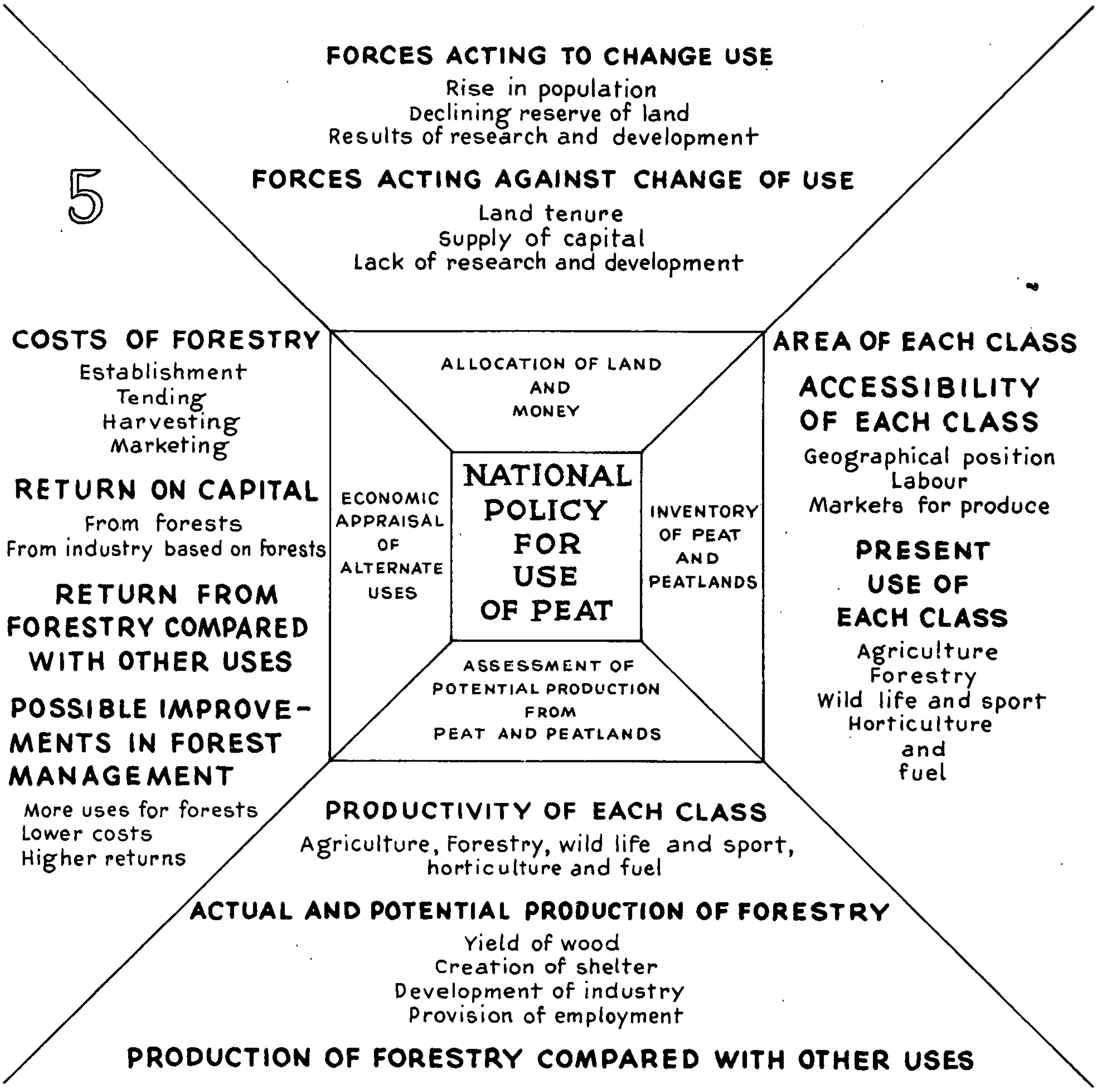
Cultivation – method, depth, spacing; Draining – method, depth, spacing
Fertilisers – timing, elements and rates

PLANTING AND WEEDING

Spacing – related to cultivation, draining and tending; Planting stock – free roots or containers; Planting – tools, season; Weeding – control by hand, chemicals or machines.

WORK STUDY – Mechanisation and tools; reversible ploughs; circular spades; aircraft

5


FORCES ACTING TO CHANGE USE
Rise in population
Declining reserve of land
Results of research and development
FORCES ACTING AGAINST CHANGE OF USE
Land tenure
Supply of capital
Lack of research and development
COSTS OF FORESTRY
Establishment
Tending
Harvesting
Marketing
RETURN ON CAPITAL
From forests
From industry based on forests
RETURN FROM FORESTRY COMPARED WITH OTHER USES
POSSIBLE IMPROVEMENTS IN FOREST MANAGEMENT
More uses for forests
Lower costs
Higher returns
ALLOCATION OF LAND AND MONEY
ECONOMIC APPRAISAL OF ALTERNATE USES
NATIONAL POLICY FOR USE OF PEAT
INVENTORY OF PEAT AND PEATLANDS
ASSESSMENT OF POTENTIAL PRODUCTION FROM PEAT AND PEATLANDS
AREA OF EACH CLASS
ACCESSIBILITY OF EACH CLASS
Geographical position
Labour
Markets for produce
PRESENT USE OF EACH CLASS
Agriculture
Forestry
Wild life and sport
Horticulture
and
fuel
PRODUCTIVITY OF EACH CLASS
Agriculture, Forestry, wild life and sport, horticulture and fuel
ACTUAL AND POTENTIAL PRODUCTION OF FORESTRY
Yield of wood
Creation of shelter
Development of industry
Provision of employment
PRODUCTION OF FORESTRY COMPARED WITH OTHER USES