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BULLETIN No. 22

EXPERIMENTS IN TREE PLANTING ON PEAT

LONDON: HER MAJESTY'S STATIONERY OFFICE

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By

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1954

FOREWORD

There is probably no greater potential field for the expansion of forestry in Great Britain than the peat-covered hills and moorlands of the north and west. It has long been realised that planting of trees, if it could be successfully accomplished, would bring those lands into a higher state of production and would greatly increase the resources of the country. Before the 1914 to 1918 war, several private landowners had already made important contributions to our knowledge by their pioneer attempts at afforestation on sites of this kind. The Forestry Commission, from its inception, was concerned in the afforestation of peat and its first essays in this direction showed, as earlier work had demonstrated, that peats varied much in quality and in suitability for planting. At an early stage, the Commissioners began to pay close attention to the problems, and they initiated a programme of investigations and experiments which has been going on now for about thirty years and which has resulted in important developments in technique. This Bulletin summarises the results of numerous experiments carried out in various parts of the country, experiments which have dealt, mainly, with methods of establishing crops of trees on peat. A report of work of a more fundamental character, carried out by Dr. G. K. Fraser, of Aberdeen, is available in this series, as Bulletin 15. *Studies of Certain Scottish Moorlands in relation to Tree Growth.* (H.M.S.O. 2*s*. 6*d*.).

This new publication has been written mainly by Mr. J. W. L. Zehetmayr, one of the Commission's Research Officers, who has been engaged for a number of years in experimental work on peat.

Chapter 2 has been written by Mr. James Macdonald, Director of Research and Education, while Chapter 3 has been contributed largely by Mr. J. A. B. Macdonald, Conservator of Forests for South Scotland. The occasion has been taken to publish in the form of an appendix, an important contribution to the subject of peat planting made in 1923 by Dr. (now Professor) H. M. Steven, on which much subsequent work was based.

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Chapter 1

THE CHARACTERISTICS OF THE PEATLANDS

PEAT consists of plant remains preserved in a more or less decayed state through waterlogging. Its development occurs under conditions of high rainfall or poor drainage, and it may form either under a water surface in lakes or on the soil surface. As the depth of peat increases it comes to bear a distinctive vegetation of species capable of maintaining themselves in this purely organic soil.

The peat areas available for afforestation are of the acid 'moss' or bog types rather than the alkaline fen type. They lie in the high rainfall areas of the north and west of Great Britain over rocks which are for the most part more acid, harder, and more ancient than those occurring in the rest of the country. The Carboniferous series is the youngest which bears peat of this type over any great area of its surface.

The term *moorland* is used loosely to cover a much wider area than the *peatland*, and it is necessary to distinguish the latter from the drier eastern moors which may be termed *heathland.* Any area where the organic remains exceed six inches in depth may conveniently be regarded as peat for the purposes of afforestation. It may be noted here that the Geological Survey recognises and defines peat as a 'drift' when over two feet deep. Here such a covering is considered as *deep peat*, since trees planted on peat of this thickness are virtually isolated from the underlying soil or rock. In contrast, on thinner peat the underlying soil may play an important part in influencing growth once the roots start to exploit it.

The heathlands of the east may be distinguished from the typical peatlands, as areas where the plant remains form a thin layer consisting of raw humus rather than the true humus which, being found in greater depth, constitutes peat.

The formation of the two types is largely determined by rainfall but is modified by other factors. In the colder regions of the north of Scotland peat forms in areas receiving as little as thirty inches per annum, whereas in south Scotland and the north of England the forty inch isohyet more nearly defines the area where peat formation is common. Poor local drainage in depressions may lead to peat forming in the east, and conversely free drainage leads to the formation of nearly typical heaths in the west, but broadly speaking, the above division forms a useful basis in considering afforestation techniques.

Additional differences are those in vegetation. On the peatlands there are very few trees save for occasional remnants of ancient and often native Scots pine, whereas on the heaths, birch and Scots pine are widespread. The heaths are commonly dominated by common heather (*Calluna vulgaris* L.) whereas this species, though abundant, is rarely dominant on the peats under the prevailing forms of land usage prior to afforestation. After the intensive draining which accompanies afforestation, heather often becomes dominant for a period. The characteristic and abundant species of the unenclosed peatlands in addition to *Calluna* are deer grass *Trichophorum caespitosum* (L.) Hartman =*Scirpus caespitosus* L. ; cotton grasses, *Eriophorum vaginatum* L. and *E. angustifolium* Honk ; *Molinia caerulea* (L.) Moench, *Erica tetralix* L., and the mosses : *Sphagnum* spp. and *Rhacomitrium lanuginosum.*

The formation, structure, and classification of peat have been considered at length by Fraser (1933 and 1943). The later paper considers peat in all its aspects and in particular in relation to agriculture, horticulture and industry. The earlier paper considers peat in special relation to forestry, and the peat types defined there have been widely adopted by practising foresters.

Classification of peat deposits

The main distinction drawn is between climatic and local peat deposits. The former includes the whole of the regional deposits of Scotland and northern England, the latter the small peat areas of Wales and the southern and eastern half of Great Britain. The latter type may form in depressions where various combinations of low temperature, high rainfall and/or poor drainage, coupled with the absence of water rich in minerals, lead to the formation of basin bogs of an acid nature : this type is Tansley's Valley Bog (Tansley 1939). In addition, in areas where the drainage water is richer and fen peat has formed, its development may continue to a stage where the peat surface rises above the water inflow and becomes dependent on precipitation, in which case an acid "raised bog" will develop. Such local basin bogs of the valley or raised type are found in many areas suitable for afforestation and present local problems, but their area is generally small relative to that of the individual afforestation scheme.

The picture is very different, however, in the parts of Great Britain where climatic peat develops. Here no semi-aquatic vegetation need precede the formation of acid peat, as is necessary for local deposits ; the high rainfall with low insolation and high humidity allow peat to form over the soil surface regardless, within wide limits, of locality factors such as soil type, slope and altitude. Thus it may often happen that the greater proportion of any area available for afforestation in the region is covered with peat.

Climatic peat is divided by Fraser into "blanket moss" and "hill (sub-alpine) peat". This latter type, as its name implies, lies higher on the hills, is subject to a more rigorous climate, and carries a vegetation in which mosses play an important part while growth of vascular plants is poor. Through its subjection to drought as well as high rainfall, it resembles in many ways the wetter heath types of the east. The afforestation areas do not lie on this peat type apart from certain of the peat experiments planted at high elevation.

There remains the blanket moss or blanket bog type which covers huge areas to a varying depth and which is the chief concern of this Bulletin. (See Photo 1.). Within this type there are often local developments of basin peat, originally formed in lochans, lochs or lakes which give rise to areas of deep peat varying in size from pockets a few yards across to great bogs hundreds of acres in extent. Also easily recognisable in blanket bog areas are the knolls, typically underlain by moraine but also on occasion by rock, where the peat rises locally and becomes thinner and tougher. Between these extremes lies peat, neither basin nor knoll, which is divided in this work into slopes and flats, the distinction having considerable importance in forestry as affecting the drainage and the exposure. The phenomenon of flushing must also be mentioned here. If peat is traversed by drainage water the composition and vigour of the vegetation alter, even though the seepage water is extremely poor in nutrients. These five features of the blanket bog, basin, knoll, slope, flat, and flush are constantly referred to in the description of the experiments as a means of defining the site.

Types of Peat

Fraser recognises three main types of peat based on its structure, the pseudo-fibrous, fibrous, and amorphous peats, with naturally many transitional forms. These types are largely dependent on the vegetation and on the conditions under which the deposits accumulate. The following descriptions are taken from Fraser (1933).

(*A*) *Pseudo-Fibrous Peat Characteristic of Scirpus dominated areas.*

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

Pseudo-fibrous peat has been observed as a surface peat, only in the west Scottish high rainfall area, and elsewhere where *Scirpus* vegetation has been found.

(*B*) *Fibrous Peat Characteristic of Calluna and Eriophorum dominated areas.*

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

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

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

(*C*) *Amorphous Peat Characteristic of Molinia dominated areas.*

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

Apart from the foregoing broad regional and structural basis, peat cannot be classified except upon the basis of the vegetation from which it is derived.

Vegetation types on peat

The three main classes of vegetation have already been distinguished above, the *Scirpus*, *Calluna-Eriophorum* and *Molinia* areas. Broadly these are characteristic of the Western Highlands, north and central Scotland, and the borders (Fraser 1933). Eriophoretum is also abundant in the Pennines (Tansley 1939) but until recently no experimental planting had been carried out in this area. A bewildering number of intermediates occur between these types, and their inter-relationships have nowhere been fully investigated. Most of the common plant species occur on all the peat areas, it is their relative frequency which is the most vital point in the establishment of trees. Fraser (1933) has described in some detail the vegetation of the area around Inverliever Forest, Argyll, while Tansley has given a general description of the 'moss or bog formation'. Examination of the literature shows that practically no ecological work has been done in the climatic peat area of the north and west of Great Britain apart from Fraser's study and a superficial examination of eleven sites in the Northern Highlands of Scotland by Tansley in 1937.

Tansley divides the bog formation into six communities which are however of very different status ; two of his classes, Rhynchosporetum and Schoenetum, do not occur in the areas under consideration. *Sphagnum* spp. have played an enormous part in the development of the peat areas, especially of the deeper peats and basin bogs, yet to-day *Sphagnetum* with active peat formation is not found on any great scale except in the west of Ireland and the western Isles of Scotland. Locally patches of *Sphagnum* are abundant in the wetter hollows of the other peat types. Tansley's remaining three communities Scirpetum, Eriophoretum and Molinietum correspond with the three classes of peat recognised by Fraser.

It is convenient at this point to list the more important species of the peatlands and note their occurrence and their reaction to treatment both under current agricultural and forestry practice.

Scirpus caespitosus, or deer grass, is dominant or abundant in the whole of the northern and western Scottish peatlands. It has long been recognised as a danger signal in afforestation. Fraser regards *Scirpus* as the climax species for much of the blanket bog. He also points out that it is resistant to burning and grazing and thus comes to dominate areas managed under the long established regime of sheep rearing.

It would appear, however, from observation of areas of *Scirpus* bog enclosed within afforested areas but left as unplantable, that protection of *Scirpus* dominated blanket bog may result in a great change in the vegetation. This change is slow, certain areas enclosed for thirty years have not yet reached a stable condition. Certainly within that time the appearance alters greatly. The characteristic of burnt-over *Scirpus* peat is its smooth appearance and paucity of species. Fraser draws attention to the effect of repeated burning in eliminating mosses and causing the formation of a hardened surface on the peat, which being waterlogged is colonised by algae. After long enclosure the *Scirpus* has become more tussocky, the flora has greatly increased and other species, particularly *Calluna*, become much more obvious. Where these changes will lead is difficult to say, probably many more years are required before a new equilibrium is reached in which *Scirpus* may not be the dominant. Certainly, after draining prior to planting, *Scirpus* often gives way to *Calluna* as the dominant species.

Eriophorum vaginatum, or cotton grass, is another species which by nature of its growth form, in dense tussocks, is brought into greater prominence by burning. The peat areas in hand for afforestation do not include, at present, any great area of the Pennine Eriophoretum described by Tansley, but this species is abundant in much of the blanket bog, generally on the relatively richer areas of *Scirpus* bogs and in the poorer wetter hollows in *Molinia* areas. *Eriophorum angustifolium* is also widespread between tussocks of other species colonising bare peat in surface water channels along which it spreads by its long rhizome. The cotton grasses are often eliminated, within a few years, by draining, being replaced by grasses, particularly *Deschampsia flexuosa* and *Molinia*, or by *Calluna* if it was originally present on the area.

Molinia caerulea, or purple moor grass, is another species which, in its areas of greatest extent, the Border hills, is largely maintained by burning and grazing which in this region has probably continued over five hundred years, as compared with under two hundred in the Highlands of Scotland. *Molinia* bog and *Molinia* meadow were distinguished by early ecologists by the presence of tussocks in the former. Tussocks probably develop only on the relatively richer areas, but may be eliminated by severe burning. After enclosure and planting there is often a redevelopment of tussocks, with great luxuriance of growth, which ends with the suppression of the grass as the trees close canopy. In the *Scirpus* and *Eriophorum* areas, *Molinia* is an indicator of better flush conditions and is found along natural seepage zones. It often develops very rapidly after the draining and phosphate manuring which accompany afforestation, but this phase is often brief and it is succeeded after a year or two by *Calluna*.

Calluna vulgaris, or heather, is, as Tansley points out, the species most univerally present on all the peat areas ; but he concludes that it is not a blanket bog dominant, though in the drier parts it becomes co-dominant with *Scirpus*. Grazing and burning may eliminate *Calluna* and though, on many sheep walks, this is regarded as a sign of over-grazing, it is probably responsible for its absence from much of the lower slopes and more fertile areas of the Borders which have come to consist of pure *Molinia*.

In contrast, reduction of the intensity of management for sheep often leads to dominance of *Calluna* on peat areas in the regions of lower rainfall, or in those of higher rainfall where natural or artificial drainage leads to drying out of the surface. Tansley distinguishes such "heather moors" on deep peat from the 'heaths' of the east, but nevertheless does not consider them part of the 'bog-formation'. In afforestation it has been recognised that after enclosure and draining *Calluna* is likely to dominate rapidly any peat area in which it is frequent. This is particularly important as affecting the use of certain species for planting and is fully discussed later.

Thus areas of *Scirpus* and *Eriophorum* blanket bog may be converted after planting to 'heather moor'. In this state Tansley concludes that the floristic composition differs very little from that of heath, except that the latter is poorer in bryophytes and lichens. For afforestation purposes there remains the vital difference that one is on deep peat while the other overlies mineral soil at no great depth.

The vigour and height of *Calluna* in relation to its age, together with the relative abundance of flowers, is a valuable indication of the fertility of the peat ; the form of the stem is also an indicator of the exposure. Areas with long heather are the only ones among the peatlands which are on occasion burnt prior to planting.

Erica tetralix, or cross-leaved heath, is a common species of the peat areas and well known as an indicator of waterlogged conditions and the need for intensive drainage. *Erica cinerea*, the bell heather, is common only on the drier knolls and steep banks where conditions are nearer the heath than peat type.

The rushes *Juncus articulatus* and *J. communis* agg. are recognised as indicators of flush conditions and the presence of rich peat, often with much mineral matter. Their presence is much more common in flushes on the richer *Molinia* peatlands, whereas flushes in *Scirpus* may bear *Molinia* but no *Juncus*. Bog myrtle, *Myrica gale*, and reed grass, *Phragmites communis*, are also local indicators of richer conditions ; the latter is a relict from an earlier phase when pools of open water were common.

Other species such as Bilberry, *Vaccinium myrtillus* and Crowberry, *Empetrum nigrum*, are indicators of locally drier conditions where *Calluna*, if it is present, may be expected to become dominant on enclosure.

Certain of the effects of treatment on peat vegetation have been mentioned above. Fraser (1933) has noted the effect of long continued grazing and burning in planing down the vegetation and accentuating the surface waterlogging. The effects of enclosure and draining have been briefly noted above, but these changes have not been studied in detail.

The aim of afforestation is quick closure of canopy, and this is followed by complete suppression of the natural vegetation. This change is associated with an acceleration of the growth rate of the trees owing to the increased supply of nutrients and the commencement of a process of peat aeration. This latter results from the decay of the roots of the original vegetation and of those trees removed in thinning, from drainage and from the penetration of the peat by living roots. That this may result in the shrinkage of the peat is indicated already in some areas. The next stage, which has hardly yet been reached, may be expected to be the appearance of a new flora on the forest floor. At this time there will be great scope for observation and recording of the phases of invasion. One real danger is that peat forming species will again appear as more light reaches the floor after the dense 'thicket' stage is passed. Though drainage will have been improved there is little doubt that humidity under the canopy will at least be as great as in the open, and it must be remembered that the natural pine relicts of the west of Scotland are in many cases standing in a dense tussock vegetation of *Calluna* and *Sphagnum* which prohibits regeneration.

In concluding these brief introductory remarks on the peatlands it may be reported that they form the biggest area of land which is not in intensive use in Great Britain. They could, if successfully afforested, provide an increase in the national resources, which would be of immense importance to the sparsely populated areas concerned. In the most easily worked peat areas of the Borders, afforestation is already transforming the economy of the region. The extension of this transformation to the North and West Highlands of Scotland has already begun, but is much restricted by the intractable nature of the peat covering. Work over the last thirty years has resulted in a certain extension of the land deemed fit for afforestation, but many years more will be required to decide the final limits to which trees may be planted.

Chapter 2

THE DEVELOPMENT OF PEAT PLANTING IN GREAT BRITAIN UP TO 1919

ALTHOUGH large-scale planting of trees on peat is a comparatively recent feature in British forestry, earlier generations of planters had made numerous attempts to establish plantations on land covered with peat, in the course of which they enjoyed some succcesses and experienced numerous failures. Generally speaking, they succeeded on the easy peats, for example, those supporting a vegetation of grasses and rushes ; on the more difficult peats, they usually failed to establish a crop.

It is clear that the older planters failed on difficult peats, and on peats which would not nowadays be regarded as difficult, because, with very few exceptions, they did not seem to appreciate the necessity for a technique different from that which gave good results on mineral soils. At the same time, they were handicapped by the paucity of coniferous species at their disposal, for Sitka Spruce, Japanese larch and *Pinus contorta* did not become available in quantity until after the twentieth century had opened. From the scanty records which exist, and from evidence of plantations which survived into recent years, one may conclude that most of the planting on peat which was undertaken up to the end of the nineteenth century was carried out with Norway spruce. Scots pine was used to some extent but European larch only rarely.

Among early records may be mentioned the attempt to afforest a bog on the borders of Midlothian and Peebles-shire made by the Duke of Argyll about 1730 (Chambers, 1864), an attempt which apparently did not meet with much success. More interesting is the account of the work carried out, in Ireland, about the end of the eighteenth century, on the estate of Lord Mountjoy in County Tyrone (McEvoy, 1802), There, on what were described as "thin, wet, spouty soils, in general, much exposed", those in charge of the estate developed a form of turf planting, probably the first use of this method to be recorded anywhere. The objects "to increase the depth of soils of this nature, and also to drain and render them wholesome for the reception of plants" showed a sound appreciation of the problem on what was, apparently, a thinnish flush peat overlying a compacted, impervious subsoil.

"One third of the surface was stripped and laid upon the other two-thirds, causing the two swards to meet, the better to reduce them. This encreased the depth of vegetable soil from four to six inches, over which two inches more of the substratum was thrown up, which gave a depth for planting of eight inches. The last covering not only encreased the depth but served to give weight and stability to the whole. In performing this work, it was of little consequence whether the furrows and ridges were formed crooked or straight ; they were sometimes one way and sometimes the other ; the disposition of the ground always directed the courses of the ridges ; up and down hill where the land was not over steep or sudden ; but where the ground tended abruptly, the direction was always carried obliquely up the hill, the better to prevent the soil from being washed away. Where the soil was much disposed to moisture, the breadth of the furrows was three feet, that of the ridge, six feet, but in soils more dry, the breadth of both were encreased".

It is curious that the idea, worked out on this estate, should not have been pursued elsewhere ;

but there is no record that this happened, and it is probable that the notion of turf-planting was, for a time, lost.

During the nineteenth century, although numerous plantations were formed on peat, no new advances seem to have been made in the technique of afforestation save for one interesting exception, the use of Sitka spruce on peat at Durris, in Kincardineshire, in the eighteen-eighties (Crozier, 1910). This marked probably the earliest recorded departure from the use of the three staple species in peat planting. In plantations such as that described by J. A. B. Macdonald (1928) and those recorded during a survey of woodlands in the 1914-1918 war (Guillebaud & Macdonald, 1928), dating all from the middle of the century, the species and the methods of planting were those which were standard ; the peats which were afforested were none of them difficult.

It is not certain whether the foresters of that time attempted to plant on more difficult sites, the results of their work having now disappeared, or whether they found by experience, at an early date, what was plantable and what lay beyond the bounds of possibility. But there is little evidence of any serious attempt at widespread afforestation of difficult land ; the only venture of this kind, at Knockboy in Western Ireland, undertaken, it is said, under political pressure, ended in failure. (Forbes, 1943).

At the same time, it is interesting to note that the pioneer work then being carried out by the Belgians in the Ardennes attracted little notice in Great Britain. Starting as far back as 1836, Belgian foresters, working on the *Molinia* moors of the Hertogenwald, evolved from an older Prussian method, the system of turf planting and intensive drainage which is now generally associated with their name. Yet it is not till 1907 that we hear of its adoption in this country. In that year, Stirling-Maxwell, (1907) whose great work at Corrour, in Inverness-shire, laid the foundation for most of the subsequent developments in the afforestation of peat, published an account of his experiments with the Belgian system of turfing and draining. Although he had been planting at Corrour since 1892, he stated that "results of draining and planting in the ordinary Scotch fashion have been disappointing" and he was hopeful of better results with this foreign method. In a later article (1910) he showed the advantages of the new system after several years experience.

Turf planting was also practised at Glencoe, Argyll, round about 1910 on a small area of peat, using the Belgian system ; this is recorded in a booklet (Anon., 1911) in which an account was given of the plantations on that property.

On the other hand, the afforestation in the Crown Plantations at Inverliever in Argyll, where work began in 1909, and where much of the land was peat-covered, was effected by direct planting into the natural herbage, turf planting being used only on some experimental areas. Similarly at Moorburnhead (Guillebaud et al. 1927) in the south of Scotland, where from 1913 onwards the Duke of Buccleuch undertook the planting of a considerable area of moorland covered with peat about a foot deep, direct planting was used although the plantations would have established themselves more rapidly, as we now know, if turf planting had been employed. The peat in this area was mainly *Molinia*, or *Molinia* in one or other of its variants, although there were patches of good *Deschampsia caespitosa* ground and more difficult stretches covered with *Calluna*, *Eriophorum* and *Scirpus*.

One noticeable feature of the work carried out about this time is the general inadequacy of draining where no turf planting was practised. This was seen at Inverliever as well as at Moorburnhead.

What little turf planting had been carried out up to 1919 followed the Belgian practice quite closely.

Where there was no turf planting, the young trees were planted direct into the peat, usually by a form of deep vertical notching. At Inverliever, the semi-circular spade was used for most of the early planting, and, although a T notch was later used, the sites were screefed either before or at the time of planting. At Moorburnhead, a shallow L notch was used, about four inches deep, which led to the bending of the roots, almost to a right angle, at the base of the notch. As it happened, this method was quite successful ; and for peat planting of spruces, it probably was an improvement on the deep vertical notch. No screefing was done in this plantation.

As for species, the first two decades of this century saw the gradual advance of Sitka spruce to the premier place in the planting of peat. At Inverliever, it was, at first, used on a very small scale, Norway spruce being preferred, but it gradually became more and more important as the unsuitability of many of the sites for Norway spruce became apparent. At Moorburnhead it figured largely from the beginning, and at Corrour it took an important place in the plantations. Norway spruce, on which much reliance was placed at the beginning, gradually diminished in importance.

Scots pine was relatively little used except at Inverliever in the early stages, when it soon showed itself to be unsuitable. Mountain pine was planted on a small scale both at Inverliever and Corrour.

European larch soon proved its inadequacy for peat planting, and Japanese larch, at first used very sparingly, began to acquire more prominence, although at Moorburnhead it gave disappointing results. Of other species, a little use was made of *Abies procera*, and it is interesting to note that, as long ago as 1907, Stirling Maxwell was suggesting *Picea omorika* and *Chamaecyparis nootkatensis* as possible trees for planting on peat.

The use of phosphatic fertilisers was adopted at Corrour with the Belgian system of turf planting, while top dressing of checked or poorly-growing plantations with high grade basic slag was also being practised there from about 1907 onwards. (Stirling Maxwell, 1925). Elsewhere, fertilisers do not seem to have been used.

One more development, in the period prior to 1919, falls to be recorded. At Inverliever, between 1914 and 1920, a system of classifying land in respect of plantability was gradually evolved by Crosfield and Boyd, working under the direction of R. L. Robinson. This classification was based on the vegetation, for it was held that the vegetation on the ground was important for two reasons, for its effect on the establishment of young trees and because it acted as an indicator of the character of the soil. In view of the importance which this method of classification subsequently attained in the determination of plantability and in the selection of species for planting, it is of interest to put on record the peat types which were recognised and described at Inverliever and the prescriptions which were recommended for each. These notes have been transcribed from a paper prepared by Boyd shortly before his death in 1920.

Peat Types

Plantable

1. Purple *Molinia ;* pure, or with other grasses or rushes ; little ling or heath, and bog-myrtle.

   Spruce ground, either Sitka or common. the latter rather the better where bog-myrtle abounds. Where ling predominates, spruces develop very slowly. Some draining necessary.

2. Mat of yellow moss, with *Deschampsia caespitosa*, *Agrostis canina*, bilberry and a little heath, ling and occasionally *Molinia* ; all in varying proportions, with or without traces of *Scirpus* throughout and occasionally traces of rushes and *Luzula*.

   Spruces. Require thorough drainage or other treatment. Plants develop slowly on natural surface. This is much in evidence in various mixtures of plants. The best quality is indicated by complete absence of *Scirpus*, and *Molinia* or rushes appearing. Where this type occurs on fair to steep slopes with peat, (seldom over six inches deep), good drainage or other treatment is necessary. The best treatment has not yet been settled, but, when definitely settled, it is probable that this soil will all grow spruces fairly well.

Doubtfully Plantable

3. Ling predominant, or with plants as in 2 subordinate, and with traces of *Scirpus* all over.

   Spruces, or *Pinus montana uncinata* first, and spruce later. Good drainage necessary—preferably a few years previous to planting.

4. Same as 2, but *Scirpus* more plentiful and general.

   Same as 3, but more doubtful.

Unplantable

5. *Scirpus*, pure or very plentiful, with plants as in 2 ; or with heath, ling, bog asphodel, little *Deschampsia caespitosa* and patches of *Sphagnum*.

   This quality might be worth experimenting with by good drainage, etc. Peat varies much in depth. Parts partially drained some years ago show improvement in quality of vegetation. It is not probable that much of the variable ground would produce a profitable crop of timber in the first rotation, and the poorer parts doubtful for longer.

6. Swampy ground, with much cotton-grass. Some *Scirpus*, *Sphagnum*, moss ; and grass and rushes are scarce.

   Usually deep peat, and flat on surface. Rather hopeless generally but margins, where rushes are in evidence, might be improved by drainage so as to grow spruces.

This classification shows a shrewd appreciation of the possibilities of afforestation on the peat clad lands of Argyll ; and the types which Boyd regarded as unplantable or as doubtfully plantable correspond to types of land on which it has since been necessary to conduct comprehensive series of experiments. His prescriptions for treatment show a marked tendency towards the use of spruces ; this reflects the opinion prevailing at the time, an opinion which persisted for many years more.

The work on peat, therefore, was at an extremely interesting stage when the new developments, which followed the establishment of the Forestry Commission, began in 1919. A system of classifying peats was being worked out ; turf planting had been adopted in a small way and experiments were being made with fertilisers. It remains now to follow the changes which took place in the vastly wider field which was opened up by the intervention of the State in Forestry.

Chapter 3

DEVELOPMENTS IN PEAT PLANTING SINCE 1919

We have seen that, up to 1919, the usual method of planting on peat was more or less the same as planting on mineral soils although there was the notable exception of Corrour. The Forestry Commission, when it started, followed generally the old methods. Taking the country as a whole very little of the land they acquired for planting, to begin with, was peaty, except in the north-west of Scotland, where an intractable peat predominated in some of the new planting areas. It was in those areas, on which considerable stretches of peat-covered land was afforested, that the inadequacy of the method of direct notching speedily became apparent ; and it is true, to a considerable extent, to say that the unfortunate results of some of those plantings led directly to the long series of experiments on peat which this publication is intended to record. The results were probably made worse by the wholesale use of spruces on those difficult peat sites ; obviously there was a trend of opinion in favour of spruces about that time, a trend which is reflected in Boyd's paper quoted in the previous chapter.

It must appear rather surprising that the officers of the infant Forestry Commission overlooked the experience of the Belgians and Germans and indeed of Scottish estates like Corrour and Glencoe, which would have provided evidence as to the need for some form of turf planting on the poorer peatlands. It is well to remember, however, that none of the experimental turf plantings in this country were then more than a few years old. In 1920, for instance, the evidence in favour of turf planting was relatively inconclusive even at Corrour, although not many years later it became overwhelmingly positive. Some of the earliest turf plantings on private estates had failed on the poorer peats because they had been given no phosphate, others were carried out on high quality peats where turfing was hardly necessary, but, above all, experimental technique was undeveloped in these days, there was no such thing as replication, and treated and control plots were seldom on strictly comparable sites.

The result of this direct planting on poor peat, was the phenomenon, later well-known, of 'check', in which the spruces did not die, but remained in a condition of stagnant growth, frequently for a very long time. Even to-day a few individual spruces, whose roots had been notched into the sodden peat thirty years ago, may still be found alive and not six inches taller than when they were planted (See Photo 2). Checking is dealt with by Fraser (1933) who gives some examples of the kind of growth which is made by young trees in that condition. The direct planting on those peatlands had been carried out without much draining, and this was one of the first reasons seized upon to account for the failure. However, a campaign of new draining, carried out on many wet peaty areas during a period of unemployment in the middle 1920's, produced little improvement. Probably the first indications that better results might have been secured by turf planting, were observed where drainside debris or turfs happened to have been planted, but there must have been doubt as to whether the improvement was due merely to the proximity of the drain or to the slightly elevated position of the plants on the drainside spoil.

Among the plantations which did not prosper was a bold attempt to establish a trial plot at an elevation of 900 feet at Achnashellach, the first experiment on peat carried out by the Forestry Commission. This experiment introduced *Pinus contorta*, one of the first occasions in which it was used by the Commission.

Within three years of the first planting on poor peatlands however, a good deal of attention was being paid by the Commission to the obviously unsatisfactory growth of spruces on peat. In October, 1923, H. M. Steven produced a report "Root Form on Peat" (See Appendix) which showed that the nursery root system of spruce trees planted into poorly drained moorland invariably became moribund ; only when the plant had developed a completely new system from adventitious roots, did the tree commence to grow at all well. Steven records that the new roots operated almost entirely on the surface of the peat and ran "mainly through the herbage plant remains." He had examined the roots of some of the species planted on turfs by Boyd at Inverliever in 1912, and of one turf-planted Sitka spruce he writes "the original root system is not clearly defined and probably has developed to some extent ; the original roots appear to have reached the natural surface at time of planting ;" the observation was of very great importance as he had almost invariably found in examining directly notched spruces that the original nursery root systems, though intact, were at best quite undeveloped.

Steven carried the results of his observations into effect in experimental plantings at Inchnacardoch in the winter of 1923/4 by trying out several new methods of very shallow planting. In one experiment, he introduced for the first time a turf planting treatment, the so-called Belgian one, but without any phosphate. The site was on poor *Scirpus* peat and subsequent growth was very poor—almost certainly phosphate deficiency was the limiting factor. He continued his experiments with other very shallow methods of planting in 1924, but none of these were really successful on wet peat ; obviously any level below the actual surface was too deep and too wet for the roots to develop comfortably, and we now know phosphate is necessary on such a site. It is interesting to find that in the same year he laid down an experiment to compare pitting and notching at Glenrigh among *Scirpus-Calluna* on thin tough peat on a morainic knoll. This rather suggests that even he did not, at that time, expect that very shallow planting or turfing was likely to be necessary except on quite wet peat types.

On the other hand, a close examination of Steven's report on *Root Form on Peat* leads the reader inevitably to think of turf-planting ; and there is no doubt that the knowledge of his conclusions was followed by attemps at turf-planting in various parts of the country.

When, in 1925, M. L. Anderson succeeded Steven in this research work, he laid down a series of experiments which employed shallow turfs inverted on the surface of the bog alongside the ditch from which they had been cut. The turfs were about 5 inches deep and 15 inches square. Anderson was convinced that the roots would ramify most readily on top of and not into the peat, so he planted the spruces in such a way that their roots were sandwiched between the natural ground surface and the inverted turf. The simple side notch which he used to allow the stem of the plant to pass through the turf has since been very widely adopted. This experiment and others were established on a stretch of *Calluna-Scirpus* clad peat named the Lon Mor, within Inchnacardoch Forest in central Inverness-shire. The Gaelic name means "big waste". The Lon Mor had already been selected by Steven as a thoroughly difficult example of north western blanket bog containing both basin bogs and slope peats. Anderson found that while losses following notching in peat had been very high, losses with the shallow turf method of planting were exceedingly light (4 per cent with seedlings and even less with transplants). Among the experiments which he laid down that year (1925) were the first manuring trials. These later proved without any doubt whatsoever the efficacy of a phosphate dressing.

It is important to note that from the first he envisaged the use of a plough for turning out the necessary planting turfs, and as a matter of fact much of the turfing carried out to-day by draining ploughs approximates very closely to Anderson's 1925 ideas.

After shallow turfs had been used in experiments in Scotland from 1925 until 1927, Belgian turfs came into favour from 1928 until 1935 in the experiments, when they in turn gave place to thin vertical slices of turf. There were several reasons for these changes. Peat is, as a rule, much more easily undercut at ten inches than at five inches, and in 1928 the possibility of securing tackle to provide turfs mechanically was still remote, hence the return to the deeper Belgian turf. The change from the ordinary Belgian type of turf to the thin vertical slice was due in part to experiments which showed that the heavy Belgian turf tended sooner or later to sink into the surface of the bog and to become amalgamated with and sodden like it. Also the vertical slice turf gave a deeper and therefore better drainage channel. The point to observe is that there was a return again to a thin turf within ten years.

The Commission's field staff, perturbed by the poor results on the peaty land, had tried several changes in methods of planting before turf planting came into favour. For a period it became the practice to screef all surface vegetation, chiefly in an effort to reduce the weed competition. As a rule the screefing was carried out by a mattock, shaped like an adze, which provided a very shallow screef, but in one forest at least (Newcastleton) a very deep depression produced by a tool called a rail spade was being made about 1925, with particularly disastrous results, as the water lodged in the hole and often drowned the plant. It is of significance to record that areas of peatland were planted in Inverliever Forest in 1921 by direct planting. This rather goes to show that the early (Boyd) turf planting experiments at that forest must have produced little in the way of a convincing positive result.

The dates of the first turf plantings made by the Commission in the course of ordinary planting, as opposed to Research Branch experiments, are not known very precisely, but it is quite possible that several foresters who had received their earlier training at Glencoe Estate did practise turf planting in a very small way as early as 1921. That year for instance it is believed that some turfs cut from individual holes were used in one part of Glentress Forest. Some Belgian turfs were employed by the local forester (also from Glencoe) in a small trial at Inchnacardoch in 1923, this trial was placed alongside one of Steven's experiments. Probably a few Belgian turfs were employed in South Laggan forest also that year. In 1924 two acres of turf planting was carried out at Bennan Forest (now Cairn Edward) and a small amount also at Dalbeattie Forest. In the following year (1925) two acres were planted on turfs at Loch Ard Forest and small patches also at Newcastleton and Barcaldine. It was not until 1926 or 1927 that turfing was employed on any scale in the Commission's Scottish forests ; by 1929 however, it had become general for spruces. This planting followed the Belgian style but often a much smaller turf was used than the large turfs which the Belgians favoured. Murray (1929) states that the use of the semi-circular spade for direct planting into peat became obsolete about 1923, and suggests that turf planting became more frequent from about that year onwards. He also refers to the use of the side notch at a comparatively late date by one of his foresters in the south of Scotland.

Planting on peat did not begin in England until several years after the first ventures by the Forestry Commission in Scotland. In 1926, however, work started at Kielder Forest in the valley of the North Tyne, near the Scottish Border, and the earlier planting was done by direct notching into the surface with a Schlich spade while a small experimental area included turf planting. In the following year, a small area was planted on turfs which were cut and inverted beside the hole from which they were taken. In 1928, the bulk of the planting was on turfs and from 1929 onwards, turf planting became standard.

In Wales, Belgian turfs were used in the experiments laid down by Steven at Beddgelert Forest in 1929.

In November, 1926, R. L. Robinson as Technical Commissioner of the Forestry Commission issued a memorandum to his field officers on *Norway and Sitka spruce Planting with reference to Difficult Sites.* (Robinson, 1927). This remarked upon the satisfactory results being obtained experimentally by what was called "mound" planting, and upon the need for modifying prevailing practices for planting spruces. The side notch method as developed at Lon Mor was to be tried out in the forests. The disadvantages of direct planting were listed as :—

(*a*) excessive deaths,
(*b*) unduly heavy beating up
(*c*) prolonged weeding and
(*d*) increased length of rotation.

The memorandum went on to say that the practice on wet sites of planting a row of spruces on the turfs thrown out of drains should become universal, although curiously enough, the spreading out of drainside turfs was not suggested. It was largely as a result of this memorandum that turf planting quickly became general on the peatlands, and within two years was universal as the planting method for spruces in these forests.

From 1927 onwards, for a year or two, attempts were made to salvage some of the poorest early areas where direct planting into the peat had resulted in, at very best, severe check. Many experiments were conducted to test methods of raising the checked spruce bodily, e.g. by cutting out a turf where the plant stood and placing this on the surface of the bog. The attempts were unsuccessful except where phosphate was applied and a satisfactory draining system introduced in addition to the lifting process. The most satisfactory growth of all, in these salvage trials, was made by new plants, and especially by *Pinus contorta* introduced into the area on new turfs with slag.

Although pine/spruce mixtures had been tried experimentally in a very small way before 1924, the real pioneer pine/spruce mixtures were laid down that year in Glen Urquhart Forest. This represents one of the first acknowledgments that spruce checked on heather, and was the first use of pines as nurses. This practice spread on to heaths and peatlands alike, usually as alternate plant or alternate line mixtures until the early 1940's, when a 2-rows pine followed by 2-rows spruce mixture came into favour, although more on the heaths perhaps than on the peatlands. The reason for the change was undoubtedly the failure of the spruce to survive or keep pace with the pine nurse on the more difficult, usually more heathery, types. It was about 1935 before there was much attempt in the forests to try species other than the two common spruces and Scots and mountain pines in any quantity on the peat types. About that time *Pinus contorta* gained favour which increased—especially in Scotland—until by 1951-52 altogether some six and a half million were employed annually—a high percentage of them on the peat types. Japanese larch also began to be used in increasing numbers on shallow peat types with quite considerable success.

The Lon Mor experiments had shown by 1926 that basic slag was effective on the poorest peat types, and by 1928 it was becoming the practice to give two ounces of basic slag to each tree on planting in the peatland experiments in the north west of Scotland. Within a year or two basic slag was being employed in a number of forests in Scotland, especially in the north, and orders for this fertiliser increased to such an extent that in the interests of caution, Headquarters, about 1930, issued the dictum "an ounce of patience is worth a ton of slag". Ample evidence from experiments soon showed that phosphate was essential on the poorest peat types, while on the better types there was little reason to give any application. In the 1930's ground mineral phosphate gradually displaced basic slag for experimental plantings on the poorer peats, but this change-over did not become general in the northern forests until after the 1939-45 war. The use of phosphate never became common in English Border forests, mainly no doubt because *Molinia* ground predominated and only on poorer types is phosphate necessary.

Once turf planting became general on the peatlands, a great deal was done to reduce the cost of the operation by making it a piece-work job ; vast areas on both sides of the Borders were drained and turfed by hand ; conditions were relatively easy and the men became very expert. At Newcastleton men were actually cutting turf drains and spreading the turfs, five and a half feet apart, at an inclusive rate of 1/- per chain before war broke out in 1939 ; on the Kielder side the piece-work rate was very little higher. In western forests, where the ground is often irregular and generally stony, 2*s.* 6*d.* per chain was a common pre-war rate for draining and laying out turfs.

The first recorded attempt to develop a type of plough specially designed to turn out planting turfs on peat was made by Anderson in 1927 at the Lon Mor. It became immediately obvious that horses—the only form of traction then available—were useless on soft and irregular peatlands, and it was not until just before the war that the first satisfactory trials of tractor-drawn ploughs were made on soft peaty land. In 1933 Messrs. Henderson of Catrine had demonstrated a useful draining plough at Loch Ard Forest, but the traction was by means of a winch and wire rope which resulted in the method being rather slow and costly.

In 1937 however, the first track laying tractor—a little Bristol—became available for use on peatlands at Fleet and Corriedoo forests in south Scotland, and a wheeled tractor—a John Deere—was obtained in the following year and employed at Twiglees and elsewhere. It did good work on shallow peat types with ploughs of the Solotrac type. New crawler outfits obtained just at the time of the outbreak of war operated at Cairn Edward, Corriedoo, Twiglees, Castle O'er, and Forest of Ae in 1939/40, and also on a few peat areas in north and west Scotland.

The greatest stimulus to the mechanisation of turfing was given by the war. Labour being scarce, the need increased for turning out turfs in quantity with less labour, and the war also brought into the country more crawler tractors than ever before. During this period Cuthbertson, of Biggar, developed his draining plough and subsequently modified it for use as a forestry draining and turfing tool. Later he produced a double mouldboard type which set out turfs on either side of the drainage channel, and in 1950 he put on the market an amphibian tractor to work on the softest and wettest bogs.

Improvement in machines, labour shortage, and increased wages have now, between them, resulted in little hand draining and turfing being carried out at all, except in very rough country. At the present time the equipment generally favoured for the afforestation of poor peatlands in the irregular peaty country of the north and west is the Cuthbertson single mouldboard draining plough. Where the double mouldboard Cuthbertson can be worked, it is in great demand, but the drainage system has to be superimposed with the single mouldboard draining type. In the Scottish and English Border country, where there are smooth slopes and great stretches of relatively shallow peat, the Begg plough is an alternative, but Cuthbertson ploughs are employed where the peat is deeper.

For a period after the 1939-45 war it became the practice on reasonably good peat types to turn out large turf ridges spaced about 21 to 24 feet apart, and to cut up and spread the turfs by hand. This was done—and is still done to a lesser extent—partly because suitable ploughing outfits were scarce, but also because of fears that windblow might be serious where close deep drains had been ploughed close together at five foot spacing. On the heavy Border soils especially it seemed likely that trees growing on the narrow ridge between deep drains would have a very insecure base. The difficulties created for extraction in the future by closely spaced single-furrow drain ploughing were also in the minds of those concerned. A few years later, however, it became evident that early growth was not so good by this less intensive method as on plough ridges obtained from drains at 5 feet apart. Obviously the new method provided the plant with less inverted turf to root in, and with less intensive drainage ; it also made the competition by surrounding vegetation more serious. However as areas so turfed were almost always on fairly good peat the ultimate result was not in doubt, provided the widely spaced furrows were subsequently maintained as drains. The solution in many areas has been the use of two ploughs, one providing shallow continuous turf ridges for planting, the other deeper drains at intervals depending on the intensity considered necessary for the particular area.

Although complete "mock ploughing" and other very intensive forms of cultivation which provide reversed turfs over 80 to 100 per cent of the surface were tried experimentally with very good results, no methods more intensive than 5 foot single furrow ploughing or 10 foot ploughing with the double mouldboard plough have ever been put into practice in the forests. Generally speaking the most difficult peatlands were omitted in all large scale programmes.

Since the end of the 1939-45 war, during which little drain maintenance was possible, the cleaning and deepening of drains on the peat types has demanded considerable attention. Any neglect is likely to have unfortunate consequences through waterlogging, poorer growth, and potential windblow.

Chapter 4

THE EXPERIMENTAL AREAS

THE problems and general history of the afforestation of peat in Great Britain have been covered in the preceding chapters. Those that follow give an account of the experiments laid down by the Research Branch of the Forestry Commission in the past thirty years. In many respects it can be only a progress report in that few of the experimental plantations involved have reached the thinning stage. In the majority of the experiments the initial problem has been to establish a crop on ground regarded at the start as unplantable by normal methods, and in this respect success or failure in the early years is in itself a result worthy of recording now, even though the ultimate size and value which the trees will attain cannot yet be forecast.

The task of the Research Branch has from the start been to enable the best use to be made of the areas acquired for afforestation, and to do this largely by tests of new methods under controlled conditions so that the results may be demonstrated to the practising foresters. Planting necessarily overshadowed all other forest work in the new state service, and quick establishment became a major aim because it reduces unremunerative tending operations and allows the maximum effort to be made on planting. When patience is urged in the matter of establishment it is often forgotten that while this virtue is being exercised, many years increment may be lost over wide areas, and the building up of the essential national timber reserve seriously delayed. Thus it becomes apparent that expenditure on establishment not contemplated in well afforested countries and often not practical for the private owner, become essential to the Forestry Commission in Great Britain, and it is for this reason that the work on peat has been concentrated to such a large extent on establishment trials. The results achieved assist afforestation in two ways, by promoting better growth on the areas known to be plantable and by the continual extension of the limits of the ground on which planting is considered practicable.

The costing of operations has been a subsidiary task to the trial of methods for afforestation. In many cases costs will be the test of a point of technique which has given some slight benefit, and similarly costs are the deciding factor between alternative methods which have given the same result. On the other hand costs have not been allowed to deter the Research Branch, since if an operation is costly but effective some less costly means of achieving the same end may often be devised, even though at a later date. The outstanding example on the peatlands is the mock-ploughing carried out by hand on poor peat ten years before it was possible to plough these areas mechanically.

The method of work of the Research Branch has been very largely by the use of experimental plots. Ideas or new techniques suggested or devised from time to time by foresters, both in Great Britain and abroad, have been incorporated into one or more controlled experiments, in order that they might be tested in strict comparison with other methods. Thus the majority of forest experiments consist of a number of plots of trees with different techniques employed in each. The earliest trials often consisted of a very few plots, but as time went on they have tended to become more complicated, in some cases perhaps unnecessarily so. The methods of design, layout and analysis have been largely adapted from those devised at Rothamsted for use in agricultural research.

The alternative method, of observation in the forest, has been used for investigations into specific problems ; in afforestation however the straight forward experimental approach is generally simpler owing to the number of variables involved. It is inevitable, however regrettable, that in many cases the fundamental problems are left unsolved by this objective approach, but the slender resources of the Branch had necessarily to be directed upon the immediate practical problems.

The experiments with which this Bulletin is concerned number about 330 in Scotland and northern England and about thirty in North Wales. They have been concentrated as far as possible in a number of experimental reserves, for convenience of access, maintenance, and demonstration. Often however when special problems have arisen it has been necessary to site experiments at other forests or on particular ground types not available in the reserves. The location and more important features of the sites of the main concentrations of experiments are set out below, and are shown on the adjacent map.

Inchnacardoch Forest, Inverness-shire

This forest lies to the west of Fort Augustus at the head of Loch Ness and is the most important site used for experimental work on poor peat. The annual rainfall is about sixty inches and there are within the forest two reserves :—

The Lon Mor. The history of this area has been briefly described by J. A. B. Macdonald (1945). It was selected as a typical stretch of deep basin peat in contrast to the shallow slope peat being used at other forests. The Lon Mor lies at 550 feet above sea level on a shelf on the northern slope of the Great Glen. The River Oich runs at 100 feet elevation half a mile to the south-east, while to the north and west the hills rise steadily to over 1,500 feet, so that the general aspect is south-east. The main exposures are however north-east and south-west to winds up and down the Great Glen. The area consists of three basins with peat up to twenty feet deep, separated and enclosed by rocky or morainic ridges on which the peat grades down to as little as six inches. The bedrock is granite-gneiss. The three basins with the enclosing ridges amounting to some forty-five acres and in recent years an additional twenty acres on the west side have been used for experiments.

The original vegetation was that characteristic of the poorest deep peat and was dominated by *Scirpus caespitosus* with frequent *Erica tetralix*, *Calluna vulgaris*, *Eriophorum vaginatum*, *E. angustifolium* and *Myrica gale*. *Sphagna* were abundant especially in the wettest areas and in local hollows in the peat. The natural drainage consisted of sluggish underground seepage channels marked at the surface by bands of *Molinia caerulea*, but drainage was so poor that areas of open water occurred scattered over the area. On the drier knolls the vegetation again included *Scirpus*, *Molinia* and also *Erica cinerea*.

In commencing work on this area much attention was paid to drainage, the main seepage channels being opened up into drains which over the years have become up to five feet wide and three feet deep. Considerable work has also been done on deepening the main outlet where it crosses a moraine barrier.

The "P.22" Reserve. This is an extensive slope of *Scirpus* clad blanket bog lying to the north of the Lon Mor and extending from 600 to 900 feet elevation so that the area occupies the middle slopes of the hills and faces south-east. The area includes the wide valley of the Auchterawe Burn so that aspects vary from east to south. This part of the forest was planted in 1922 with Norway spruce which had for the most part failed by 1930 when the experimental work was extended to this area. The peat ranges from a few inches to several feet deep, the thinner parts being on morainic knolls which stand out from the main slope, the deepest on intervening peat flats.

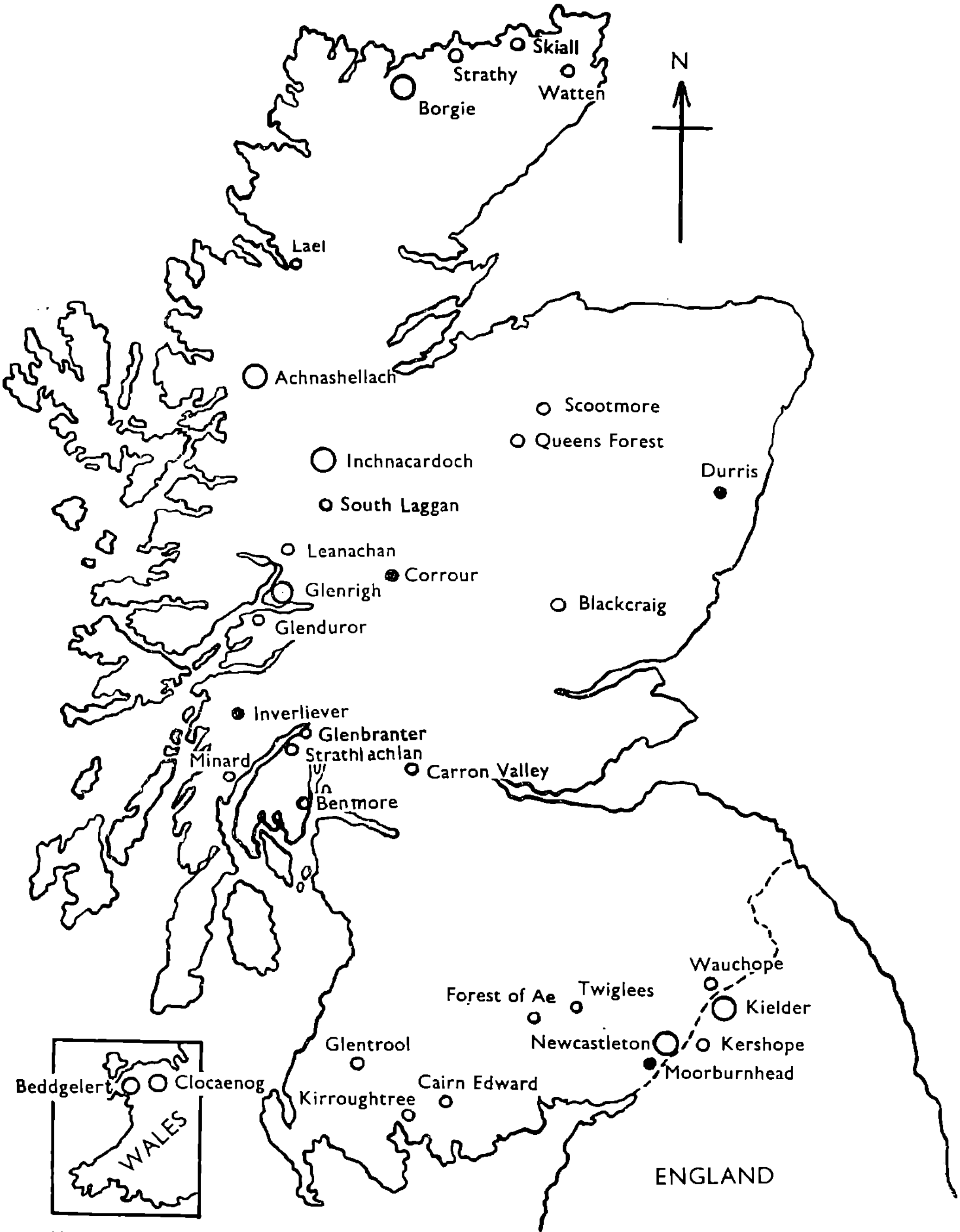
The vegetation was extremely poor at the start and in particular had been impoverished by burning. Thus it appeared that at one time the morainic mounds had carried birch scrub but only vestiges remained in 1930, the vegetation then being dominated by *Calluna-Erica cinerea*. The surrounding deeper peat areas were dominated by *Scirpus-Calluna* while slightly flushed areas carried *Myrica-Molinia* with occasional *Molinia* strips along the seepage channels. As on the Lon Mor a system of main drains was considered of prime importance before experimental planting commenced. The experiments, amounting to some fifty acres, lie scattered over five hundred acres of the blanket bog.

On these two experimental areas at Inchnacardoch approximately one hundred and fifty experiments have been planted since work started in 1921. By good fortune only eight were lost in the great fire of 1942 which did so much damage to this and the neighbouring forest.

Achnashellach Forest, Ross-shire

This was one of the earliest acquisitions made by the Forestry Commission and lies along the River Carron, which runs south-west into Loch Carron. The forest includes a large area of blanket

LOCATION OF PEAT EXPERIMENTAL AREAS.



KEY :—

PIONEER PLANTATIONS—CORROUR. ●

MAIN FORESTRY COMMISSION EXPERIMENTAL AREAS—GLENRIGH. ○

OTHER FORESTRY COMMISSION EXPERIMENTAL AREAS—LEANACHAN. o bog dominated by *Scirpus*. The underlying rock is of granulitic schists overlain with morainic deposits except on the steepest slopes. The rainfall is about eighty inches per annum in the valley and up to one hundred inches on the hills, which rise to 2,000 feet to the south-east and 3,000 feet to the north-west. A great part of the area is classified as unplantable on account of altitude, exposure and the difficult peat type. Research work started in this forest as early as 1921 and some thirty experiments have been carried out, located in various parts of the forest.

Glen Carron and Glen Uig. Several experiments in this area form an interesting series, all on the same type of ground on steep slopes, but at varying elevations from 400-900 feet and exposed to the south-west. The vegetation consisted of *Scirpus-Calluna* mixed with some *Molinia* and *Myrica*, and occasional *Molinia* flushes. The peat is for the most part shallow, under one foot deep, but varies from three inches to three feet. Many of the knoll tops are bare, the peat having apparently been eroded by wind and rain, this process probably having been accelerated by repeated burning. Beneath the peat there is evidence of strong leaching of the morainic soil, often with formation of an iron pan. Much of this part of the forest was planted with Scots pine in 1923 but by 1928 its appearance was so bad that the experimental work begun in 1921 was considerably extended. All the earlier experiments in this area were lost in a fire in 1942 but the more important 1928 series fortunately survived.

The Golden Valley Experimental Area. Another group of experiments lies three miles down the valley. Soil and vegetation conditions are fairly similar to those described above but they show rapid fluctuation from knoll to hollow to an even greater degree. The moraine is thicker, the slopes more gentle and the altitude is less, from 200-500 feet. This side valley runs northwards into the Carron, and is thus relatively sheltered from the south-west winds up the main valley.

This area again had been planted and failed prior to research work being undertaken, and is now almost entirely devoted to the testing of various provenances of contorta pine and larches under difficult conditions of soil and vegetation, without the added complications of high elevation or severe exposure.

Glenrigh Forest, Inverness-shire

This forest, in many ways comparable to Achnashellach, lies some fifty miles due south of the latter and occupies the promontory between Loch Linnhe and Loch Leven. The annual rainfall is eighty inches and much of the area is peat covered, while a considerable proportion is of bare rock. Experimental planting was carried out on the difficult peat types from 1924-1938 but has not been extended since then. The thirty experiments lie mainly in the Inchree experimental area which faces south-west down Loch Linnhe less than a mile away. Though at a low elevation of from 200-400 feet this area is fully exposed. The underlying rock is mainly acid quartzite but at least one narrow band of slate passes into the area leading to locally improved conditions. Morainic knolls form a conspicuous feature of the topography and the peat is generally thin with a ground vegetation originally dominated by *Scirpus* and poor *Calluna*, with occasional *Molinia* and *Juncus articulatus* flushes.

The experimental areas of the three forests described above are of outstanding interest among those on peat from the point of view of afforestation, in that they lie on areas which for twenty-five years have been considered as unplantable and are still regarded as only doubtfully plantable. Experimental work has subsequently been extended on to areas as poor elsewhere, but since age is a vital factor in the assessment of the success of any afforestation scheme, these areas with their lead of from ten to twenty years will remain of prime importance in defining the limit of plantability for many years to come.

The forests and experimental areas to be described below contain many further experiments on the technique of peat planting and trials on intermediate and relatively better types of peat.

Kielder Forest, Northumberland

This is the largest forest area acquired by the Forestry Commission up to the present time, incorporating wide stretches of the English Cheviots. Recently a general account has been given of the planning and scope of the planting operations. (Forestry Commission, 1950). The area consists of rolling hills rising to over 1,800 feet around the North Tyne valley with a rainfall of over fifty inches on the tops, falling to forty down the valley to the east. The bedrock is of carboniferous sandstone with a covering of boulder clay. The vast majority of the area is peat covered and shows a wide range of conditions; thus while most of the land planted in the early years was of the relatively easy amorphous peat type dominated by *Molinia*, latterly poorer areas of *Calluna* and *Eriophorum* or even *Scirpus* peat have been afforested. There still remain great areas of high lying *Scirpus*-dominated blanket bog, and also large raised mosses with deep peat which are classified as unplantable.

Many of the sixty experiments planted here have taken the form of advance plantings and are thus scattered over the area. Those concentrating on points of technique were generally planted for convenience near the trial plantations. The first series were laid down in 1926-30 following a survey of the North Tyne valley by Steven. They all lie in Smales beat, the first area acquired, mainly on *Molinia* types with a plentiful admixture of other species, which led at the time to doubt as to their plantability. The second series on *Calluna* types followed in 1936-39, including Kielder and Mounces beats. All these experiments have been engulfed by subsequent full scale afforestation to which they served as valuable guides. A third series has been commenced on the *Scirpus* types in recent years, sited to test the large stretches still classified as unplantable on sites comparable to those described at Inchnacardoch, i.e. on deep peat hollows or blanket bogs.

Newcastleton Forest, Roxburghshire

This forest is on the Scottish side of the border adjacent to and very comparable to Kielder, though containing comparatively little of the poorer peat types While none of the early experiments were located here, a survey was carried out in 1927 some details of which have recently been published together with a historical account of methods in this and adjoining forests. (Macdonald, J. A. B., 1953). Fifteen experiments have been laid down since 1936 mainly on the problems of spruce provenance and those of maintenance rather than the establishment of plantations on peat.

Borgie Forest, Sutherland

This was the first area acquired by the Forestry Commission in Scotland and lies on the north coast (See Photo 1). At this high latitude and on blanket bog over acid metamorphic rocks the early plantations were unsatisfactory and in 1930 a number of trial plantings were made by the Research Branch. These were most promising but unfortunately almost the whole forest and the experiments were burnt in 1942. The experience gained has however been of great value as a guide to the subsequent replanting of the forest and in making the recent decision to extend work in the far north of Scotland. (Zehetmayr, 1953). The rainfall in this area of about forty inches is somewhat less than in the majority of the peat covered regionsof Scotland, but this is compensated by low temperatures and low insolation associated with the high latitude.

Beddgelert Forest, Caernarvonshire

This forest forms part of the Snowdonia National Forest Park. (Forestry Commission, 1948). The rainfall is about one hundred inches per annum and peat formation is thus facilitated, occurring particularly in the hollows. The geological formation is Ordovician with slates and shales often overlain with moraine and boulder clay. About twenty experiments were planted from 1927 to 1932, mainly in the peaty hollows on three sites.

Cwm Du. This deep peat bog lies at 1,000 feet but exposure is not severe as the surrounding hills rise to 2,000 feet, the forest planting itself extending to 1,700 feet ; the general aspect is easterly. The peat is over six feet deep but not of the poorest type, being dominated by a mixed vegetation of *Eriophorum*, *Molinia* and *Scirpus* in varying proportions, with ericaceous shrubs, rushes and grasses. (See Photo 12). The early work at this site has been described by Steven (1929).

Cae Coch. A similar but rather poorer basin bog at a lower elevation of 800 feet and exposed to the south-east.

In both these areas the establishment of a main drainage system was given high priority at the commencement of the experimental planting.

Y Gyrn. A very variable area only partially covered with peat lying at about 1,000 feet and fully exposed to the south-west. A large collection of species plots has been established here, a proportion of them on peat. The vegetation was mainly of *Molinia* with *Calluna* and *Scirpus*.

Clocaenog Forest, Denbighshire

This forest is primarily an area of upland moors dominated by *Calluna*. There are however small areas of peat on which some dozen experiments have been planted. They lie in the Ty'n y Waen area which ranges from 1,300-1,400 feet. The peat is for the most part thin, the deeper parts dominated by *Molinia* grading into the fibrous *Calluna* peat of the heaths. The rainfall is about sixty inches per annum and the experimental area at 1,300-1,400 feet is exposed and subject to severe frosts.

The remaining sixty experiments are scattered through about twenty-five forests in Scotland and the locality details are given where necessary with the description of the experiments. Far more research has been carried out on the poorer types, and there are great areas of south and west Scotland where few experiments have been planted because establishment is relatively easy. The experiments are described primarily in relation to the poorer peats, while results from the better areas are quoted where possible to keep the subject in perspective. The summary falls into three main sections :— Ground preparation and planting, choice of species, divided into the main and lesser species, and manuring ; and in addition there are chapters on the trial plantations laid down by the Research Branch and the various other items of research undertaken on peat.

Note on numbering of experiments

Registered experiments. The name of the forest is followed by the experiment number and the Forest Year indicated by the symbol "P". (Oct. 1st—Sept. 30th) in which the experiment was established (not necessarily the year of planting) e.g. Inchnacardoch 52.P.28. The numbers run consecutively from year to year in each forest.

Preliminary trials. These were laid down by Research Officer (Scotland) between 1933 and 1946 and were mostly small scale manurial trials. The Forest name is followed by the year of planting and a number, but these do not run from year to year, e.g. Inchnacardoch P.T.37/3 may be followed by P.T.39/1.

Note on assessment of experiments

In the early years losses are recorded mainly for the purposes of replacement or beating up. After the first two years the losses due to the accidents and chances of planting are considered to have been made good, and subsequent losses may be safely attributed to the rigours of the site, or the unsuitability of the species or treatment. Early and late losses are thus often distinguished as indicative of the effect of rather different agencies.

Losses are generally expressed as percentages except where the numbers of plants employed were so low as to make these misleading, in which case the number of dead and the total planted are given.

Heights were at one time measured in inches which were altered to feet as the trees grew taller. For convenience in averaging, tenths of feet are now employed and all heights up to about eight to ten feet are so measured and expressed. Over ten feet, measurements are made to the nearest foot and averages calculated to the nearest half foot.

When the plantations reach the thinning stage mean height can be misleading as to the real effectiveness of the crop or species. A system of measurement of dominant heights is used. This is in effect a sampling method recording the heights of the tallest trees in about every twenty square yards (200-250 per acre are the limits set). Thus the average represents the height of potential or actual dominants over the whole area sampled and is not affected by thinning as is mean height. This method is valuable where some plots are taller than others and have been thinned, since use of mean heights here would tend to accentuate differences. Similarly in young mixtures, where species differ markedly in height, use of dominant rather than mean heights is a better indication of whether a mixture will be achieved.

In certain of the larger experiments use of true top height (i.e. the mean height of the hundred largest trees per acre) is now possible, combined with volume measurements, and this method will be extended as the experiments grow older.

Chapter 5

SITE PREPARATION AND PLANTING

THE correct procedure to be followed in preparing peat covered areas for planting and the best method of actually planting the young trees have been from the outset major problems in the afforestation of peat. Despite a great deal of experimentation the complete solution has by no means yet been achieved.

Three major phases can be recognised in the experimental as well as in large scale plantings : first the short-lived direct planting period, second, fifteen years of hand draining and turfing, grading into the third, the present phase of ploughing which is still in the development stages, with only short term experimental results available.

DIRECT PLANTING

The first experiment laid down on peat was planted by direct notching on a poor, high and exposed site at Achnashellach (1.P.21). The majority of the plants died within two or three years but a few lingered on, alive but not growing—in a state of complete check—until the experiment was accidentally burnt in 1942. At other forests too the earliest experiments were all directly planted, some by notching, some by pitting, and growth was in the main very poor indeed. The actual method of direct planting made little or no difference to growth, but variation in ground and vegetation type had considerable effect. One such experiment at Inchnacardoch (2.P.22) covers a variety of vegetation types at an altitude of 1,100 feet, and its fate is typical of that of the early plantings ; a few spruce in the *Molinia* flushes have reached twenty feet whereas on the poorer parts, originally dominated by *Scirpus*, they have failed completely ; Scots and mountain pines are growing slowly on all the vegetation types but only after considerable losses and a long period of check.

It is interesting to record that Anderson was so convinced of the futility of direct planting into poor peat, that he did none when he commenced operations in the Lon Mor experimental area in 1925, and it was not until 1927 that a directly planted block was laid down for demonstration to visitors (Inchnacardoch 38.P.27). Of one hundred Norway spruce and the same number of Sitka spruce, only one plant remains alive today, though nearly half of the trees in the transplant section were recorded as being alive in 1938, having grown at most two inches in eleven years.

Several direct, but extremely shallow, forms of planting were used in experiments inspired by the report *Root Form on Peat* (See Appendix) and the growing realization that roots ramified only in the most superficial layers of the peat. In the first of these trials (Inchnacardoch 7.P.24) the method entailed spreading the roots of the plants in a shallow saucer shaped depression less than two inches below the ground surface. At the same forest other experiments achieved even more superficial planting, by spreading the roots on the surface and pegging them down with canvas (23.P.27), and by piling screefed vegetation on the roots after these had been spread flat on the ground (32.P.27). A slight improvement in growth in the first few years resulted from those methods, but nothing of practical significance emerged.

Direct planting was rather more successful with pine and larch on the thin peat types of Achnashellach and Glenrigh. Scots pine, Japanese larch and Norway and Sitka spruce were notched and pit planted in the first experiment at the latter forest (1.P.24). There was no difference in growth with the two methods, but notching was much cheaper. Both pine and larch have grown over most of the area though very slowly in the parts dominated by *Scirpus* and *Calluna*. Spruce as in other areas grew only on the *Molinia* flushes.

On a better ground type with more *Calluna* and less *Scirpus*, Sitka spruce planted in mattock-dug trenches has survived and is growing in mixture with Scots and contorta pines (Glenrigh 13.P.28). Twenty-five years after planting the spruce dominants have attained a height of over twenty feet where top dressed with phosphate in 1939, and have outgrown the pines. Without phosphate however, they are themselves in danger of suppression.

At Achnashellach several further methods of direct planting were used with eight species as indicators (10.P.28). The unit was a single plant so that, after the early years, height growth was not strictly comparable owing to interference between species. A system known as Manteufel's, or the Bavarian, (also called pit-and-mound, or "Wareham pit"), method of planting into piled moraine after removing the turf, was the most successful for most species. Direct notching was the worst treatment in all cases, various pitting methods and planting in mattock trenches being intermediate. The growth of hybrid larch is excellent in this experiment, averaging twelve feet at sixteen years from planting, compared with Japanese larch nine feet, mountain and Scots pines six feet, contorta pine five feet, and Sitka spruce four feet. European larch reached five feet with the Bavarian method, the only method with which more than one or two plants of this species survived. A surprising feature is that the larches show relatively less sensitivity to method of planting than the pines. Thus the range of the average heights of hybrid larch with the different planting methods is only eleven to fourteen feet, but that of Scots pine is four to eight feet. This may be due partly to the suppression of pines by adjacent larch but is sufficiently unexpected to merit notice.

On the thin *Molinia* types of the Border country direct planting was used widely in the early days, but experimental work commencing rather later there, only two experiments were so planted (Kielder 2.P.27 and 5.P.27). In the former Scots pine was planted by different direct methods but was so badly damaged by blackgame that any treatment differences were obliterated, while Sitka spruce went into prolonged check. This area was replanted in 1935. In the latter these species grew after a slow start (See Photo 3).

The general conclusion from all these experiments is that direct planting is useless on the poorest *Scirpus* peat, gives a slow start on intermediate types and leads to reasonable growth only on the richest types of peat with a *Molinia* or *Juncus* flush type vegetation. Even on the latter types however, it suffers from the drawbacks that early growth is generally extremely slow on account of intense root and shoot competition from the ground vegetation. As a result, weeding of directly planted crops must be both intensive and prolonged. One further disadvantage is that frosting is intensified over fine leaved vegetation, and this may lead to damage and further retarding of the young plants. It is for these reasons that direct planting is virtually never used today on any peaty area.

TURF PLANTING

Comparison of direct planting with turf planting

The early history of turf planting is outlined in Chapters 2 and 3. As a result of its introduction, comparisons of this method with direct planting were laid down between 1924 and 1928 in all the experimental areas then in existence. Even so, the very great merits of turf planting were not demonstrated in experiments as early as might have been expected, for the first of these trials, at Inchnacardoch, were on such poor peat that turfing alone was not sufficient to promote good growth. (6.P.23 and 7.P.24). Later it was found that the addition of phosphatic fertilizers is essential on such land.

Meanwhile, as direct planting was obviously a failure on all but the richest peat areas, turf planting was being developed and widely adopted both in experiments and general practice so that the experiments became merely demonstrations. A good example at Inchnacardoch was on an area of peat, six to eighteen inches deep over moraine, dominated by *Scirpus*, *Calluna* and *Molinia*, where plants were introduced on turfs into an older, directly planted experiment (Inchnacardoch 5.P.23 and 62.P.28). Until burnt in 1942, these experiments provided a most striking contrast. While the older plants remained in complete check, those on turfs grew steadily so that in fourteen years contorta pine reached ten feet, Japanese larch nine feet, and spruces four feet.

At Glenrigh, pines, larch and spruces in a turf planted experiment (4.P.27) grew better and overtook the same species in an adjoining older experiment which had been planted by pitting and notching (1.P.24). In an interesting trial in the same forest Sitka spruce on turfs was compared with a special shallow planting by a T-notch ; the former was only slightly superior in the early years and growth is now almost even (11.P.28). A point here is that both sections were drained, so that the T-notched plants had an advantage over those in the majority of directly planted areas in which few drains were cut. Nevertheless, this is a demonstration of the essential point that spruce roots must be kept near the surface for successful establishment on peat.

Several experiments at Achnashellach incorporated comparisons of notching and turfing. In one of these (2.P.27) Japanese and hybrid larches were planted by these methods in alternate lines on an exposed knoll. Here again the notched plants were probably aided by the turf drains, and after fifteen years, pitted plants reached four to five feet, while those on turfs averaged only a foot more. The losses were however halved by turf planting. Sitka spruce with basic slag in a similar trial (5.P.27) reached four feet where notched and six feet where turf planted, while unmanured plants regardless of planting method were still in full check when burned in 1942. On sites such as these, turf planting alone is not enough to ensure speedy establishment of spruce and larch.

One Welsh experiment falls in the category of intermediate quality peats, growth of both Norway and Sitka spruce being fair with direct planting but considerably improved by turf planting, and in particular the plantations are much more uniform where established by the latter method. (Beddgelert 8.P.28).

The early Kielder experiments were laid down on the poorer sections of the available planting land with *Calluna* and *Scirpus* in addition to *Molinia*. The effects of turf planting and protection from blackgame are illustrated in Diagram I. Heavy losses occurred in this case with direct planting, but it is clear that the survivors grew well after a slow start. There is no question here of spruce checking indefinitely as on the poorest types of peat.

These experiments on the intermediate quality peats serve to illustrate the fact that while successful plantations can be raised by direct planting, as indeed was done in the early days, the start is slower and losses are higher than with turf planting, and this slow start means more tending and prolongation of the fire risk, both matters of prime importance. Turf planting is however only one factor in speedy establishment on these sites.

In the Borders excellent plantations have been raised by direct notching as at Moorburnhead, Dumfries-shire, and in the first planted areas at Newcastleton. One early experiment (Kielder 6.P.27) lies partly on good quality *Molinia* peat, and it is possible to make the comparison between turf and notch planting. Notched spruce grew more slowly, only about half as fast in the first nine years, and Norway was proportionally slower than Sitka spruce. Losses were, however, low and canopy has formed throughout the experiment which by 1952 was approaching the thinning stage. Direct planting is undoubtedly a potential method of establishment on these better quality peats ; however, had it been persisted in, the volume of timber at present standing in these forests would be much less and in addition the drainage problem would by now be acute. On land such as this, turf planting without additional treatments is sufficient to provide the desirable speedy establishment (See Photo 10).

Turfing technique

This system of planting involves opening a network of drains in the peat and spreading the turfs so obtained to provide mounds on which to plant. The tools and methods involved have been described by MacEwan (1930). The effects of the general draining of the ground by the ditch, and the local draining of the turf by its being raised above the level of the bog, both contribute to the improved conditions for growth. This is demonstrated by certain experiments in which turfs were

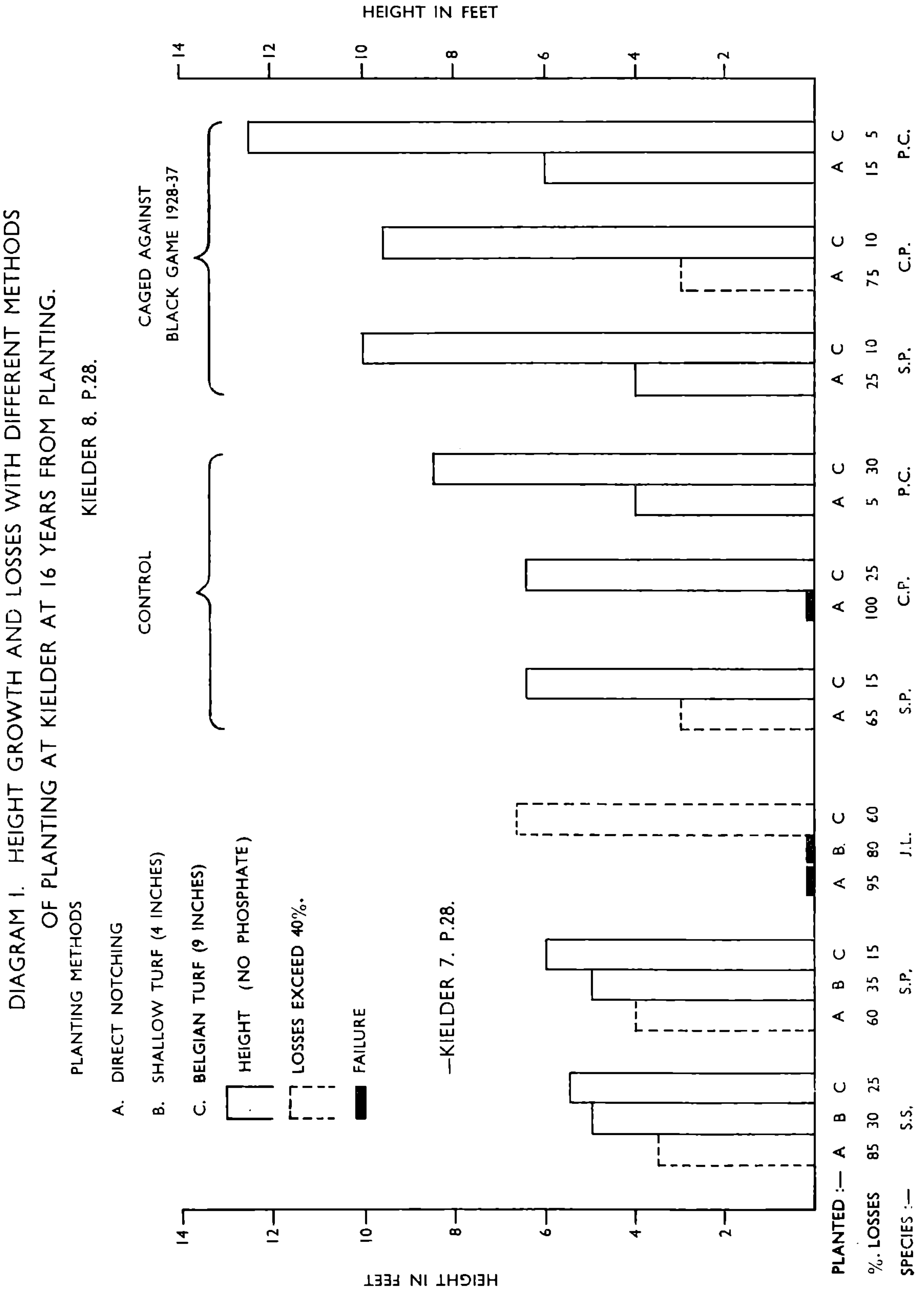


DIAGRAM I. HEIGHT GROWTH AND LOSSES WITH DIFFERENT METHODS OF PLANTING AT KIELDER AT 16 YEARS FROM PLANTING.
PLANTING METHODS
A. DIRECT NOTCHING
B. SHALLOW TURF (4 INCHES)
C. BELGIAN TURF (9 INCHES)
HEIGHT (NO PHOSPHATE)
LOSSES EXCEED 40%.
FAILURE
—KIELDER 7. P.28.
KIELDER 8. P.28.
CONTROL
CAGED AGAINST BLACK GAME 1928-37
HEIGHT IN FEET
14
12
10
8
6
4
2
PLANTED :— A B C A B C A B C A C A C A C A C A C A C
%. LOSSES 85 30 25 60 35 15 95 80 60 65 15 100 25 5 30 25 10 75 10 15 5
SPECIES :— S.S. S.P. J.L. S.P. C.P. P.C. S.P. C.P. P.C.

cut individually from holes, instead of in lines to form drains (Glenrigh 4 and 6.P.27). These holes in some cases became filled with water to the brim for long periods, and growth was poorer than where drains were provided.

Investigation of the technique of employing the turfs from drains formed a large proportion of experimental work in the years 1924-1928. One matter calling for experimentation was the comparison of the high or Belgian turf nine to ten inches thick, with the shallow turf, developed by Anderson in the early experiments at Inchnacardoch, which was only about four to six inches high. An early experiment on the poorest peat at this forest (49.P.28—Diagram II) shows that plants on the shallow turfs grew slightly better than those on the high turfs, but that grouped shallow turfs were considerably superior to either. The shallow turf had by this time been in use at Inchnacardoch for some years, but in 1928 there was a change to the Belgian type of turf until about 1935, when the results of this and other experiments suggested a return to shallower turfs. Thereafter until the advent of ploughing they were cut in thin vertical slices so that the vegetation lay at one edge. Such shallow turfs are far easier to cut than a surface shallow turf formed of the toughest upper layers of peat, and this method also produces a drain of more suitable dimensions.

By contrast, in Wales high turfs have been shown to be superior to shallow; thus in one experiment Sitka spruce reached eighteen feet on high turfs after nineteen years but only ten feet on the shallow turfs. Corresponding figures for Japanese larch were eleven and nine feet (Beddgelert 8.P.28). High turfs are still used in this area on those peats which cannot be ploughed.

At Kielder also, high turfs gave both better growth and lower losses in one experiment (7.P.28—see Diagram 1), and a second experiment illustrates both this point and the allied subject of drain spacing (Table 1).

Mean Heights of Sitka spruce at 14 years from planting in Kielder Experiment 17.P.30

TABLE 1 — Feet

	Drain Spacing		
	Nil	Wide (20 feet)	Close (12 feet)
Direct Planting	3.8	—	—
4 inch shallow turf	—	4.7	5.5
9 inch high turf	—	4.6	6.8

The directly notched plants have grown slowly and the trend in height is clearly in favour of high turfs and closer drains. In fact, large turfs and Belgian spade planting have remained characteristic of this area. The reasons for the superiority of high turfs on this type of peat appear to be that lifting the plant on to the large mound removes it from the competition of the strongly growing *Molinia*, and this is not off-set by the weight of the turf causing it to be become amalgamated with the surface as occurs on deeper peat. In twenty year old plantations in the Border country, the outlines of the large turfs are still clear, surrounding the butts of the trees under the needle litter.

However, in a repetition of this experiment at Beddgelert (11.P.28) the type of turf makes little difference. Belgian, shallow and slice turfs were all used, but so long as the spacing of the drains was small, twelve feet or less, growth was even. Where however the spacing increases to twenty feet the growth is no better than in the directly planted control, so on the site of this experiment draining was apparently the limiting factor.

Both turfing, and ploughing, which has almost universally replaced it, involve far more work than the actual planting, so that these operations are carried on almost all the year round in preparation for a few weeks of spring planting. The question arose as to within what limits of time the ground should be prepared for a given season's planting and in particular as to whether there was any advantage in draining more than one season in advance.

To run off surface water well before planting would appear to be a beneficial operation, but in practice one draining experiment showed that at least there was no benefit in advance turfing and draining and that it might be harmful (see Table 2). This is probably because any advantage due to draining is off-set by the deterioration of the turfs; by their sinking back into the peat, by their breaking up by weathering, or by their becoming invaded by ground vegetation. The turfs turned out during the intensive draining operation must be used for planting, as it would be quite uneconomic to cut new ones. For these reasons ground preparation during the year before planting has become the rule in peat afforestation, apart from the occasional site where it is necessary to cut main drains in advance in order to dry it sufficiently for tractors to operate.

That planting on old turfs can on occasions be disastrous was shown in an experiment at Kielder where a plot of Sitka spruce was planted on ground prepared three years previously; at ten years from planting this plot averaged only three feet high and

Mean Heights at 17 years from planting in Inchnacardoch Experiment 55.P.28.

TABLE 2 Feet

	On Belgian Turfs		On shallow turfs	
Turfs prepared :—	Contorta pine	Sitka spruce	Contorta pine	Sitka spruce
Two years in advance....	8.4	2.0	7.6	1.9
One year in advance	9.2	2.7	7.3	1.4
In year of planting	9.1	2.8	8.3	1.8
Difference for significance at 5% level....	1.2	0.6	1.1	0.6

Note.—The two sections of the experiment are not on the same ground type so that comparisons between the two methods of turfing are invalid. There is obviously no improvement with advance ground preparation, and there is a suggestion of inferior growth on older turfs, though only in one case are the differences significant.

had suffered heavy losses, compared with a mean height of five feet and negligible losses in other plots planted on new turfs. (Kielder 29.P.36).

On the other hand it has been found that in certain years plants on recently cut turfs may suffer heavy losses. A freshly cut inverted turf will, under suitable conditions, dry out rapidly since the double layer of vegetation may act as a barrier to the passage of water into the turf. As the weight of the turf becomes effective and the vegetation starts to decay it ceases to act in this manner and becomes in fact the most suitable zone for root growth. An experiment designed to test this point of the timing of turfing and planting for Japanese larch failed to show any great differences, though losses in plots planted in October and April, immediately after turf cutting, were rather above average (Inchnacardoch 119.P.36). Clearly results in an experiment of this type might vary greatly from year to year. A minimum delay of two to three months between turfing and planting to allow for a limited amount of consolidation is an ideal which, however, cannot be always adopted in practice.

Other points of turfing technique were investigated in two small trials at Inchnacardoch in 1937, which sought to re-test points on which earlier experiments in 1927-28 had failed to give a result, owing to phosphate not being applied to the plants at that time. Turfs cut from below the surface, were shown to have no advantage over the normal type cut from the surface peat (Inchnacardoch P.T.37/5). In addition, the normal method of reversing surface turfs, vegetation downward, was shown to be slightly better than leaving the vegetation upward. (Table 3). This experiment was on a poor peat type where growth of vegetation on turfs is slow; the use of unreversed turfs in areas of rapid growth would probably have been disastrous.

Heights and Percentage losses at ten years from planting in Inchnacardoch Experiment P.T. 37/7

TABLE 3

	Sitka Spruce	Japanese Larch
Reversed Turf	3.9 ft. (3%)	5.7 ft. (10%)
Turf not reversed	3.3 ft. (5%)	4.7 ft. (23%)
Difference for significance at five per cent level	0.55 ft.	1.9 ft.

Methods of planting on turfs

Two very early experiments on the Lon Mor (Inchnacardoch 10 and 13.P.25) tried various methods of inserting spruce plants, both transplants and seedlings, into the shallow turf. The plants did not receive phosphate and checked badly, but early growth and losses showed that the side-notch method was as good as the others. As it was also the quickest method, it was generally adopted for planting the shallow turfs used in Scotland. The turf is split vertically with a spade from the centre to the outside, the plant inserted through the notch, and its roots then spread out in the double layer of decaying vegetation between the turf and the surface peat.

One disadvantage of the side-notch is that in dry seasons the notch may gape and cause the plant to dry out. Accordingly some years later, two experiments at Inchnacardoch (98 and 99.P.32) tested alternative methods of planting seedlings, since these suffer relatively heavier losses. In one method a T-notch which did not split the edge was cut in the turf, in another a dibble was used to make a hole in the turf ; the roots being threaded through. For that particular season there was no real difference in losses, and subsequently growth has been even. The experiments were not repeated and the side notch remained in widespread use on shallow turfs, in spite of the disadvantage that it may be necessary to walk through new plantations in a dry summer closing up gaping turfs.

The roots of seedlings are often not long enough to enable them to be spread on the surface under the turfs as is done with transplants. For this reason deeper planting of seedlings was tested in 1932-33 at a number of sites. At Kielder, seedlings of Norway spruce were planted throughout the winter and spring at two depths, normal and deep, the latter having only about an inch of shoot showing above the turf (20.P.32). Losses with deep planting by the third year averaged only thirteen per cent compared to thirty-eight per cent with normal depth. The majority of the losses were in the hot dry summer of 1933, the second season in the forest. Also within four years, the deeply planted seedlings led in growth by several inches, in spite of their initial disadvantage in height due to the deeper planting. (See Photo 4).

An identical experiment at Beddgelert (19.P.32) showed no such difference. This was attributed to the fact that the peat did not dry out so readily in this area, as it did at Kielder. At Lael (Ross) however a similar experiment showed a slight advantage in planting Sitka spruce more deeply than usual, leaving three inches of shoot showing, but none in burying all but the tip (6.P.32). The next year at Kielder (22.P.33) first year losses of Sitka spruce were fourteen and twenty-two per cent for deep and normal planting respectively, but the plants subsequently checked badly and thus no useful results were obtained from subsequent growth records.

Thus with seedlings, deeper planting is a worthwhile insurance against drought in places where the peat is friable. Seedlings were in fact little used with turf planting at that time, 1932, but this question of deep planting has arisen again with the increasing use of seedlings on ploughed peat.

The circular or Belgian spade has continued in use in England, particularly in the Kielder district. While theoretical objections may be raised to the doubling-up of a high proportion of the roots, which can take place, the fact remains that large areas of satisfactory plantation have been planted by this method, which does not allow holes to gape in dry weather, a factor of increasing importance as one goes south.

Spacing

No experiments have been laid down specifically on this subject on the poorer peats. A number of experiments on the better types form part of a major research scheme dating from 1935-6, which is in part responsible for a recent decision to increase standard spacings in normal practice. On the poorer peats it was from the start concluded that closer than normal spacing would be required. Many of the very small early experiments were planted at two or three feet spacing, in order to obtain quick suppression of vegetation. As the turf planting system developed spacing of drains and the size of turf provided controlled the spacing of plants. Drains at 13½ feet with three lines of turfs spaced at 4½′ x 4½′ were commonly employed in the work on poor peat ; while on *Molinia* and in general practice drains at 20 feet with four lines of turfs at 5′ x 5′ were normal. Many of the most satisfactory experiments were planted by these methods, and as a result since the advent of ploughing the custom in Research planting on poor ground has been to maintain the equivalent of 4½′ x 4½′, approximately one plant to twenty square feet. As, with ploughing, turf ridges generally lie at 5 feet apart, spacing in the lines is reduced to 4 feet.

Turf Nurseries and Pot-grown Plants

Two special systems for raising plants for use on turfs on poor peat were tried in the early days. (See Photo 23). The turf nursery system was developed by Sir John Stirling Maxwell at Corrour for planting in exposed positions and at high elevations. (Stirling Maxwell, 1936). The aim was to extend the planting limits on exposed peat, and the method was to transplant Sitka spruce seedlings into a peat nursery at the planting site ; the nursery consisted of rows of turfs placed close together alongside the ditch from which they had been cut. Slag was added and the plants left close set for two years so as to facilitate weeding and beating up. The turfs were then lifted and spaced out at the planting distance. Three small plantations were raised by this method on Forestry Commission areas at Inchnacardoch (21.P.26), Glenduror, Argyll (1.P.26), and Glenbranter, Argyll (1.P.26) ; and in the last forest a control plot of ordinary turf planting was added two years later (2.P.28). This area has grown as well as the section from the turf nursery. The relatively high cost of the turf nursery system precluded its general adoption.

The idea of acclimatizing plants to the conditions of the planting site also underlay a system for raising plants in pots. Spruce seedlings were potted in peat to which a little soil was added, and set in a nursery at the planting site. Two years later they were planted out with the ball of soil enclosing the roots ; unfortunately no phosphate was used and the plants checked (Inchnacardoch 30 and 31.P.27). Costs would certainly have been too high for more than limited application of this scheme.

PLOUGHING

The Early Stages

It was assumed by Anderson in 1925 that ploughing would become feasible on the peatlands at some future date with the development of suitable ploughs and caterpillar tractors. A horse drawn turf cutter was in fact designed and tried out on the Lon Mor in 1927 but the horse was not able to pull it on this intractable *Scirpus* peat. In the next year experiments were started on ploughing on the intermediate quality peats and, incidentally, on the less difficult heathland areas. The experimental plough used was drawn by three horses, but even so on the *Calluna-Scirpus* peat of Glenrigh it was found possible to turn only a few furrows, and even then several breakdowns occurred, (Glenrigh 14.P.28). Eye-witness accounts speak of the heavy and sometimes dangerous job of guiding the bucking plough. Although the cause is still debated, the fact remains that one of the horses succumbed within the next week ! Growth of Scots and contorta pines, and Sitka spruce on this ploughing has been little different from that of turfed controls.

This was to be the last attempt at ploughing peat for over ten years, but a method for small scale experimentation was devised, the results of which it was hoped would be valuable when tractor ploughing of the peat became possible. In this system of "mock ploughing" as it came to be called, furrows were turned over by hand to simulate single furrow or complete ploughing. The outstanding success of these mock ploughing experiments was a considerable factor in demonstrating the results which might be expected from ploughing to foresters used to hand methods ; and indeed in causing them to press for ploughs.

The Mock Ploughing Experiments

The first trial was in 1926 on the Lon Mor but was a costing, not a comparative trial. This was followed in 1928 by the comparative trial, already referred to under turfing methods, incorporating a grouped shallow turf system of ground preparation. (Inchnacardoch 49.P.28—Diagram II). Turf drains were cut for every line of trees instead of for every third or fourth line as in turfing practice. As shown in the diagram some turfs were shifted from the line to give each plant a compact group of four turfs on which to start growth. Fortunately, this experiment was one of the first to be given slag as a routine measure at planting. Sitka spruce made a most rapid start with this system, growing for the first five years at twice the rate of the turf planted plots. Then, the slag effect wearing off, all plots were in semi-check until top-dressed in 1939, when vigorous growth was renewed. This trial has been referred to as 'perhaps the most interesting of all the peat experiments' and its demonstration value is still high.

A chance to develop this technique of mock ploughing came in 1930 with the handing over of an area at Borgie to the Research Branch. By that year it had become apparent that much of the ground classed as plantable when inspected for acquisition in 1920, was in fact unplantable by methods then current. Normal planting operations virtually ceased in 1929, and trial plantations were made by the Research Branch (Borgie 1, 2A, 2B, P.30 ; 3.P.31 and 5.P.38). All of these, except 3.P.31, were planted on mock ploughing, in this case complete, the whole surface turf to a depth of six or eight inches being cut off and inverted by hand. (See Photo 5). The exception, 3.P.31, was planted on standard turfs. No strict comparisons can be given of height growth since the different methods were used in separate experiments, but it was possible to select areas originally charted as of the same vegetation type, and record height growth on them for rough comparison (Table 4). In 1942 almost the whole forest, including the majority of the experiments, was burnt. By then, however, the results were clear and gave an excellent starting point for further work.

Mean Heights attained after eleven years growth on Calluna-Scirpus-Molinia vegetation at Borgie

TABLE 4 — Feet

	Expt. 3.P.30 Planted on turfs	Expt. 2B.P.30 Complete mock ploughing
Mountain pine	3.2	5.3
Scots pine	3.9	6.2
Contorta pine	7.1	10.6
Sitka spruce (pure)	—	6.6
Sitka spruce in mixture with contorta pine	4.6	9.7

Note.—The ground types varied considerably in these plantations ; Scots pine ranged from two feet mean height on *Calluna* knolls to seven on *Molinia*.

Tough Peat Knolls

Another series of experiments which gave most valuable evidence on the value of complete mock ploughing was laid down in 1935 and 1936 to investigate "one of the most serious problems with which the Scottish Conservancies have to deal". A senior officers' meeting had so stigmatised the small morainic knolls, bearing *Calluna* or *Calluna-Scirpus* vegetation on thin tough peat, which are widespread in the north and west of Scotland.

DIAGRAM II. HEIGHT GROWTH OF SITKA SPRUCE WITH DIFFERENT METHODS OF TURFING IN INCHNACARDOCH EXPT.49.P.28.

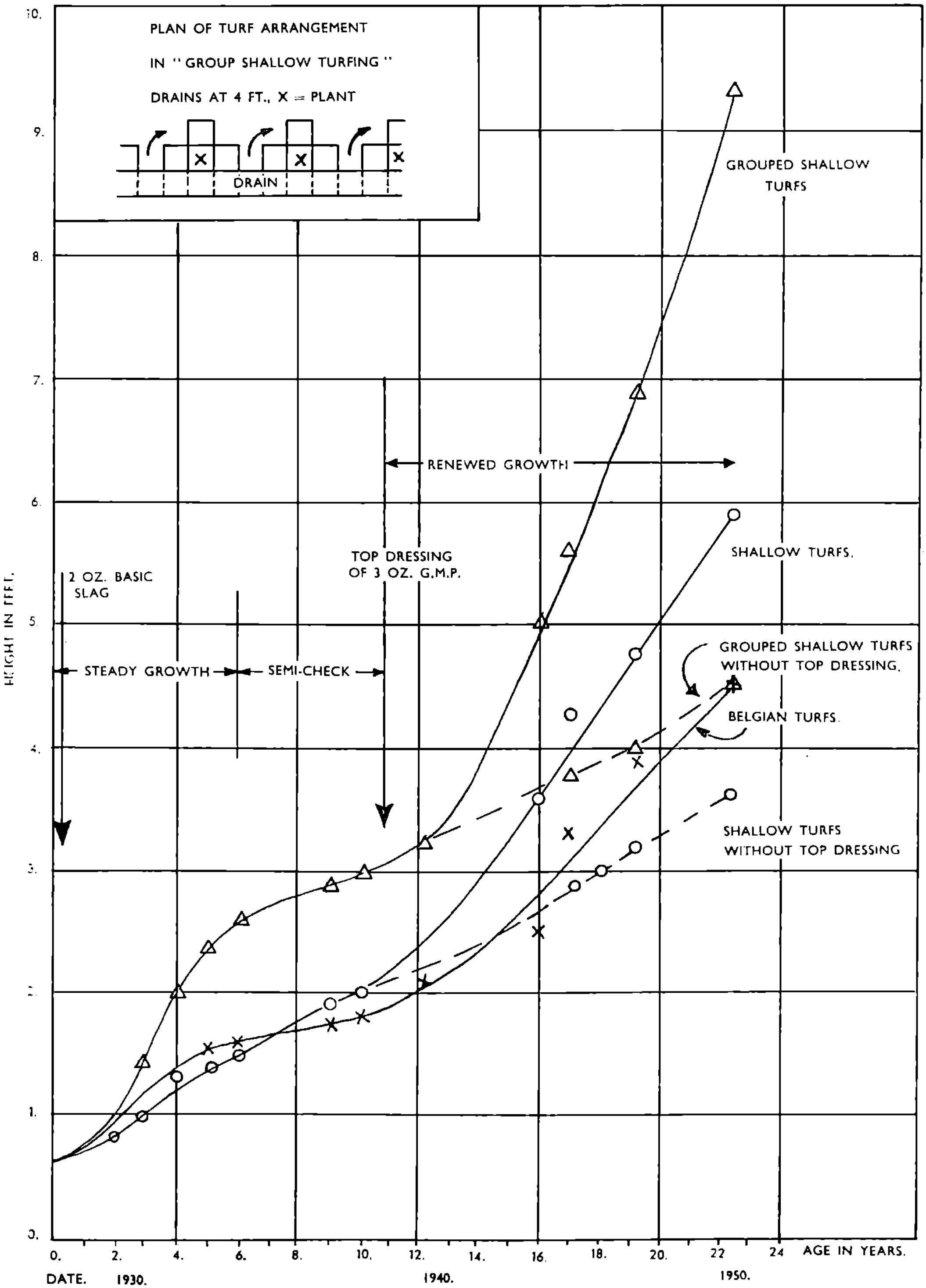
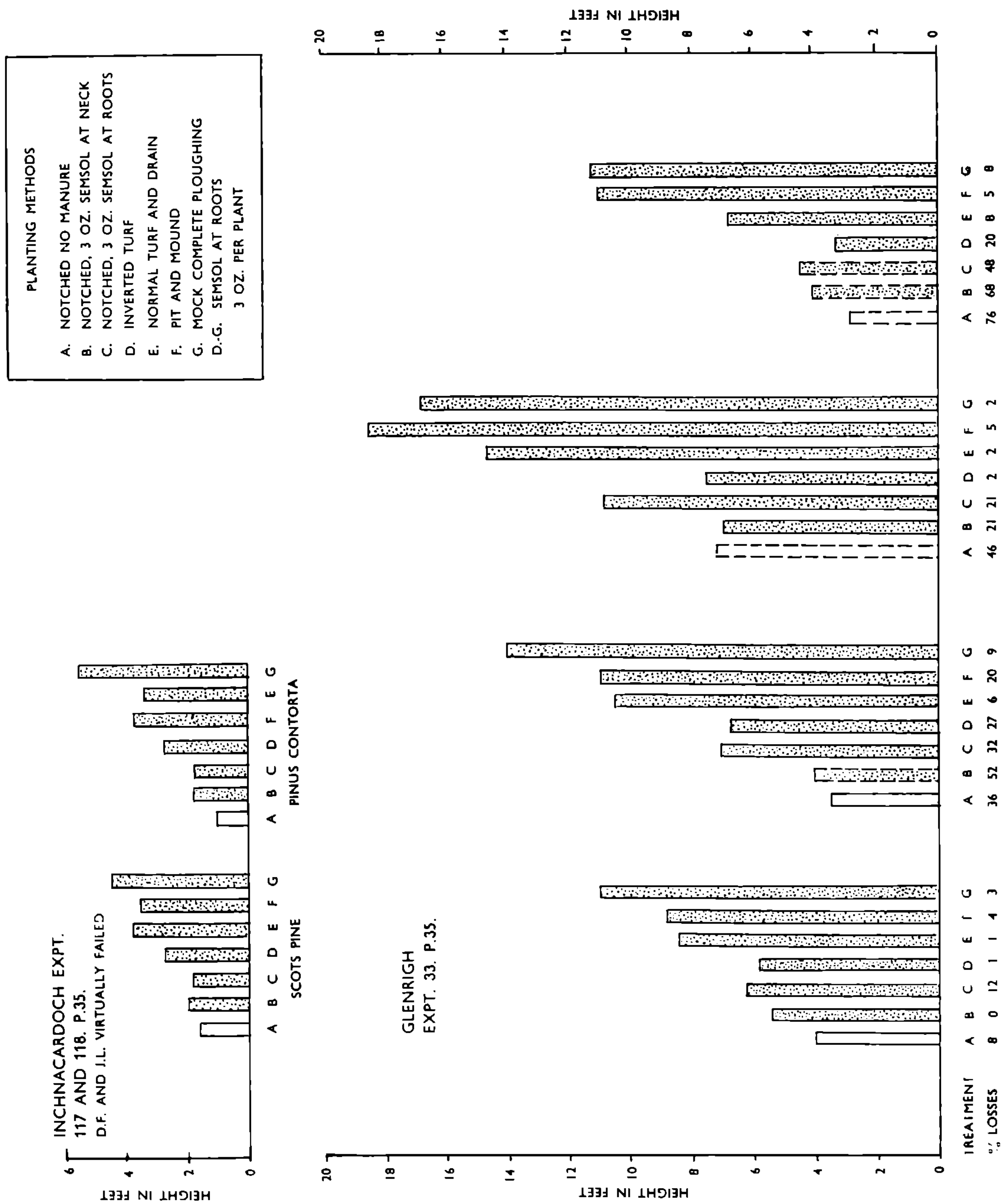


DIAGRAM III. HEIGHT GROWTH WITH VARIOUS METHODS OF GROUND PREPARATION ON TOUGH PEAT KNOLLS AT 12 YEARS FROM PLANTING.



Notes.—Broken lines indicate losses exceeding 40 per cent.
Stippled columns represent plots which received phosphate.
Pit and Mound=a simplification of Manteufel's method. (*See p. 18*)

Even in the better peat areas they caused small but often numerous blanks in otherwise complete plantations, as when planted in the normal way the trees generally checked.

The small size of the site, rarely more than fifty yards across, and the hummock shape, made the laying out of precise replicated experiments difficult. Accordingly, a standard layout was used on ten such knolls in six forests in different parts of the country. Seven ground preparation methods and four indicator species were employed, direct notching, turf planting, and mock ploughing all being incorporated. The results are in some cases striking but often conflicting, attributable for the most part to site factors and to a certain extent to vagaries of the climate in the year of planting, differences of planting stock, and other causes outside the control of the experimenter. The results and notes given (Diagram III) serve therefore to illustrate the difficulty of generalising even from a group of experiments, and also the complexities of a problem which had at first sight seemed straightforward—how to find the most satisfactory species and method of ground preparation for a particular site type.

Notes on Diagram III. The tough peat knoll experiments. Glenrigh Expt. 32.P.35 was an outstandingly successful experiment of the group. The diagram does not bring out one important fact, that while many Douglas fir are poor, possibly due to early suppression, others are well above any of the contorta pines in the intensive treatments.

Inchnacardoch Expt. 117 A. & B. P.35 and 118 P.36 occupy three adjacent knolls, the results from which have been averaged to produce the diagram. There has been severe damage by blackgame and roedeer.

Other similar experiments were:

Inchnacardoch 117C. P.35. Best species—Scots pine followed in order by Japanese larch, contorta pine and Douglas fir. Best preparatory methods were mock ploughing followed by "pit-and-mound", and turf and drain. Japanese larch and Douglas fir suffered heavy early losses where notched.

Leanachan (*Inverness*) *Expt.* 6.P.35 *and Bennan* (*Kirkcudbright*) 3.P.35 both suffered very heavy losses in the first year due to use of a proprietary phosphatic manure, in what proved to be a drought year. Replanted in 1936 the experiments showed very uniform growth ; that at Leanachan was burned in 1939 having previously suffered few losses, while at Bennan, Japanese larch and Douglas fir suffered considerable losses after replanting. This plantation now forms a very satisfactory mixture with all four species in the canopy, and Japanese larch and Douglas fir providing the tallest individuals. Differences between ground preparation were much less marked than at Glenrigh.

Leanachan Expt. 7.P.36 *and Bennan Expt.* 4.P.36. The 1935 experiments having failed at these two sites repetitions were laid down the next year but basic slag was employed in the place of Semsol. Again there was fairly even growth but at Bennan all species had heavier losses on turfs and on mock ploughing than where directly planted. Leanachan 7.P.36 was destroyed by fire in 1941. Bennan Expt. 4.P.36 has grown much more slowly than 3.P.35 and suffered heavy losses from frost and game.

Borgie Expt. 4.P.35. Contorta pine grew best, Scots pine was damaged by blackgame ; the other species checked. Best preparatory methods were standard turf and drain, and, most unusually, the inverted turf method. Losses on mock ploughing were very heavy. Destroyed by fire in 1942.

Blackcraig (*Perthshire*) *Expt.* 1.P.35. Japanese larch is the fastest growing species ; all the others are growing very slowly. Turf and drain, and mock ploughing are the best methods of ground preparation.

The results may be summarised as indicating that all the species proposed could be used in certain areas on knolls, and the safest choice is contorta pine. The present method is generally to use this species, sometimes in mixture with Sitka spruce. Japanese larch is also used in some areas in the north. The good growth of Douglas fir in two places has caused widespread interest, The knolls should be ploughed whenever possible, otherwise drained and turfed. Slag is beneficial to all species and is normally applied to Sitka spruce or Japanese larch, but is often not used for contorta pine.

Other features of interest illustrated, are that although Semsol, a proprietary manure found to be dangerous in dry years, was used on all the seven knolls planted in 1935, it led to disastrous losses only in two, at Leanachan and Bennan. The high losses with mock ploughing at Borgie might in part be due to Semsol, since this treatment is the one most likely to result in drying out the peat, while the notching and inverted turf methods would keep the Semsol wet and therefore innocuous. On the other hand, at Bennan (in 1936), slag was used and the ground prepared well in advance, yet turfing and mock ploughing gave higher losses just as they had in the previous years experiment.

In contrast, the Glenrigh and Inchnacardoch knolls, five out of the total of ten, showed the expected heavy losses with direct notching, particularly with Japanese larch and Douglas fir.

The account of these experiments must also include those on rather similar *Calluna-Scirpus* knolls at Kielder and in North Wales. At the

Mean Heights at eleven years from planting in Kielder Experiment 26.P.36.

TABLE 5 Feet

	Scots pine	Pinus contorta	Japanese larch	Sitka spruce	Mean all species
Turf and drain	4.7	5.3	3.9	3.4	4.3
Pit and mound	4.6	4.7	4.6	3.2	4.3
Replaced turf	3.6	3.6	2.1	2.3	2.9
Difference for significant at 5%	0.7	—	—	—	—

Note.—Plots were replicated only for Scots pine.

former forest the pit-and-mound method of planting and normal turf planting are compared with a method where the soil was stirred below the turf and this was then replaced. This last method is inferior to the others for all species (Table 5.).

On the same knoll a demonstration of the mock ploughing system was added a few years later. It has given most striking results, as the great superiority of ploughing over turf and drain has been achieved with one of the less sensitive species, namely contorta pine (Table 6).

Mean Heights at eight years from planting in Kielder Expt. 34.P.39.

TABLE 6 Feet

	Pinus contorta	Sitka spruce
Pit and mound	3.8	0.9
Turf and drain	4.1	1.7
Complete mock ploughing	6.6	3.2

Again in Wales somewhat similar experiments with contorta pine on *Calluna* knolls have shown pit-and-mound and normal turfs to be superior to the replaced turf (Clocaenog 11.P.33), but an anomalous result is that replaced inverted turfs proved better than normal turfs in an adjacent experiment (18.P.34). The normal turfs suffered the heavier first year losses and this result may be largely due to a drought in the first year, the effects of which would be avoided by the plants on inverted turfs, a system which usually gives too wet a planting spot.

The Tractor Ploughing Experiments

The first experimental tractor ploughing on peat was carried out at Borgie in January 1939 using a crawler tractor and a modified Ransome Unitrac Major plough. The furrows cut were much larger than those produced by agricultural ploughs, being from ten to twelve inches deep and twelve inches wide. The experiment (6.P.39) included mock ploughing, Belgian high turfs, shallow turfs, and slice turfs besides complete and single furrow ploughing. The last was spaced at five and fifteen feet ; with the wide spacing the plough ridge was cut up into turfs and distributed by hand as in the turf and drain system. The plough is in fact used in this case not for any cultivation effect but as a mechanical means of draining and to provide the minimum amount of turf.

This experiment which would by now have provided most interesting information, was unfortunately destroyed by the fire in 1942 ; at which time there was little difference in the growth in the various plots. Sitka spruce, contorta pine, and Japanese larch were of good appearance ; Norway spruce and Scots pine were somewhat poorer. Early losses had been heaviest with Scots pine and Japanese larch, and were generally rather heavier for all species on complete ploughing and on shallow turfs than on single furrow ploughing and high turfs. The experiment was completely replanted after the fire, but the fact that the ground preparation was by then three years old has prejudiced the results. A great growth of *Molinia* has sprung up, often almost smothering the plants. Sitka spruce is now the healthiest species, with Japanese larch next but not very promising, the pines are poor and Norway spruce completely checked. The ploughed plots, both complete and single furrow at five feet, are superior to all the turfing methods. The results are still of some interest as showing the persistence of the effects of ploughing, but are of little use for the intended straightforward comparison of methods of ground preparation.

In the summer of 1944 an area of *Scirpus* peat over moraine was ploughed at Achnashellach using a Solotrac plough with a D2 Caterpillar tractor for both single furrow and complete ploughing. Owing to shortage of labour it was not possible to plant up this area until 1946 when an experiment (26.P.46) was laid down using many species and mixtures and with the addition of turf planted and directly notched controls. Unfortunately almost all the species used suffered heavy losses in the severe winter of 1946-47, but, after beating up, the plots have made a good start on the ploughed ground. The tractor used for this experiment had been by no means satisfactory having rather narrow tracks. It was not possible to plough certain pieces of the more broken or steeper ground as had been planned, and the furrows were shallow, varying in depth from eight to ten inches. By the next year, 1946, it was felt that the equipment available, a wide tracked crawler tractor with a Cuthbertson draining plough, warranted an attack on the worst of the peat types, on the Lon Mor and "P.22" areas at Inchnacardoch. A considerable area was successfully ploughed with single furrows at five foot spacing, the furrows being as much as sixteen inches deep and serving as drains. A series of experiments was laid down, (Inchnacardoch 128-134, P.46) (See Photo 8) in which the many species used have for the most part made an excellent start despite severe damage by the 1947 frost ; Table 7 shows a comparison with growth in older turf planted experiments nearby :—

Growth at six years from planting in turf planted and ploughed experiments on the Lon Mor at Inchnacardoch

TABLE 7 Feet

	Contorta pine	Sitka spruce
49.P.28 Turf planted	—	1.5
52.P.28 Turf planted	2.3	1.0
49.P.28 Mock ploughed	—	2.6
128.P.46 Ploughed	4.2	2.3
44.P.28 Turf stripped, cultivated with field crops	—	3.5

The only growth equalling that on ploughing attained in earlier experiments, was with the grouped shallow turfs in Inchnacardoch 45.P.28 (Diagram II) and in an intensive cultivation experiment where planting followed field crops (Inchnacardoch 44.P.28). (See Photo 20). These experiments in 1946 were followed the next year by a large trial plantation (135.P.47) containing a number of species and mixtures ; here also early growth has been excellent, pines, spruces, hybrid larch and Douglas fir all having suffered low losses and made good early growth.

None of these plantations have controls of turf planting ; they mark a new stage in that ploughing was the accepted basal treatment. Having once proved that the land could be ploughed on a field scale the ploughing was utilised for trials of other points of technique.

Ploughing has in fact re-opened a number of problems on which research had been carried out previously, since a far better medium for early growth is now available. Thus all the recent experiments on other subjects such as species trials, direct sowing, and the use of one year seedlings for planting, have been established on ploughing as a matter of course ; and results have often been better than before solely on this account. One such series of experiments has a direct relationship to ploughing and is designed to determine the best position of planting on the high ridges of peat turned out by the draining plough. While results are awaited, the practice of the Research Branch is to plant in a step cut in the ridge so that the tree gets some protection in the early years from wind and drought, and so that the roots may reach the layer of decaying vegetation beneath the plough ridge. Early indications from these experiments are that planting on top of the ridge is not as satisfactory as planting on the side or in the cut step. (Kielder 49.P.48 ; Twiglees, Dumfries-shire 4.P.48 and Glentrool, Kircudbrightshire, 3.P.49 and 6.P.50).

The main problems raised by the rapid development of this new technique are of long term drainage and windfirmness. Due to fears for the stability of the crop, ploughing at five feet with the draining plough was practised only for a very short time. In the first ploughed experiments at Inchnacardoch rooting of each line of trees is likely to be confined for many years to the five foot width between drains.

On the better peat areas this difficulty was quickly met by using single furrow ploughing at wide spacing and spreading out turfs cut from the ridge. Ploughs were scarce and labour plentiful in this period and this method achieved the best use of the draining ploughs available. (See Photo 6).

As the supply of ploughs improved the current method arose of using two types of plough for any one area and practically divorcing drainage from turf provision.

Methods changed so rapidly for some years that only now is the pattern of current practice becoming clear. The methods are necessarily diverse but broadly speaking fall into the following classes :—

(*a*) On the more difficult peat types requiring intensive draining the Cuthbertson double mouldboard plough provides shallow furrows at ten feet and turf ridges at five feet. (See Photo 7.) Draining is by the single mouldboard plough which turns out one deep furrow after each one or two double mouldboard furrows, and also provides turf ridges for one row of trees. The spacing of the two types of furrows is adjusted so that adjacent rows of trees are 7 feet apart *across* the *deep* furrows which are to form the permanent drains, and 5 feet apart elsewhere.

Alternatively, the whole area may be ploughed with the double-mouldboard plough, working at a ten foot spacing to provide turf ridges at five feet apart. Then the single mouldboard plough can be used to cut deeper drains running *across* the first set of furrows.

(*b*) On the less difficult areas, Begg and other light ploughs may be used to provide planting turf as alternatives to the double mouldboard. Spacing of drains is generally wider and sometimes the only deep drains put in at planting are long deep contour drains at a spacing of two or more chains. Here it is intended that certain of the shallow furrows shall be converted to drains at a later stage.

(*c*) The cutting of single turfs from single mouldboard ploughing is employed on areas where the double mouldboard cannot operate owing to the steepness of the slope.

(*d*) Hand draining and turfing continues on the steepest and most rocky areas where ploughs still cannot operate. A certain amount of filling by hand of gaps and unploughed pieces is required on all but the most straightforward ploughed areas.

The lighter ploughs and the double mouldboard all provide turfs up to 8 inches high which can be planted without expensive paring down or step cutting such as is often used with the high turf cut by the draining plough. The shallow furrows left by these turfing ploughs will be allowed to fill with litter or peat unless as suggested above particular furrows are selected to supply a drain found to be necessary at a later stage in the development of the crop.

There remain however further problems in the preparation for planting of peat areas. All the ploughs now in use provide a long continuous strip of turf for planting. Early root investigations showed that in poor peat areas the turf was very fully exploited by the roots before they spread out into the untouched peat. If this pattern is followed by plants on ploughed ground it raises the alarming possibility that all the main roots of the plantation may be orientated in the line of ploughing. Investigation on this point is required in the earliest ploughed plantations. Some form of complete cultivation between drains might be employed to avert this ; the "complete mock ploughing" experiments give valuable evidence of the effectiveness of the method but attempts to mechanise the operation have met with little success. Only very small areas were effectively ploughed during trials with a 'Prairie Buster' at Minard and Inchnacardoch, and in fact it was the failure of these attempts which led to the acceptance of the double mouldboard type of plough.

DRAINING AND OTHER METHODS OF SITE MODIFICATION

Draining Intensity

This subject has been separated from that of planting somewhat arbitrarily, since on peat the two are always intimately connected, for any increase of the amount of turf provided per plant automatically increases the draining intensity. Thus in the experiment at Inchnacardoch already quoted (49.P.28—Diagram II, page 25) the single-furrow mock ploughing treatment had 'furrows' spaced at four feet instead of the thirteen feet in the plots with turfs and drains. It is for this reason that the two effects can only be completely dissociated experimentally, never in practice. There remains however the problem of the type of draining as even with the same amount of labour spent on an area, the depth and spacing may be varied considerably.

In order to find the absolute effect of drainage on peat, Dr. G. K. Fraser, of the Macaulay Institute, laid down a number of experiments, one of which lies on the Lon Mor. In 1928 a plot of one-tenth of an acre of poor basin peat was isolated by a deep drain cut down to the moraine or rock some two to six feet below the surface (Inchnacardoch 45.P.28). Posts were also driven down to the rock against which observation of any shrinkage might be made. After twenty years the vegetation type with dominant *Scirpus* remains unchanged except within a foot or so of the drain, while the shrinkage of an inch or two round the posts has been attributed to the feet of visitors rather than to any effect of drainage.

There is however ample evidence of the effect of drainage on the growth of trees on the Lon Mor, and also now in the earlier plantations an effect of the tree crop and drainage together can be seen in the elimination of the vegetation. Undoubtedly the biggest alteration in the peat is initiated by the closing of canopy and suppression and decay of the natural vegetation, which may be followed by shrinkage of the surface.

In 1928, again on the Lon Mor, blocks of contorta pine and Sitka spruce were established on two intensities of draining over quarter acre plots. Belgian turfs were employed cut from drains at twelve and eighteen feet (Inchnacardoch 52.P.28). (See Photo 9). In the more intensive treatment close spacing was supplemented by regular deepening, and this intensive treatment led to improved early growth of the contorta pine, which attained a mean height of four feet at ten years compared to three feet on the control area where the drains were merely maintained, not deepened. The spruce however checked in both areas. The contorta pine now provides the most striking forest block on the Lon Mor, having a top height of thirty-three feet at twenty-five years from planting, and has recently undergone its first thinning. Though no height difference associated with the draining difference is now visible, three pairs of volume plots have recently been established in order to record any volume differences which may result. An attempt is also being made to record peat shrinkage consequent on afforestation.

In addition recordings of the level of the water table in test wells in this experiment show that in general it lies in the intensively drained plots at twice the depth recorded in the controls. It seems likely that in course of time this must affect the production in the plots. There is a considerable fluctuation in the general level closely correlated with the immediate past rainfall.

The comparison of draining intensities is a difficult matter experimentally, since added to the normal difficulties of finding a suitable uniform site is the difficulty of preventing interaction of the treatments. Plots and surrounds have had to be larger than average and often it has only been possible to lay down a single series of plots at any one site. It is therefore on the number of experiments giving the same result that evidence must be built up, rather than on the results of any particular outstanding experiment. Two cases have already been noted of closer drain spacing improving growth of Sitka spruce ; at Kielder (17.P.30) and at Beddgelert (11.P.28). In contrast at Benmore (4.P.35) and at Glenrigh, Inchree area (10.P.28) spacing of drains at different widths led to no appreciable difference in growth with a variety of species, the reason probably being that the peat in these areas is shallow and over permeable moraine. In the second of these forests, at a different site, Corrychurrachan (Glenrigh 9.P.28) five species were planted on plots with drains spaced at three, seven and eleven yards. Mean heights increased with the draining intensity almost in every case, the greatest improvement being with Japanese larch and Sitka spruce. There are three more such trials at Clocaenog, with Japanese larch, contorta pine and Sitka spruce (8 and 9.P.33, and 19.P.35). In all cases there was a slight increase in mean height with increased intensity, but the most noticeable result was the more uniform growth with close spaced drains. This brings out the point that on many peat types differences in natural drainage are very local and that intensive draining may be necessary only in patches. Thus on complete mock ploughing, which makes no allowance for drains, the method adopted at Borgie was to wait two to three years after planting and then to drain any sections which appeared to require it.

Thus once the point has been established that draining can actually increase growth, there is little point in seeking an optimum spacing. The experiments demonstrate the importance, in field scale work, of expending the available labour on the sections of the area which most require it, and this judgment of the natural drainage and vegetation types must be one of the main tasks of the foresters in charge of preparation of peat for planting, whether by ploughing or other methods.

Draining Depth

There remains the question of drain depth. A series of experiments was laid down in Scotland in 1935 on both heath and peat sites in which depth and spacing were varied. The types of drain used were shallow mock plough furrows about six inches deep, standard turf drains, one foot deep, and special drains three feet deep. Spacings were approximately three and nine yards, but since the plough furrows did not provide enough turf for planting when widely spaced, this comparison was omitted. Results for the two experiments of the series which lie on peat are shown in Diagram IV.

The site at Ae was dominated by *Molinia* with *Juncus squarrosus*, *Calluna*, *Erica* and *Eriophorum* on about eight inches of peat overlying boulder clay. Though the plots are not replicated, the diagrams shows that for all three species, depth of draining is consistently more important than spacing. The deep drains have doubled the height growth of Japanese larch.

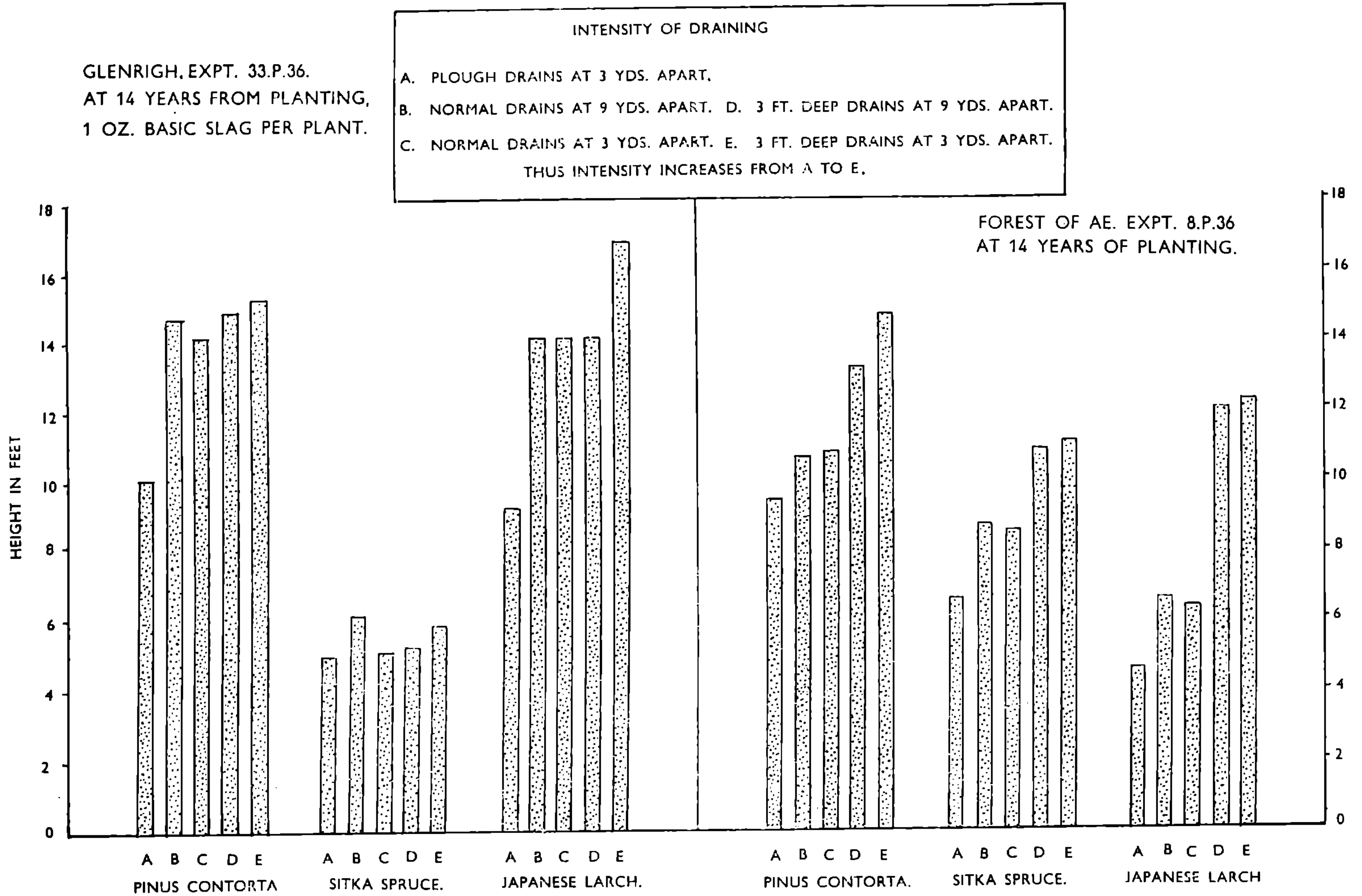
At Glenrigh, Sitka spruce has grown slowly in all treatments due to the poor *Scirpus-calluna* vegetation type. The other species have grown poorly on the mock plough furrows but otherwise show only slight differences except that Japanese larch has grown very well in the most intensively drained plots.

This work has recently been followed up by intensively draining pole stage spruce plantations in the Borders, in order to investigate the effects on growth and stability (Newcastleton 12.P.49 and 13.P.51 ; and Kielder 54.P.49).

Burning and Grazing

The first experiment at Inchnacardoch (1.P.21) attempted to compare the growth of Norway spruce on two plots, one of which had been burnt over in the previous year. Unfortunately the ground vegetation had not been charted before burning

DIAGRAM IV. HEIGHT GROWTH WITH VARIOUS INTENSITIES OF DRAINING.



Notes.—(a) The plough drains indicated by "A" are shallower than those indicated by "B" or "C".

(b) Both the Glenrigh and the Forest of Ae experiments received one ounce of basic slag per plant.

and at a later date doubts arose as to whether the areas had in fact ever been comparable.

The only attempt since that date to measure the effect of burning before planting is in a combined grazing and burning experiment at Newcastleton (2.P.36). The site is an area of poor *Molinia-Scirpus* at 800 feet elevation which at that time would normally have been considered unplantable. The majority of the experimental area was left open to grazing by sheep on the adjoining land from 1936 to 1942. Part of this grazed land was drained, and part burned every second year, in 1936, 1938 and 1940. Six control plots were enclosed against the sheep and of these two were drained, a third was planted up with Japanese larch and a fourth with Sitka spruce. The vegetation of the whole area was charted. In 1942-1943 the experiment as a whole was drained, turfed and planted up, after recharting of the vegetation. In addition to the general vegetation charts, detailed records of small quadrats were made in 1936. Recharting was carried out in 1942. In general remarkably little change in the vegetation was observed in most of the plots, but in those which were burnt *Calluna* had largely disappeared and *Sphagnum* had become more abundant, while in the plots planted in 1936 *Deschampsia flexuosa*, which was not recorded in 1936, had become locally abundant.

Now ten years after the planting the whole area is dominated by *Calluna*, but the burned plots are still distinct in that the *Calluna* is shorter. Growth on the area has been poor, the 1943 plantings being slower than the 1936. Japanese larch has failed twice in the 1943 section, through a combination of frost, game damage and poor site conditions, while Sitka spruce is very slow. Differences are not significant, but it appears that the repeated burning may have led to even slower growth. The area is now due for recharting and it is hoped later to publish a record of the ecological observations, possibly at the end of the establishment period.

Flushing

The marked change in natural vegetation and much faster tree growth on areas where drainage water is moving freely through the peat, led to the laying down of three trials to determine whether it was possible to produce the flush condition artificially. The first trial was on the "P.22" area (Inchnacardoch 104.P.33) where a burn was diverted to flush an area of poor peat dominated by *Scirpus*. Uniform flushing was not achieved and there has been no benefit to the contorta pine, Japanese larch and Sitka spruce, planted two years later in 1935. Two similar trials were started in the latter year at the Forest of Ae (Dumfries-shire) on areas dominated by *Calluna-Molinia* and by *Scirpus*. In the first the flushing was apparently only successful for a short time and then only on a small part of the area. In the second however, the ground vegetation had been completely changed by 1948 and was recharted. The central flushed area is now occupied by two communities dominated by *Deschampsia flexuosa/Holcus lanatus* and *Juncus communis*. The water which has produced this change was tested for conductivity in 1935 by the East of Scotland Agricultural College and gave a figure of 40 gemmhos, indicating a very low mineral content. The flushing was continued for longer than was originally intended and, despite this low mineral content, has led to a change from poor *Scirpus* to a rich flush type vegetation. It is quite clear from the interim reports that the change has proceeded slowly down the plot from the water source. The two flanking control areas are now dominated partly by *Calluna-Vaccinium* and partly by *Molinia-Vaccinium*. This change is largely the result of enclosure, since, while the experiment has been in progress, the whole area surrounding has been changed from a sheep walk to a young plantation. Both areas were planted with Sitka spruce in 1948 and the earliest growth records show faster growth on the flushed section, though owing to the increased luxuriance of the vegetation, losses were also higher.

Cultivation

Intensive ground preparation was carried out in two early experiments at Achnashellach (8 and 10.P.28) on areas dominated by *Scirpus-Calluna* on shallow peat overlying deep moraine. The method was to open trenches up and down the area and to form beds—"lazy beds"—between them with the excavated moraine and peat. Growth has been superior to that in adjacent turf planted plots for almost all the species used, which included Scots, contorta and mountain pines, Japanese and hybrid larch and Sitka spruce. The unit was a single line of each species so that comparative growth rates are of little interest owing to nursing and competition effects. Hybrid larch is however outstanding, reaching eighteen feet at sixteen years compared to the sixteen feet of Japanese and twelve feet of Scots and contorta pines.

A similar small scale trial was laid out on the Lon Mor in the same year (Inchnacardoch 60.P.28); here planting was carried out on the morainic core of a knoll, on moraine spread over the adjacent basin peat and on the piled peat taken from the knoll. The latter proved the poorest substratum, the spread moraine best ; contorta pine has done better than Scots pine (Table 8).

Heights at 19 years from planting in Inchnacardoch Experiment 60.P.28

TABLE 8 Feet

Planted :	On core of knoll	On spread moraine	On piled surface peat
Scots pine	6.7	7.3	6.8
Contorta pine	9.8	12.2	6.4
Sitka spruce	1.5	1.1	Failed

Note.—Single plots of 16 plants were used.

These intensive cultivation experiments serve to demonstrate that shallow peats with underlying moraine have great possibilities for afforestation, being capable of supporting far better growth than the vegetation and peat types would suggest. It is not necessary to go to any such lengths in ground preparation as did these experiments, carried out at a time when the outlook for plantations on these peat types was to say the least not rosy : tractor ploughing is in fact the solution.

On the poor deep peat of the Lon Mor it was, at this same period, desirable to show that trees could be grown even if only by very intensive methods. Accordingly in 1928 a chain square plot of poor *Scirpus* was chosen for a trial of intensive cultivation combined with the raising of field crops prior to planting (Inchnacardoch 44.P.28). First the area was isolated down to the rock by a deep drain, the depth varying from a few inches to six feet. The surface peat was then stripped to a depth of eight inches and basic slag applied at a rate of five hundredweight to the acre. In 1929 potatoes and oats were raised followed by a second crop of potatoes in 1930. The area was finally planted up with Japanese larch and Sitka spruce in 1933. Growth started very well, the spruce reaching three feet and the larch four feet in five years. For comparison it may be noted that the Sitka spruce on the grouped shallow turfs in the most successful early planting of this species reached three feet only after ten growing seasons. (See also Table 7, page 29). Later growth of the Japanese larch has been poor except on a small section of the area where it has reached twenty-six feet, while Sitka spruce has reached twenty-five feet with slag and eighteen feet in the control after eighteen years. (Photo 20).

Chapter 6

THE SPECIES MOST COMMONLY EMPLOYED IN THE PEAT EXPERIMENTS

The vast majority of the experimental plantations on peat contain one or more of seven conifers, Scots, mountain and contorta pine, Japanese and hybrid larch, and Norway and Sitka spruce. At the present time these are the only well tried and reliable species for use both in afforestation of difficult ground and also in comparative trials of methods. For a short period in the early years other species such as European larch and birch were regularly employed, while contorta pine was rarely seen. Gradually, however, it became apparent that only the seven species listed could be relied upon to grow on the poorer peat, even if slowly, once certain minimum requirements were fulfilled, and thus serve as indicators of the effects of treatment by different methods. As their use in experiments became the rule so attention was focussed more and more on the reactions of these species to treatment, their comparative growth and behaviour, their variation in form, particularly as related to seed origin, and also the best type of planting stock and methods for producing it in quantity. Thus it is that there is now (1953) a wide difference in the knowledge of the behaviour of these species compared to that of the fifty other species which have been used in the experimental plantations on peat. For these seven species alone is there sufficient evidence to draw general conclusions and to set out in detail the silvicultural characters which determine their use and the technique to be employed for each in afforestation.

The use of mixtures and nurse crops on peat has until recently been almost confined to planting Sitka spruce with pine or larch. The whole subject of mixing of species is thus most conveniently dealt with under the section on Sitka spruce.

MOUNTAIN PINE

Pinus mugo Turra (=*P. montana* Mill.)

Mountain pine is not normally regarded in this country as a timber tree, but in the early years of the Forestry Commission it was used fairly extensively in experimental plantings on the poorer peat since it was found to grow even in severe conditions of exposure, and in the absence of the intensive ground preparation and manuring, which were later discovered to be essential for many other species. Its use has been confined almost entirely to extreme conditions of every kind since there is little point in employing this species on areas considered plantable by normal standards.

The most important use of this species to which the experiments point is on the windward edge of shelterbelts where its low dense canopy prevents the wind sweeping in under the canopy of the plantation. A most striking experimental belt is situated on the Lon Mor at Inchnacardoch (18.P.26) where two lines of this species are followed in turn by two of Scots pine and two of contorta pine. The whole now form a solid windbreak twenty feet high, shaped so as to project the wind upward over the plantation. (See Photos 8 and 25).

Comparative growth. Table 9 below illustrates the growth of the three common pines in various experiments.

These figures have been chosen as representative of about twenty experiments each incorporating a number of treatments, and illustrate several points in the behaviour of mountain pine. Its relative insensitivity to conditions is shown in that the total range of heights in the table for mountain pine is four to fourteen feet while for contorta pine it is four to twenty feet.

To consider the first experiment in the table, almost all species failed when directly planted in the earliest experiment at Achnashellach (1.P.21), part of this area was then turf planted in 1928 (6.P.28). In extreme conditions of exposure and altitude, and on poor deep peat, mountain pine was the tallest species in a very poor plantation in 1942, at which time the experiment was burnt.

In rather less extreme conditions as represented by the next two experiments, mountain pine may compare well with Scots pine but both generally fall behind contorta pine in rate of growth. This is because, of the three, Scots pine suffers most severely from exposure and its growth relative to that of contorta and mountain pines is poorer than normal. Finally the last experiments demonstrate the behaviour on peat land which was considered at the time as marginal for normal forest planting. Here the early growth rate of both Scots and contorta pines is greater than that of mountain pine. This supports the view

TABLE 9

Growth of Mountain, Scots, and Contorta pines in various experiments.

Vegetation and Peat Type	Experiment	Age	Heights in feet			Notes
			Mountain pine	Scots pine	Contorta pine	
Blanket bog slopes :—						
Scirpus-Eriophorum	Achnashellach 6.P.28 (burnt 1942)	14	4.2	2.5	3.8	Turf planted without phosphate at 900 ft.
Scirpus-Calluna	Borgie 2.P.30 (burnt 1942)	12	5	6	10½	Mock ploughing with slag.
Thin peat over moraine :—						
Scirpus-Calluna knoll	Inchnacardoch 18.P.26	20	6 7	6 8½	9½ 13½	Control } Lon Mor shelter belt Slag, 1930 }
Scirpus-Calluna-Molinia knoll	Benmore 3.P.33	20	14	16	20	Turf planted with slag
Calluna-Scirpus steep slope	Inchnacardoch 96.P.32	20	8	12	13	Direct planting with phosphate.
Calluna-Scirpus knoll	Bennan 2.P.32	20	7½ 8½	14 17	17½ 20½	Control 2 oz. slag.
Deep basin peat :—						
Molinia-Scirpus-Calluna	Beddgelert 3.P.27	20	8	12	18	Turf planted without phosphate at 1,000 ft.

that only in exceptional circumstances is it necessary to employ mountain pine for planting on peat. Thus in trial plantations at Inchnacardoch (75.P.29), Borgie (3.P.30), and Queen's Forest (1.P.30) where this species was employed, there is evidence in each case that contorta pine would grow faster than mountain pine and the former would now be employed.

Provenance. Two varieties at least of mountain pine may be readily distinguished. Most of the older peat plantations consist of an upright form, in some cases the seed being supplied originally as var. *rostrata* Hoopes (=var. *uncinata* Ramond). This form is distinguished by its generally upright habit and single stem. In complete contrast prostrate forms exist, the seed of which was supplied as 'var. *pumilio*' which might include both var. *pumilio* (Haenke) Zenari, or var. *mughus* (Scopoli) Zenari. There is no recognisable plantation of the latter forms in the peat experiments at the present time, but progeny from prostrate plantations at Clashindarroch Forest, Aberdeenshire, have recently been used for the first row of shelter strips around trial plantations. The parent stand shows a creeping habit with multiple leaders and at twenty years from planting forms a thicket only four feet high. The addition of this row in front of upright forms will it is hoped aid the production of a roof-like slope in shelter belts.

For many years it will not be possible to say if the existing 'upright' plantations are of true var. *rostrata*, a tree of sixty to eighty feet, or var. *rotundata* (Link.) Hoopes, a tree of about thirty feet. (Dallimore and Jackson, 1948). This last variety is of intermediate habit between var. *pumilio* and var. *rostrata*, so that the trees in certain of the plantations which, though generally upright, have several stems, may well be of this form.

It is apparent that to range the three forms in ascending order in shelterbelts would be ideal. At the present time virtually every trial plantation is being surrounded by wind breaks incorporating two forms, one prostrate and one which may turn out to be either intermediate or upright.

Reaction to treatments. The table illustrates for two experiments the relative insensitiveness of the species to application of phosphate; similar results are illustrated in Diagram X (page 75). Again, in an experiment at Inchnacardoch (77.P.29), from one to three ounces of slag were applied without any increased response, whereas the growth of Sitka spruce planted in mixture improved considerably with the increased dosage. Even so the response to phosphate may on occasion be large, as in one experiment at Achnashellach (Diagram XII, page 78) when the height growth was doubled on a very poor site; that of Scots pine was trebled.

Another experiment at Achnashellach shows that mountain pine may also respond well to improved planting methods ; growth was doubled by mound planting instead of direct notching (10.P.28) but in a second experiment in the same forest there was no response by mountain pine to drainage (8.P.28), though larches and, to a lesser extent, other pines did respond.

Use in mixture. Mountain pine has been used successfully as a nurse for Sitka spruce (Achnashellach 7.P.28, Inchnacardoch 75.P.29) and also for Scots pine (Borgie 2.P.30). The effects are compared with those of other species in the sections dealing with the nursed species.

SCOTS PINE

Pinus sylvestris L.

Scots pine, as the only native conifer available for use in afforestation, has naturally been planted widely in the experiments on peat. For a number of reasons, however, it has not been used as extensively in experiments as several of the exotic species. Firstly, as a native tree it was, from the start, used in the afforestation of peat without the need for extensive testing such as is required for exotic species ; secondly it is a relatively unexacting species and will grow slowly on peat in all but extremely bad conditions ; and lastly it has the disadvantage that on nearly every type of peat another species can be found which will make faster early growth and thus give earlier indications of the effectiveness of experimental treatment. Thus, on poor *Calluna-Scirpus* peat, contorta pine, on thin peat, larches, and, on good *Molinia* peat, spruces, all grow faster and have been used more extensively as indicator species. Severe damage from blackgame about 1930 also limited its use in experiments for some ten years. There has been evidence in recent years that another blackgame peak may be approaching, damage to Scots pine being severe at places as widely separated as Inchnacardoch, Inverness-shire and Glentrool, Kirkcudbrightshire.

The results of trials may be summed up briefly. Scots pine will grow on all types of peat provided that the exposure is not too severe and that the peat is not waterlogged; it is also susceptible to phosphate deficiency. If these conditions are not satisfied plantations may die out after a few years, as occurred in the first experiment at Achnashellach (1.P.21). The hardness, in other respects, of this species is demonstrated in other experiments where after many years of semi-check, plantations are now established and growing steadily on such areas as the Lon Mor and "P.22" at Inchnacardoch (19.P.26 and 2.P.22).

TABLE 10 **Comparison of Height Growth of Scots and Contorta pines in various experiments.** Feet

Vegetation and Peat Type	Experiment	Age	Quality Class S.P.	Dominant Heights		Notes
				S.P.	P.C.	
Deep basin peat:— *Scirpus*	Inchnacardoch 19.P.26 S.P. } 47.P.28 P.C. } 52.P.28 P.C. }	25	— III	7 23	17½ 31	No phosphate Slagged.
Slope peat :— *Scirpus*	Inchnacardoch 86.P.30 and 93.P.31	20	IV to III	13 to 20	15½ to 19	Poorest growth on knolls. Best growth on slopes. } Species mixed in groups
Calluna-Eriophorum Vaccinium	Kielder 8.P.28	25	III-IV	21	25	No phosphate.
Thin peat over moraine :— *Scirpus*	Achnashellach 7.P.28	25	IV	19	21	Heavy phosphate dressing.
Calluna-Scirpus knoll	Glenrigh 32.P.35	12	— —	8½ 10½	11 14½	Turf planted. Complete mock ploughing.

All experiments were turf planted and received 2-3 ozs. phosphate per plant unless stated otherwise.

The place of the species in peat afforestation is mainly on the drier peats and knolls, on sites in fact which may approach the typical heath formation except that they are of small extent, and owe their relative dryness to topography rather than to low rainfall.

Comparative growth. Examples have already been given of the growth rate of Scots pine on various types of peat and its growth rate compared to other species. (See Photos 13 and 14). Table 10 above gives the mean heights of plots or blocks of Scots pine on various ground types. The height of contorta pine from neighbouring comparable areas is also given.

These results may be summarised by saying that the growth of Scots pine even on the better types of peat only approximates at the present time to Quality Class III of the Forestry Commission Yield Tables (1953) and while the growth of some plots on deep peat reaches Quality Class IV there are many others where growth falls far below this. Few of these plantations, however, have had the benefit of current technique which would at least have reduced the initial period of slow growth.

For further comparisons of growth rates on different vegetation types see Table 9 (p. 35) and Table 12 (p. 39) and Diagrams X-XII (pages 75-78).

Reaction to treatment. Scots pine responds well to treatment at establishment on all the poorer types of peat. Evidence is given for the response to ground preparation and planting method in Diagrams I (page 20) and III (page 32), and to phosphatic manuring in Diagrams X-XII. In many cases growth over the first twenty years has been more than doubled by improved technique. (See Photos 22 and 25).

Over a period of years, about 1930, Scots pine were attacked very severely by blackgame and several experiments were caged to investigate the extent to which this damage was retarding growth. Diagram I (page 20) illustrates one experiment in which the mean height of the plantation was reduced by three feet, all the damage being suffered between planting in 1928 and about 1933 when the numbers of birds greatly decreased. So severe were attacks at Inchnacardoch during this period that planting of Scots pine was abandoned on the Lon Mor for almost ten years.

Provenance. The majority of the large number of comparative trials carried out on the provenance of Scots pine have been planted on the eastern heaths. A few such trials are on peat, and bear out the general conclusion that no imported seed has given faster growing plantations than those raised from the native Scottish seed, while in many cases plots from seed from the limits of the range of Scots pine have failed. On tough peat knolls in the Lon Mor, plots from seed collected at Pitgaveny and Darnaway in Moray, Loch Maree in Ross-shire and Glen Moriston in Inverness-shire are growing well, having attained about fifteen feet high after twenty years, whereas plots of Scandinavian, French, Baltic and Finnish origin are almost invariably poor (Inchnacardoch 84.P.29). Several of the same foreign lots are poor or have failed entirely in the high elevation experiments at Inchnacardoch (25.P.29) and South Laggan (8.P.28), while plots of Scottish origin are over twenty feet high in the first trial and growing steadily, though not so tall, in the second. Clearly it is most unwise to use seed of foreign origin for this species.

Age and type of plant. 2 plus 1 transplants have been the normal stock for planting but a few trials of seedlings have been made on peat. Thus in a trial of species on a field scale at Glenrigh (5.P.27) half of each block was planted with two-year seedlings. These have done well, losses being low for both seedlings and transplants. On the better ground, dominated by *Calluna-Molinia*, seedlings have grown as well as transplants ; but on a poorer type, *Scirpus-Calluna*, they fell rather behind in the early years.

In 1946 one year old Scots pine seedlings two to three inches high were planted on the Lon Mor on single furrow Cuthbertson ploughing (Inchnacardoch 130.P.46). Losses were very low and early growth has been good (Table 11).

This result is most encouraging ; the difference in height between transplants and seedlings in 1952 was half due to the initial difference at planting, so that the transplants have made only fifteen per cent faster growth than the far cheaper seedlings. The first year seedling stock in these trials came from Inchnacardoch heathland nursery.

Scots pine in mixture. The number of experiments in which Scots pine has formed canopy in mixture with other species is few. Many others are not yet old enough for any interactions between the species to be apparent. For experiments where it is used in mixture as a nurse its effects are compared with those of other nurses in the section dealing with the nursed species.

There remain certain experiments where the intention was to raise a mixed crop, or where Scots pine was itself to be nursed. In two large trial plantations at Inchnacardoch (86.P.30 and 93.P.31) areas of relatively drier *Calluna-Scirpus* peat on knolls and slopes were planted with Andersson groups (See page 82) of nine contorta pine surrounding four Scots pine ; where exposure was more severe mountain pine replaced the contorta. Results are given in Table 10 above ; there are no controls of pure Scots for comparison but both species are growing well, the Scots and contorta both being up to twenty feet high at twenty years of age, with mountain pine falling behind. Contorta and Scots pines are also planted in mixture at Queen's Forest (1-9.P.30) at an altitude of 1,600 feet. The growth of the Scots is better than where planted pure elsewhere in the plantation, and it has been suggested that this mixture should be used in marginal sites rather than pure contorta pine, the latter being a relatively untried species. In recent years this mixture, in the proportions of three contorta pine to one Scots pine, has been incorporated in a number of trial plantations and pilot plots.

CONTORTA PINE

Pinus contorta Doug. and variety *latifolia* S. Watson (=var. *murrayana* Engel.)

This species is a comparatively late introduction into Great Britain, having been first planted about 1855 and even then it was for many years rarely used in plantations. Very little was known of its capabilities when the Forestry Commission was set up, and its use on any scale in peat experiments dates only from 1928. Previously the species had failed badly where directly planted at Achnashellach (1.P.21). The early growth and appearance of the 1928 plantings were so promising as to make contorta pine within a very short time one of the main indicator species for experiments on all the areas of poor peat.

The position to-day is that this species is recognised as one that will grow faster than any other in marginal conditions of every type. In exceptional cases mountain pine has grown better, but generally the conditions in such experiments have been such

Heights and losses of Scots pine six years from planting in Inchnacardoch Experiment 130.P.46.

TABLE 11

	1+0 seedlings Initial Height 2—3 in.		2+1 transplants Initial Height 4—6 in.	
	Losses	Height	Losses	Height
No manure	5%	Under 1 ft. checked	Nil	Under 1 ft. checked
1 oz. phosphate	Nil	2.3 ft.	Nil	2.9 ft.

Comparison of growth of Scots pine according to Forestry Commission Yield Tables (1952) with growth of Contorta pine in Inchnacardoch Experiment 52.P.28.

TABLE 12

	Main Crop					Thinnings		Total crop Volume
	Age	Top Ht.	Stems per acre	Mean Girth	Vol/acre	No.	Vol/acre	
Scots pine, Q.C.II.	25	32 ft.	1,030	13 in.	940 H.ft.	410	240 H.ft.	1,200 H.ft.
Contorta pine	25	31 ft.	980	13 in.	1,030 H.ft.	130	100 H.ft.	1,130 H.ft.

Notes. Figures for contorta pine are based on measurement of two 1/20 acre areas in intensively drained plots.
Volumes are in Hoppus measure over bark.
Q.C.=Quality Class.

that no tree crop at all has been produced, as in the early experiments at Achnashellach (1.P.21 and 6.P.28). Contorta pine is, however, the outstanding species in the high elevation experiments and has generally grown better than any other species in all the other experimental areas on land which would normally be considered as unplantable. It must be recognised, however, that this is a very variable species and that the correct variety must be employed. In conditions of exposure this is the heavier branched coastal form, while elsewhere the inland form with a narrower crown is more satisfactory. Though the contorta has occasionally suffered windthrow in experiments on peat, it cannot be said yet that it is relatively less windfirm than other species, since on the sites concerned few other crops have attained a height sufficient to involve the risk of windthrow.

For the moment it may be said that contorta pine has been used to a very limited extent in Forestry Commission plantations, other than those of the Research Branch, but there has since the war been a great increase in its use under conditions of exposure and elevation or on poor *Scirpus* peats, which are considered unsuitable for Scots pine.

Comparative growth. Tables 9 and 10 (pages 35 and 37) show the early growth of Scots and contorta pines in a number of experiments. On peat land in moderate exposure and at moderate elevations it is clear that the early growth rate of contorta pine is rather faster than that of Scots pine. For the first twenty years this faster growth rate leads to an average of twenty per cent greater height growth. Very shortly it will be possible to commence comparison of volume production and it is probable that a similar relationship will emerge.

At present none of the Scots pine plantations on poor peat have been thinned, while volume estimation has just commenced in certain contorta pine stands at their first thinning. Thus in an acre block on the Lon Mor (Inchnacardoch 52.P.28, Photo 9) at twenty-five years the stand is very comparable with Quality Class II Scots pine (as defined by the Revised Forestry Commission Yield Tables (Hummel and Christie, 1953)); this must be considered most satisfactory. (Table 12).

As regards timber, pre-thinnings from this experiment were tested by the Forest Products Research Laboratory at Princes Risborough and found to be eight per cent less dense and twelve per cent less strong than the average pre-thinning of Scots or Corsican pines.

In comparison with other species, growth falls behind that of the Japanese and hybrid larches on the thin *Scirpus* peats overlying moraine, where phosphate is applied (Table 13, page 41), while on *Molinia* peat spruces also grow faster. In many intermediate sites, however, growth of contorta pine may keep level with both larches and spruces for at least twenty years and some interesting mixtures have been formed in this way.

Reaction to treatment. As with Scots pine, improvement in growth of more than one hundred per cent has been obtained on poorer peat types by draining, improved planting methods and manuring (See Diagrams I (page 20), III (page 26), X (page 75) and XII (page 78). Nevertheless contorta and Scots pines have been regarded as relatively insensitive since they grow and do not die or linger on indefinitely in a state of check, as did larches and spruces in so many early experiments. The differences due to treatment are seen rather in the increased growth rate and will soon be reflected in the volume of produce.

Provenance. As with Scots pine, the majority of the work on this subject has been carried out on the heathlands. There are, however, experiments on peat at Achnashellach (24.P.37) and Clocaenog (16.P.34) each containing plots raised from seed from different parts of Western North America, and in addition the contorta pine used in other experiments show obvious differences in form associated with different seed origins.

The extreme types are easily defined and recognised, but as they are linked by every grade of intermediate type, recognition of the latter when there are no adjacent plots of the extremes for comparison is not easy.

The 'coastal' form, beach or shore pine, has a stouter stem with longer, coarser and more ascending branches than the 'inland' form in which the branches are short and almost horizontal. The needles of the coastal form are generally shorter, a darker green, and are retained longer, thus accounting for one of the most striking differences, the much denser crown of this tree, which in the early years is rather similar in habit to mountain pine. In both the provenance experiments, the plots of the coastal form are growing faster than those of the inland. It is of interest that the poorest lot at Achnashellach, from Oregon, is from trees at 3,500-5,000 feet elevation while the majority of the other lots are from stands below 2,000 feet.

The inland form, lodgepole pine or var. *latifolia*, which commercially is a much more desirable tree, has provided excellent stands, including the acre block on the Lon Mor for which volume figures have been quoted. This form is rather more subject to crown distortion by wind than the coastal variety, and this difference is particularly noticeable at Clocaenog where the two are seen side by side at about 1,300 feet elevation.

One particular importation was made, in 1926, of a far inland type from Alberta. Stands raised from this seed lot are of excellent form even under severe conditions as in the high elevation experiments at Queen's Forest (1-9.P.30). Stands of this provenance have however suffered severely from dieback in an experiment at Kielder (10.P.30) which has naturally led to caution in the use of far inland seed.

It is clear from what has been stated that a great deal more work is required on the forms and provenance of this species.

Age and type of plant. As with Scots pine, 2 plus 1 and 2 plus 2 transplants were used in the majority of the older experiments. Two year seedlings were first used in 1928 at Inchnacardoch (53.P.28) and Glenrigh (12.P.28) and were planted without phosphate. Sections topdressed at a later date have grown satisfactorily: those left as unmanured controls have grown more slowly. Recently, first year and second year seedlings, often from heathland nurseries, have been used on a considerable scale in both experimental and general planting. Partly this was due to a shortage of transplants, but also to the seedlings having been satisfactory. One formal experiment has recently been planted comparing first year, and second year, seedlings and one-plus-one transplants, together with direct sowing. (Watten, Caithness 4.P.51). In this experiment all the lots are progeny from experimental stands planted about 1928 from a single Canadian seed source. This has proved necessary since certain older comparisons of this nature have been invalidated by the different ages used being of widely varying types.

Growth in mixture. Discussion of nursing effects is included in the section on the nursed species, and mention has already been made of successful mixtures of Scots and contorta pines. As with other species there are very few mixtures in which canopy has closed and in which growth is even, so that they may be classed as successful, but at Kielder, in two experiments, there are excellent stands of contorta pine mixed with Sitka spruce (12.P.29, 16.P.30). The original vegetation was mainly *Molinia-Eriophorum-Vaccinium*, and the top height twenty years from planting ranged from fifteen to twenty feet. So far the growth remains even, though many of the stands are of alternate plants of the two species, so that a slight difference in growth rate would upset the balance and result in the elimination of one species. In a third experiment five crops were planted, ranging from pure contorta pine, through mixtures of various proportions, to pure Sitka spruce (10.P.29). The contorta used was the far inland, slow growing type from Alberta. The Sitka spruce has to a large extent now outgrown and suppressed the contorta. In two of the five pure contorta pine plots, the dying back already mentioned is taking place. The delicate balance of these intimate mixtures is well illustrated here; a slight change of site, a change of provenance, and a mixture alters to a pure crop.

JAPANESE LARCH AND HYBRID LARCH

Larix leptolepis Murray and
× *Larix eurolepis* A. Henry

These two species are considered together since silviculturally little difference has been found between them. It should be noted that some hybrids are found in most lots of Japanese and even occasionally in lots of European larch seed collected in this country. Seed containing a high proportion of hybrids has been obtained from certain Japanese larch plantations on private estates, notably at Dunkeld, Perthshire, and Glamis, Angus. The method by which plantations of hybrids are formed is to pick them out in the transplant lines by colour and vigour, and to classify the remainder as Japanese larch. The separation is naturally not precise but does result in plantations which have on the whole distinct characters and growth rate, although in individual cases it is difficult to assign trees to one species or the other.

Japanese larch is now recognised as an excellent tree for use on the shallow peats overlying relatively base-rich moraine, such as those containing mica schist which are common in the West of Scotland. During the 1939-45 war and immediately after, when the good growth of early plantations was becoming apparent, seed supplies were very short, and now that seed is again available this species is being used on a wider scale. Care is needed in site selection since in many experiments this species has suffered severely from exposure or from frosting, and it is also very liable to damage by deer. Intensive ground preparation and manuring are also recognised as essential for this species on peat. While hybrid larch is a hardier tree probably in every respect, shortage of stock confines its use practically to an experimental scale at the present time.

Comparative growth. Table 13 illustrates the growth of the two larches in a number of experiments and also gives comparable figures for contorta pine whenever they are available.

The best growth has been attained on thin peat in the west of Scotland. Growth is much slower on peat elsewhere, as at Inchnacardoch on the Lon Mor, but even so it is only equalled by that of contorta pine and possibly Serbian spruce. (See Photo 11). Growth on the flush peat at high altitude at Inchnacardoch is most promising; though planted as Japanese larch this stand includes many hybrids. On the richer *Molinia* peats of the Borders Japanese larch has been used only occasionally in experiments, and growth has been good in certain cases. The effect of site and vegetation changes is well seen in the series of experiments illustrated in Diagrams X, XI and XII (pages 75 to 78) in which the relative growth rates of the larch and pine vary enormously.

It is apparent from the table that hybrid larch grows consistently faster than Japanese, and, where exposure increases, this difference tends to become accentuated. It must be emphasised that, in almost all the experimental areas, very poor plantations of Japanese larch exist, of which two examples are shown. (Achnashellach 17 and Kielder 25).

Reaction to treatment. Japanese larch has proved to be the most sensitive indicator of all the species employed in the peat experiments. On the one hand the tallest and most striking research plots on peat are of this species or the hybrid, and on

Height growth and Quality Class of Japanese larch in various experiments, with heights of adjoining hybrid larch and contorta pine where available for comparison.

TABLE 13

Vegetation and Peat Type	Experiment	Age	Japanese Larch		Hybrid Larch	Pinus Contorta	Notes
			Q.C.	Ht. in ft.	Ht. in ft.	Ht. in ft.	
Scirpus baisn peat	Inchnacardoch 36.P.27	25	IV	16	18	—	Heavily slagged. H.L. better form.
Scirpus basin peat	Inchnacardoch 105.P.33	18	—	11	16	—	Poor form, H.L. is 2nd generation.
Slope peats :— *Scirpus-Molinia-Calluna*	Inchna. 62.P.28	14	III	15½	—	16	Burnt 1942.
Thin *Scirpus* peat over moraine	Achna. 7.P.28	23	III	30	—	20	Species only roughly comparable.
,, ,,	9.P.28	23	II	37	—	22	
,, ,,	17.P.33	17	—	11½	13	—	
,, ,,	Glenrigh 12.P.28	25	—	—	30	28	No phosphate until 1939.
,, ,,	Benmore 3.P.33	20	III	28	33	20	
Calluna-Scirpus	Kielder 25.P.36	17	—	10½	—	20½	Exposed site.
,, ,,	28.P.36	17	III	22½	—	22	Less exposed than 25.
Calluna-Molinia	27.P.36	17	II	26	—	24½	Better peat type than 28.
Flush peat *Pteridium-Calluna-Molinia*	Inchnacardoch 95 and 96.P.32	20	II	27-36	—	—	Contains H.L. Excellent plantations at 800-900 ft.

Notes.—A large number of experiments have been quoted on account of the great variation in growth rate. All were turf-planted, and had phosphate applied, unless noted otherwise.

Q.C.=Quality Class. H.L.=Hybrid larch.

the other a higher proportion of failures, have occurred than with any other species. In the last respect it differs from Sitka spruce, the most widely used indicator, in that it does not linger indefinitely in check, thus providing the opportunity for additional corrective treatments to be applied ; if satisfactory planting conditions are not provided for Japanese larch, heavy early losses or complete failure ensue.

Japanese larch failed almost completely in several early experiments on the poorer peat types (Inchnacardoch 5.P.23, 19.P.26, Achnashellach 2.P.22 and Kielder 7.P.28) and it was not until both turf planting and application of phosphate became routine treatment for this species that successful plantations were established on these areas. As regards planting, examples given in the text of Chapter 5 and in Table 5 (page 28) and Diagrams III (page 26) and IV (page 32) show the extreme sensitivity to methods of planting, ground preparation, and intensity of draining. For the long series of manuring trials at Inchnacardoch, Japanese larch and Sitka spruce were chosen as indicators and the results of some thirty experiments are considered in Chapter 8 (page 67). The extreme sensitivity of Japanese larch to the application of phosphate is repeatedly shown, two ounces promoting good growth where controls failed. (See Photo 21).

Provenance. Only one experiment to compare different provenances of Japanese larch has been planted on peat (Achnashellach 23.P.37). This includes plots from home collected seed and also from several places in Japan. The site of the experiment is very irregular and as yet no differences attributable to provenance have been observed.

Nearby are a number of plots raised from seed collected from various hybrid larch plantations near Dunkeld. Such seed, though known as 'hybrid larch' may be produced by pollination of hybrid larch by hybrid, Japanese or European larch. This fact, in addition to the Mendelian segregation of the characters in the second generation, results in the production of an extremely variable tree with every type of intermediate from the true European to the Japanese form. So far there is little difference in the mean growth of the various lots though there is great variation in the heights of individuals. Such stands are not likely to be as successful as those of the true hybrid.

Age and type of plant. Transplants of Japanese larch aged 2-plus-1 have been the most commonly used stock though 1-plus-1 and 1-plus-1-plus-1 have also been freely used. Early trials of one and two year seedlings gave very poor results at Inchnacardoch, undoubtedly partly because slag was not applied in most cases until a few years after planting (36.P.27 and 53.P.28). Losses were also high and growth poor at Clocaenog (17.P.34). At Glenrigh, however, two year seedlings have grown well with low losses even though not slagged for six years after planting. No trials of seedlings have been made for many years but they are now under test on ploughed ground. (Glentrool 8.P.51).

Today, one-plus-one stock is generally used for larches, as with the better early growth in the nurseries, older plants of these species are likely to be too large for peat planting.

Mixtures. There are very few true mixtures at present in existence on peat which contain Japanese larch. Where the larch and Sitka spruce occur in alternate plant mixture at Kielder (12.P.28) the larch has suffered badly from exposure, having in the early years outgrown the spruce; but now it has fallen behind and comparatively few have entered the canopy. One excellent plot of this mixture exists at Achnashellach and is more fully described below (7.P.28—Diagram XII, page 78).

NORWAY SPRUCE

Picea abies Karst. (=*P. excelsa* Link.)

Norway spruce, with European larch, was, until recently, the most widely cultivated exotic conifer in Great Britain. When the Forestry Commission started planting on peat, Norway spruce was used on a large scale, but at the present time its place has been taken to a great extent by Sitka spruce, except on the better *Molinia* and *Juncus* peats. The Research Branch experiments show clearly the reason for this change.

Comparative Growth. Many of the early experiments on ground preparation, method of planting, and manuring included both spruces. Throughout these trials the early losses of Norway spruce were consistently higher. Neither turf planting nor application of phosphate reduced its losses to the same extent as those of Sitka spruce. (Achnashellach 1.P.21, 6 and 8.P.28, Glenrigh 1.P.24, 4.P.27 and Inchnacardoch 5.P.23, 12 and 13.P.28). In most of these experiments both species ultimately went into complete check and died out slowly. The early results were, however, sufficient to influence the decision to concentrate on methods for growing Sitka spruce on poor peat as being the more promising of the two. Consequently Norway spruce has rarely been used since 1928 as an indicator species in the experimental areas. Subsequently the relative growth rate of those early experiments in which the spruce did survive, has justified this decision, for nowhere does the growth of Norway equal that of Sitka spruce as shown in Table 14. (See also Photo 18).

Only on the better *Molinia* peat did spruces grow at all in the early years of direct planting, and as has been shown in Chapter 5 on ground preparation, the turf planting system has produced excellent stands. Here again Norway spruce falls slightly behind Sitka spruce in growth rate as in the experiment at Kielder. The only exception to this general rule is that in frost hollows Norway spruce grows better since it is less susceptible to spring frosts. Thus in the spruce areas it is employed in the valley bottoms and frosty flats, while Sitka spruce is planted on the slopes.

Reaction to treatment. As already explained Norway spruce has been little used in recent years as an indicator and the majority of the earlier experiments failed. From general observation it may be concluded that this species responds proportionally less than Sitka spruce.

Provenance. There have been two large and several smaller provenance trials using Norway spruce on peat. Both the large trials have been very severely damaged, the first at Kielder by fire in 1948 and the second at Newcastleton by a severe late frost in April 1945.

The provenances in the Kielder experiment covered a large part of the natural range of the species, and when the majority were destroyed differences in early growth had already emerged, the plots of central European origin having grown considerably faster than those from Scandinavia. (Table 15).

The plots in the Newcastleton experiment were mainly from a much more restricted area in Central Europe ; a single lot from Sweden also included has grown more slowly than any other. The frost damage occurred with varying severity in the different lots, but interpretation is complicated by the fact that the mean height of the plots varied at the time from three to six feet, partly at least due to their different sizes when planted. Table 16 brings out several points. First, that the height variation is as much due to provenance as to the different ages of plants used, and that frost damage is correlated with size, being most severe in the plots with the smallest plants. Allowing for size, however, it is clear that there is considerable difference in frost hardiness. The plots of Carpathian origin, the fastest growing here as at Kielder, are relatively frost hardy, as also are the plots from the Central Alps raised from the seed of 1935, and those from North Tyrol seed of 1934. That such large differences in the incidence of damage does occur, raises considerable hope that frost hardy

Mean Heights of various plots of Norway spruce at 12 years from planting in Kielder 29.P.36.

TABLE 15

Origin	Height, feet
Finland	4.2
Norway	5.5
Sweden	6.2
Czechoslovakia; France; and Black Forest, Germany	7.9—8.3
Bavaria and Harz, Germany	8.6—8.7
Carpathians, Czechoslovakia	9.5

Heights of Norway and Sitka spruce in various experiments. Quality Class and percentage losses added where of interest

TABLE 14 — Feet

Vegetation and Peat Type	Experiment		Age	Norway Spruce	Sitka Spruce	Notes
Basin peats						
Scirpus	Inchnacardoch	13.P.25	25	2.1 (76%)	2.6 (67%)	Control, no phosphate.
				2.1 (38%)	4.4 (19%)	N.S. 4 oz., S.S. 2 oz. of slag in 1928.
Molinia-Scirpus-Calluna	Beddgelert	36.P.27	25	5	9	Few deaths. Heavily slagged.
,,	,,	3.P.27	25	13	20	No phosphate
Slope peats						
Scirpus-Molinia-Calluna	Inchnacardoch	62.P.28	14	7	8½	Burnt 1942.
Scirpus-Calluna	,,	25.P.29	20	15 (V)	22 (V)	1,100 ft. Groups among pines.
Molinia-Vaccinium-Calluna	Kielder	14.P.30	23	30½ (III)	35 (IV)	No phosphate.

Note.—All were turf planted and had phosphate applied unless noted otherwise.

Heights and incidence of frost damage on Norway spruce in Newcastleton Experiment 4.P.38.

TABLE 16

Origin :—	Height in 1946 feet	% killed back by frost 1940
Large transplants from seed of 1931-33		
East Carpathians, Roumania	6.2	4%
Austria	6.2	11%
Black Forest, Germany....	5.8	18%
North Tyrol, Austria	5.3	15%
Trentino, Italy	4.6	22%
Sweden	3.5	18%
Transplants from seed of 1934		
Black Forest, Germany	6.0	14%
Trentino, Italy	5.5	16%
Jutland, Denmark	4.9	21%
North Tyrol, Austria	4.2	5%
Small transplants from seed of 1935		
"Central Alps"	4.2	22%
Black Forest, Germany	3.8	39%
Harz, Germany	3.8	43%
Difference for significance at 5%	0.55	

races may be selected for employment in sites where damage from this cause is frequent. Recent experiments at Newcastleton have shown that late flushing individuals may be selected in the nursery for use in frost hollows.

It is clear from these experiments that while Central European spruce provides the fastest growing plots, there remains much research to be carried out before the best localities or stands for seed collection are determined. Several younger experiments will start to provide information soon.

Age and Type. Normally 2-plus-1 or 2-plus-2 planting stock has been used for planting on peat. In early trials of second year and third year seedlings at Inchnacardoch (3.P.22, 9.P.25 and 13. P.25), early losses of seedlings were rather greater than of transplants, but all these experiments subsequently checked so that growth comparisons are impossible. Successful use of second year seedlings at Kielder has been mentioned in connection with deep planting (Chapter 5, page 21). At Glenrigh (5.P.27) early losses were 3% for transplants but 34% for seedlings, but both lots subsequently checked. Finally at Newcastleton (3.P.37) third year seedlings were compared with 1-plus-2 and 2-plus-1 transplants which had been either lined out normally or bedded out at close spacing. Early losses of the seedlings were forty per cent whereas transplant losses were low, only approaching the seedling figure where densely bedded out. Height growth after seven years varied from a mean of three feet for normal transplants to two feet for the seedlings.

Mixtures. No successful crops of Norway spruce in mixture have been raised in experiments ; along with many other species, mixtures are incorporated in recent experiments on ploughed peat at Achnashellach (26.P.46), and on the Lon Mor (Inchnacardoch 138.P.51).

SITKA SPRUCE

Picea sitchensis Carr.

Sitka spruce has been used more extensively in the peat experiments than any other species, having been planted in over half of the four hundred trials. There are a number of reasons for this, the fundamental point being that this species is an excellent volume producer and thus of great value in any afforestation programme designed to produce the maximum result in a short time. Secondly, good young plantations have been grown on the better peat types and the extension of its use on to poorer types by use of improved technique would be a great advance, on account of this rapid volume production. Thirdly, Sitka spruces is the conifer most resistant to exposure, both as regards defoliation and deformation of the stem, so that if it can be grown it will be of enormous value in the high lying and exposed regions on which so much of the peatlands lie. Finally, Sitka spruce has proved to be an excellent indicator species, more sensitive than pines, more consistent in its response than larches, and, through its great powers of survival, offering scope for testing remedial or stimulatory measures if the initial treatments provide insufficient stimulus.

The experimental areas on poor peat at Inchnacardoch, Achnashellach, Glenrigh and elsewhere would still not normally be considered plantable with this species, although the Research Branch experiments prove that it can be established by intensive methods. What now remains is to demonstrate that Sitka spruce can be grown by methods practical on a large scale, and the recent large scale trials may serve this purpose. In contrast Sitka spruce is used very extensively on better peat, particularly at Kielder (See Photo 10) and other forests in the Borders and in the west, and the experiments in these areas deal with points of planting technique, provenance and type of planting stock. The difficulties of using spruce on heather land are dealt with more fully below.

Comparative growth. The superiority in early rate of growth of Sitka spruce over Norway spruce has been shown in Table 14 (page 43). As far as other species are concerned comparison is not easy since the effects of ground type and treatment exert far more influence on the spruce than on pines, and while larches also are most sensitive to these changes, there is the additional complication that spruce may be nursed into much better growth in mixture than it would make when planted pure on the same site. In addition, on poorer ground types, spruces pass through a critical stage, up to the formation of canopy, during which checking may occur at any time. This may be, and in many experiments has been, avoided by suitable treatment such as additional draining or top dressing with phosphate. Once this phase, which lasts for upward of ten years, is ended by the closure of the canopy, the growth rate may completely change, as shown by results from early experiments such as Inchnacardoch 49.P.28 (Diagram II, page 25). Largely as a result of this initial check the present heights of spruce in the experiments can give little idea of its future behaviour, since the vast majority are now less than twenty years old.

Reaction to Treatment. A large part of the chapters on ground preparation and on manuring are devoted to the reactions of Sitka spruce, while the effect of mixture is considered below. Table 17 gives in broad outline an indication of the mean height reached at the same age under various conditions on the extreme and intermediate peat types. It is not possible to include results from experiments on ploughed ground, but on the poorer sites at least an additional increase in early growth rate may confidently be expected. While method of preparation, phosphate and mixture all produce large cumulative effects on the Lon Mor, turf planting alone produces excellent growth on *Molinia* at Kielder, where manuring has at most a small effect while mixture has none at all.

Reference must be made here to the interaction of heather (*Calluna vulgaris*) and Sitka spruce. (See Photo 2 and Appendix). A recent article by Weatherell (1953) gives an account of the effects of removal or suppression of heather on the early growth of spruces and Lawson cypress growing on the drier heathlands. On peat the matter is greatly complicated by interactions with other factors, notably waterlogging and phosphate deficiency. It does appear, however, that to this cause, namely heather competition, is due the checking of spruce on peat at a later stage, rather than immediately after planting, which often takes place even after good early growth following intensive preparation and manuring. The following points may be noted:—

(1) The nursing effect seen in mixtures of spruce with pines and larch follows suppression of the ground vegetation by the nurses.

(2) Mulching of the vegetation, dominated by heather, around checked Sitka spruce, may result in an immediate colour response. Within one growing season the colour of Sitka spruce planted at Kielder in 1949 turned from yellow green to green when mulched with additional turfs in 1952. This effect was not obtained by draining or phosphatic manuring. (Kielder 64.P.52).

The conclusions drawn from observations of

Actual or predicted heights reached by Sitka spruce at twenty years from planting in experiments at Inchnacardoch Achnashellach, Glenrigh and Kielder.

TABLE 17 — Feet

Treatment of Sitka spruce at planting	Inchnacardoch Deep *Scirpus* peat			Achnashellach/Glenrigh Thin *Scirpus* peat over moraine		Kielder *Molinia* peat
	No P	P	P+TD	No P	P	—
Directly planted	Failed	—	—	Failed	—	High losses
Turf planted	Failed	3.0	4–5½	Failed	6—8	15—25
Mock ploughing	—	4.0	8	—	—	—
Turfed and with Scots pine, Pinus contorta or Japanese larch	—	6–8	—	—	(i) 6 (ii) 16—20	15—25
Turfed and grouped with Scots pine	—	14	—	—	—	—

Notes.—P=Phosphate at planting. TD=top dressing later.
(i) Normal dose, spruce suppressed.
(ii) Very heavy dose. Spruce in canopy.
Information compiled from Inchnacardoch : 36, 38, 49, 86, 112.
Glenrigh : 5, 33.
Achnashellach : 7, 9, 10.
Kielder : 7, 10, 12.

checked and semi-checked areas in the Border forests during 1950-51 were that dominance of *Calluna* was associated in every case with the checking of spruce. The main factor which determined the height at which the spruce checks or whether it will form canopy is its relative vigour and size when the *Calluna* becomes dominant.

Thus all factors which reduce the amount of *Calluna* or postpone its development, e.g. heavy grazing or burning prior to planting, and more complete smothering by ploughing, weeding, and mulching, will increase the chances of spruce growing satisfactorily into canopy.

Factors which appear to be neutral are those which aid both spruce and heather, notably increased drainage. Definitely harmful to the spruce since they promote the growth of heather without aiding the spruce, are enclosure of the area and thus relaxation of grazing pressure, and advance draining.

Naturally, silvicultural treatments such as increased amounts of turf per plant, use of good planting stock, and phosphate at planting, and as top dressing, all play their part as they reduce the time taken to form canopy. A number of plots have been laid out to check these conclusions at Kielder and Kershope, Cumberland.

Once canopy is formed there is ample evidence from non-experimental plantations on the amorphous (*Molinia*) and fibrous (*Eriophorum*) peats that the spruce will grow well after suppressing the ground vegetation. This is not yet demonstrated for pseudo-fibrous (*Scirpus*) peats particularly on basin areas such as Lon Mor. The tallest pure Sitka spruce plots there, in 49.P.28 (Diagram II, (page 25)) and page 44.P.28 (Photo 20) are just in canopy but are not as healthy in appearance as might be expected at that stage. Their future development will be awaited with interest.

Provenance. The main Sitka spruce provenance experiments at Kielder and Newcastleton shared the fate of the Norway spruce, but again it is possible to extract some information from the early growth records. At Kielder, losses had been negligible throughout the experiment (29.P.36) when the plots were burnt at only ten to twelve years old. In sections planted in 1936 and 1938, plots from Masset, Queen Charlotte Islands, British Columbia, averaged eight and six feet respectively and had always maintained a slight lead in height growth over other lots. In the section planted in 1937 a plot from Danish seed reached eight feet, two feet higher than any other ; but was believed to include hybrids between white and Sitka spruces. Some of the same plants in the 1936 section were, on one occasion, reported as the most severely damaged by frost.

At Newcastleton (5.P.38) the most interesting point was the difference in the numbers of the various lots which were killed or frosted back in the April frost of 1945. Results are given in Table 18 and show that in general the lots from Queen Charlotte Islands were less frost tender than those from Washington, while the Masset lot were the hardiest. The result when considered together with the consistently faster early growth at Kielder is a most useful indication of a promising seed source.

Age and type of plant. As with Norway spruce, a number of early trials on *Scirpus* peat at Inchnacardoch and elsewhere tested two and three year old seedlings in comparison with transplants (Inchnacardoch 10, 13, 36, 38, 48, 53.P.25-28, Clocaenog 17.P.34 and Glenrigh 5.P.27). While the majority ultimately checked, early losses were fewer and growth was better with transplants, and 2-plus-1 and 2-plus-2 plants have been used in the majority of the later experiments. Much

Growth of Sitka spruce from various origins planted in Newcastleton Experiment 5.P.38, showing incidence of Frost Damage.

TABLE 18

Seed Origin	Height at 6 years Feet	% killed by frost in 1945	Mean dieback* of survivors inches
Masset, Queen Charlotte Island	5.2	11%	11
Skidegate, Queen Charlotte Island (3 lots)	4.0—4.9	20%—40%	17—25
Cape Flattery, Olympic Peninsula, Washington	5.2	45%	21
'Washington' (2 lots)	4.7—5.2	48%—55%	20—27

Note.—* = Average length of leading shoot of survivors killed by frost.

Height growth and losses of seedlings and transplants of Sitka spruce in various experiments at Kielder.

TABLE 19 Feet

Vegetation	Expt.	Age	Age when planted				Notes
			1+0	2+0	2+1	2+2	
Molinia	9.P.29	15	—	12.2	12.8	13.2	Slagged.
Molinia-Vaccinium-Calluna	15.P.30	14	—	11.3	11.8	9.2	—
Molinia-Vaccinium-Scirpus	31.P.37	10	—	5.9	—	—	—
Molinia-Erica tetralix	32.P.38	9	—	3.3 (30%)	—	—	Initial check. Now burnt.
Molinia-Eriophorum-Scirpus	36.P.39	8	—	3.3 (35%)	—	—	Initial check and frosted.
Calluna-Molinia-Scirpus	21.P.33	12	Failed Failed	3.0 (86%) 4.0 (60%)	4.0 (28%) 4.9 (28%)	— —	Control } On old Slagged. } Turfs.
Calluna-Scirpus-Molinia	22.P.33	—	—	Checked	—	—	—

Note.—All turf planted and no phosphate applied unless noted.

better growth was obtained at Beddgelert and Kielder on *Molinia* peat. At the former forest second year seedlings grew as well as transplants in two early trials (10.P.29 and 16.P.30). At Kielder a number of trials have been made which are summarised in Table 19.

All the seedlings were good plants, generally about six inches high, while the transplants were about twice the size. Clearly on good peat the seedlings and transplants were equally successful. In the 1933 experiments, however, the ground used was dominated by *Calluna* and this combined with unfavourable planting conditions—old turfs and a drought in the first year—resulted in complete failure of the first year, and heavy losses in the second year, seedlings. The 1937-39 trials fell on intermediate ground types and in one case in a frost hollow; only the earliest became established quickly. Phosphate would certainly have benefited these trials. Numbers of second year seedlings have in fact been planted in these Border forests, generally on picked sites and with selected stock, either when transplants were scarce or there was a surplus of seedlings in the nurseries. Largely on account of the risk of disastrous losses with seedlings in certain years, the transplant has however remained

First year losses, and heights at seven years from planting out, of three year-old Sitka spruce treated by various methods in the Nursery.

TABLE 20 Feet

Nursery Treatment	Newcastleton 3.P.37			Newcastleton 6.P.39	
	Age when planted			Age when planted	
	3+0	2+1	1+2	2+1	1+2
Control seedlings	4.2	—	—	—	—
Lined out at 2 inch	—	4.3	5.1	4.1 (6%)	4.6 (3%)
,, ,, ,, 1 inch	—	4.1	4.3	3.8 (5%)	4.3 (5%)
Bedded out at ½ inch	—	3.9	3.9	3.2 (13%)	3.8 (14%)
,, ,, ,, ¼ inch	—	3.8	3.0	3.0 (13%)	3.4 (30%)
Bedded out densely at 200 per yard	—	3.8	3.8	2.8 (38%)	3.2 (26%)
Difference for significance at 5%	No analysis possible. N.B. Losses all under 10% in this expt.			0.5	0.6

Early losses and heights after six years from planting of three-year-old Sitka spruce, wrenched, undercut and pruned in the Nursery. Newcastleton Experiment 9.P.40.

TABLE 21

Treatment in 3rd year in the nursery	Early losses Percentage	Mean Height Feet
Left to give 3+0 seedlings	42	2.3
Wrenched	56	2.1
Twice wrenched....	48	2.1
Undercut	26	3.2
Undercut and shoot pruned	33	2.2
Transplanted to give 2+1 transplants	7	3.7
Difference for significance at 5%	—	1.1

the conventional type of plant.

At Newcastleton, on good *Molinia* peat, another series of experiments tested three year old plants which had undergone different treatments in the nursery. The first two experiments compared lined out and bedded out 2-plus-1 and 1-plus-2 transplants and in one case three-year seedlings (3.P.37 and 6.P.39). Results are given in Table 20 and show clearly that height growth in the forest has depended on the amount of room given in the transplant lines. Here again a big difference in losses is seen between comparable experiments, which must have been due to differences in the stock or conditions during the first year in the forest. As regards type of plant, the 1-plus-2 transplants are generally superior to the 2-plus-1 stock when lined out at the wider spacings ; at closer spacings there is little difference. The three-year seedlings included in the first trial have grown as well as the transplants.

Two further trials at Newcastleton tested seedlings which had been wrenched and undercut in the nursery and the results from the more comprehensive of the two, given in Table 21, show that third year seedlings have suffered more losses and made poorer growth than 2-plus-1 transplants, and that undercutting is the only promising alternative to transplanting. In the second experiment (Newcastleton 10.P.40) wrenched seedlings were poorer than transplants. Mechanical undercutting, as an alternative to lining out, is now undergoing trials in the nurseries.

The method of raising Sitka spruce in heathland and woodland nurseries originated by Rayner at Bagley Wood Nurseries, Oxford, and Wareham, Dorset, has led to the production of large one-year seedlings suitable for lining out and in certain cases planting.

The first trial of these plants on peat was of 1-plus-1 transplants from Wareham which had been raised in a heathland nursery with "C.5" compost (Kielder 45.P.45). A block of five acres was planted, and growth has been very good, compared to that of normal stock alongside, the Wareham plants growing at double the rate in the early years and reaching five to six feet at five years compared to the three feet of the ordinary transplants.

In Scotland, about 1945, sterilization by steam and formalin had produced large first year seedlings, and these were first planted out in 1946, together with seedlings from the first small Scottish heathland nurseries, started in the previous year. Results from the first year's planting have been most satisfactory and results are summarised in Table 22.

Early losses and Height at six years in 1946 experiments employing first year seedling and two-plus-one transplants of Sitka spruce :—

TABLE 22

Vegetation and Peat	Experiment	First year Seedlings Control	First year Seedlings 2 oz. GMP	2+1 Transplants Control	2+1 Transplants 2 oz. GMP	Notes
Deep basin peat with *Scirpus*	Inchnacardoch (Lon Mor) 130.P.46	Checked (48%)	2.1 ft. (16%)	Checked (10%)	2.9 ft. (Nil)	Ploughed
Deep slope peat with *Scirpus*	Inchnacardoch (P.22) 131.P.46	Checked (1%)	1.7 ft. (8%)	Checked (11%)	2.4 ft. (Nil)	,,
Molinia-Calluna on slope peat	Achray, Loch Ard Forest PT 46/1	1.6 ft. (35%)	3.8 ft. (3%)	2.6 ft. (Nil)	3.6 ft. (Nil)	Turfed and drained

Notes.—In Inchnacardoch Experiment 131.P.46 seedlings lost 75% and transplants 60% in the exceptional severe spring of 1947. These losses were replaced in 1948 with the results shown.

GMP = Ground Mineral Phosphate.

Mean Heights and percentage losses of different ages and types of Sitka spruce three years after planting in five forests. (All are better type peats with a proportion of *Molinia*)

TABLE 23

Forest and Ground Preparation	Age when planted										S.E. ± Ft.	Dif. for sign. 5% Ft.
	1+0 Ht. Ft.	1+0 % loss	2+0 Ht. Ft.	2+0 % loss	1+1 Ht. Ft.	1+1 % loss	2+1 Passable Stock Ht. Ft.	2+1 Passable Stock % loss	2+1 Good Stock Ht. Ft.	2+1 Good Stock % loss		
Wauchope 2.P.48 Turfed	0.8	47	1.1	19	1.6		1.5		1.7		.04	0.13
Carron Valley 2.P.49 Turfed	0.8	72	—		1.4	28	1.0	65	1.3	34	.07	0.21
Leanachan 10.P.48 Ploughed	1.6		2.2		2.3		2.4		2.6		.07	0.21
Strathlachlan 1.P.49 Ploughed	1.3	13	—		1.9		1.4		1.9		.05	0.15
Glentrool 2.P.49 Ploughed	1.5		2.2	25	—		1.8		2.3		.10	0.31
Mean Height Overall losses	1.2	32	1.8	15	1.8	7	1.6	15	2.0	9		

Note.—For clarity, losses are only shown for any lot where they exceed 10%, but all lots were included when computing means.

These experiments illustrate once again that, on *Scirpus* peat, intensive preparation and type of stock count for nothing if phosphate is not applied. In contrast on the better site at Achray, Loch Ard Forest, growth of transplants but not seedlings is satisfactory without phosphate ; with phosphate the seedlings are at least as good as transplants, their response to the phosphate being proportionally greater. The severe late winter of 1947 caused the abandonment of some trials planned for that year. In both 1948 and 1949 considerable numbers of seedlings were planted in experiments, including the exceptional one year plants, over six inches tall, raised at nurseries such as Devilla; the results are set out in Table 23 above.

The most striking point is that the 1-plus-1 are significantly smaller than the good 2-plus-1 stock in only one case out of four, while they are taller than the passable 2-plus-1 in two out of four. Second year seedlings grew well, but they along with the passable 2-plus-1, suffered twice the losses of 1-plus-1 and good 2-plus-1. The first year seedlings are however significantly poorer than all other lots and their losses are much higher. These experiments justify the great increase in the employment of 1-plus-1 transplants for planting in recent years and explain the caution used with seedlings. It is to be noted that the first year seedlings suffered severe losses and made poor growth in the two experiments planted on turfs. This is undoubtedly due to the much shorter time for which single turfs prevent re-establishment of ground vegetation as compared to plough ridges. Frost was the causal agent of the losses in many cases, due to its increased intensity over the grass-covered turfs and the delicate nature of the seedlings.

The position may be summarised at the present time by stating that one year seedlings could be used on a proportion of the peat land, provided that certain precautions were taken in regard to the more delicate nature of the plants and their lesser powers of recuperation compared to transplants. The choice of site is important and in particular it must not be subject to severe frosts nor to rapid recolonisation by vegetation. Other precautions are that every care should be taken to obtain quick transport from the seedbed to the planting site, with careful handling at all stages in transit, and that every aid should be given at the site to promote quick growth. In addition the ploughing must be neither too old nor too fresh, and phosphate must be applied on all the poorer peat types. With all these factors favourable it is still to be expected that dry seasons, unavoidable late planting or damage by vermin will from time to time cause much heavier losses than would have occurred with transplants. Even so, were the overall losses to reach thirty per cent it is probable that for some areas it would be cheaper to use seedlings and beat up with transplants rather than to use transplants throughout. Seedlings have in fact been used in some quantity in recent years and one extensive experimental trial is in hand (Glentrool 8.P.51).

Sitka spruce in mixture. Experiments which employ Sitka spruce in mixture with other species may be divided into two main types, those in which the species grow up together to form a true mixture and those where pine or larch are employed to nurse the spruce into making better growth than it would if planted pure.

The experiments in the first category are practically confined to the *Molinia* peat of the Borders, and the promising mixtures of contorta pine and Sitka spruce at Kielder have already been mentioned, with an example of how easily the balance of such intimate mixtures may be upset. There is only one mixture of Japanese lárch and Sitka spruce on peat, that at Kielder which has been described already.

On other peat types with much *Calluna* or *Scirpus* present, the development of mixtures is complicated by the very different rates at which growth has started. In the earlier experiments, the pines almost always took the lead, and whether the spruce later entered the canopy at all was governed by all the factors of site and planting method, as well as method of mixing and the amount of tending received. In certain recent experiments early growth of spruce has been as fast as that of the pine, though whether this will continue cannot be foreseen. The crucial point seems to be that the nurse must suppress the ground vegetation before the initial stimulus given by good planting method and phosphate has been lost. The spruce may thus be tided over that period of check which has often occurred on poor peat when the plants are three or more feet high, when the ground vegetation has completely re-established itself but canopy has not formed. At the present time it is still not possible to give a completely sure formula for growing Sitka spruce on poor peat by nursing. The data are scattered and incomplete and there are few comparative trials of methods which are old enough to give clear results. Examples from the earlier experiments do serve to show what must be avoided and give useful lines for future work.

Spacing and arrangement of the species in the mixtures may conveniently be dealt with first. After the early experiments at Inchnacardoch had shown that pine grew slowly and spruce not at all on poor peat types, an attempt was made to nurse the spruce by planting two plants, one pine and one spruce, on a large turf (Inchnacardoch 47.P.28). No phosphate was given at planting and though a top dressing was given ten years later, the pine were by then well above the spruce, and in spite of drastic thinning all the spruce have been suppressed. Several experiments of a slightly later date contain contorta pine and Sitka spruce in alternate single line or alternate plant mixtures. In most of them a certain amount of tending has been necessary, both by cutting back of branches and later by pre-thinning of the pine to aid the spruce. Such work would not be economically practicable on a large scale. The present position in a number of these trials is shown below in Table 24.

Heights of Contorta pine and Sitka spruce in intimate mixture in various experiments.

TABLE 24 — Feet

Experiment		Vegetation	Age	Pinus Contorta	Sitka spruce	Notes and quantity of phosphate
Inchnacardoch	55.P.28	*Calluna-Molinia*	17 25	9.1 22½	2.8 9	1928 2 ozs. Pinus contorta, Sitka spruce. 1945 3 ozs. to Sitka spruce only.
,,	93.P.31	*Scirpus-Molinia*	19	19.0	7.8	2 ozs. at planting.
,,	112.P.35	*Calluna-Molinia*	12 18	7.9 21½	3.6 12½	3 ozs. to Sitka spruce, 1 oz. to Pinus contorta.
,,	113.P.35	,,	12 18	5.6 17½	2.9 8	Repetition of 112 on more exposed site.
Achnashellach	7.P.28	*Scirpus*	23	19	20	30 cwts. of slag per acre.
,,	9.P.28	,,	23	21	9	3 ozs. per plant.
Bennan	2.P.32	*Calluna* knolls	11 18	9 15	3 Dead	2 ozs. at planting. No tending during war

None of these experiments contain controls of pure Sitka spruce for comparison, though often by comparing results with nearby experiments it is possible to say that the growth of the spruce has been improved. The fate of these intimate mixtures if left to develop untended may be seen from that of the Sitka spruce at Bennan, situated in an outlying experiment which could not be carefully watched during the war. The spruce checked after planting but was starting to grow again when the pine had suppressed the ground vegetation, the stage shown in the table after eleven years. Seven years later the spruce had been suppressed as well. The results quoted for three experiments at Inchnacardoch include an earlier assessment of mean height and a recent assessment of dominant heights. These show that the spruce is falling even further behind the pine. In certain cases selection thinning is now in hand to aid the spruce.

The outstanding result in Achnashellach Expt. 9 is more fully discussed below as this experiment includes the most successful series of mixtures on *Scirpus* peat.

The next type of mixture was that adopted by M. L. Anderson in laying down various experiments incorporating his method of group planting (see Chapter 9, page 82). Mixed groups and pure spruce groups were employed in several places, and provide the best example on peat of the nursing effect of pines. The two crops were located on two vegetation types but comparison of the marginal groups which were planted on the transitional area gives the very clear results set out in Table 25.

In one case, that on the best ground in 93.P.31, the spruce is clearly established and overtopping the pine, the top height being more than double that of adjacent pure spruce. In the other Scots pine-Sitka spruce groups further selective thinning will be nesssary to prevent the spruce being suppressed. As with the intimate mixtures these early thinnings do not pay, and one advantage of these group mixtures is that the number of spruce is smaller than previously and any tending required is both localised and reduced in amount. The concentration of the spruce in a number of spots provides sufficient to form a high proportion of the final crop while none will be given expensive attention only to be cut out in thinnings at an early stage.

The next development in spacing and arrangement was to use small groups of nine plants at normal spacing so arranged as to provide a matrix of pine and larch within which the spruce groups might develop. This method was used in two small trial plantations (Inchnacardoch 120.P.38 and Achnashellach 25.P.38) of which fuller details are given in Chapter 9. So far the nursing effect is not apparent in that after twelve years the growth of the spruce is slow. These experiments indicate at least that more intimate mixture is probably necessary. Some method is obviously required which will provide the stimulus to growth of the spruce seen in the Anderson groups while reducing the necessity for frequent tending. Since the war a number of experiments have been laid down which incorporate a variety of different arrangements of pine and spruce. Possibly the most promising method, judging from the results already discussed, is that in which groups of six or more spruce at normal spacing are placed in a pine matrix with, in addition, one or two pine included within the spruce group. The suggestion is that these pine should be cut out as soon as the spruce are established so as to leave a group of spruce from which one or perhaps two would enter the canopy. If, however, the spruce in any group should fail then these pine will be left to grow on and prevent gaps being left in the plantations. At the present time no results from the use of this system can be given but it seems a logical development from the previous methods.

The next problem is to decide which species

Mean Heights of tallest trees in each group at 19-21 years from planting in trial plantations at Inchnacardoch. (Mean heights of all plants at 13 years at Borgie)

TABLE 25 — Feet

Experiment		Mixed Groups: Composition	Height: Pine	Height: Sitka spruce	Pure groups of 10-13 Sitka spruce Height :—	Notes
Inchnacardoch	75.P.29	3 Mountain pine/10 Sitka spruce	8.7	8.0	6.0	—
,,	86.P.30	9 Scots pine/4 Sitka spruce	18.3	13.7	6.1	Average area
,,	93.P.31	,, ,,	21.4	26.0	12.8	Best area
,,	93.P.31	,, ,,	18.9	15.0	7.6	Average area
Borgie	2.P.30	9 Pinus contorta/4 Sitka spruce	10.9	9.7	6.6	Burnt 1942

provides the best nurse for Sitka spruce on peat. This question is still open, for mountain, Scots and contorta pines and also Japanese larch have all been used with success in various experiments, but in very few cases can a valid comparison be made between the mixtures.

Thus at Achnashellach the four mixtures have all grown well in one experiment (7.P.28), results from which are set out in Diagram XII (page 78). Only the section which received slag is of interest in the present connection. The heights cannot with certainty be precisely compared since the mixtures are in separate half acre blocks on very variable ground. There is unfortunately in this experiment no proof that Sitka spruce would not have grown as fast without nursing, with the exceptional dressing of one and a half tons of slag per acre which was applied. Results may be compared however with the second experiment at Achnashellach (9.P.28) where a more normal dressing of three ounces per plant was given. Growth of the pines and larch in the two experiments has been of the same order yet the growth of the spruce has trebled where the heavy dressing of phosphate was received, so that it is now in canopy with the other species. One may well ask whether this experiment falls within the category of a nurse crop at all and whether the manuring has not placed it in the class of mixtures in which the species have grown together from the start, but in the absence of pure spruce plots this remains in doubt. The various plots are now being thinned, in some parts to favour the spruce and in others to retain a mixture. These plantations are of the intimate type (three nurses to one spruce) and never received any attention until the first thinning. The spruce never fell far behind the nurses in height growth and it is interesting to note the time at which the spruce overtopped the nurse ; this occurred about the tenth year with mountain pine, about four years later with Scots and about the twentieth year with contorta pine, while the spruce had not yet drawn level with the larch when thinning of this crop commenced.

The early suppression of mountain pine seen here has occurred elsewhere (Inchnacardoch 77.P.29), and has led to the suggestion that such a mixture is likely to need less attention than others and that later unremunerative thinning would be reduced to a minimum since the pine would subsequently be left to fend for itself. The difficulty is that should the spruce not grow well a worthless crop of mountain pine remains, and in addition the spruce if they succeed become very coarse on emerging from the mountain pine. However, in one of the recent experiments on mixtures (Achnashellach 26.P.46) this idea has been developed by use of mountain pine as a third species in a mixture, and its function would be to give maximum low cover around the spruce to kill out the vegetation, and at the same time to act as a buffer between it and a faster pine or larch as the second main species.

To use Japanese larch as a nurse to spruce would also appear unwise since it has already been shown to be most sensitive to environmental conditions on poor peat, and thus the chance of growing spruce would be hazarded by the possible failure of the nurse. There remain contorta and Scots pines, the relative merits of which must remain in dispute until experimental evidence is obtained ; at present this is sadly lacking. The disadvantages of contorta pine would appear to be that its growth is often too rapid so that the spruce is left far behind, and that its shade is too light to suppress the ground vegetation quickly. On the other hand where Scots pine or a densely foliaged type of contorta is used, the spruce may, in intimate mixtures, be suppressed along with the ground vegetation, unless costly tending is undertaken. The inland short branched forms of contorta pine are less likely to require such attention and if the spruce will tolerate the partial shade and if partial suppression of ground vegetation is sufficient, this should prove a useful type. The crux of the matter is that in the existing experiments the spruce has fallen far behind the pine in the early years, with the notable exception of the heavily manured experiment at Achnashellach. If this can be avoided, the species and form of pine may prove relatively unimportant. It must be emphasised that all these experiments are on outmoded methods of ground preparation and in the early years the current methods are known to benefit spruce relatively more than pine. The idea of selective manuring has been further developed with the same end in view. (Watten, Caithness 2.P.51). Thus the discrepancy in dosage seen in certain of the experiments in Table 24 might be increased, to perhaps eight ounces for the spruce and only one ounce to the pine, this last mainly to ensure its survival. The Achnashellach result suggests this might be effective, and provided the proportion of spruce is low the cost would not be unduly increased.

On many of the intermediate peat types dominated for example by *Eriophorum*, it is becoming apparent that spruce will grow pure when established by modern methods where mixtures would have been, until recently, considered essential. On large areas of intermediate peat, pine-spruce mixtures are employed as insurance, generally in two or three line band mixtures. These will, it is hoped, require a minimum of attention as regards tending. On the poorest land on which trial plantations are still required, the experiments mainly employ intimate mixtures—such as gave promising results in the earlier trials.

Two recent experiments compare these various methods of mixing contorta pine with spruce and other species on deep *Scirpus* peat. The first aim in all these nursing trials is to eliminate the early check, by ploughing and phosphate, and this may be said to have been accomplished to a great extent. The next stage is to overcome the check often met when the spruce is about three feet high and the vegetation has closed around it. This will it is hoped be achieved by the nursing effect of the pine, but if necessary additional manuring may be employed ; trials on this point are under way.

Chapter 7

TRIALS OF SPECIES LESS WIDELY USED ON PEAT

The Species trials

APART from the seven species which have been used extensively throughout the experiments on peat, some thirty-five conifers and fifteen hardwoods have been planted in varying numbers of experiments. Some of these such as Oregon alder have themselves been employed as indicator species in experiments investigating points of technique, but the majority have been planted only in species trials on various ground types in which the best technique then current was employed.

These species trials take three forms :—

(*a*) *Intensive comparisons of early growth of different species.* The earlier trials are mainly in this form, narrow strips or even single lines of many species being planted side by side in order to test their growth under closely comparable conditions. Mutual interference reduces the value of these experiments after canopy closes.

(*b*) *Comparative plots.* These may be small and replicated for precise short term comparison, or take the form of plots sufficiently large to produce forest conditions later in life, in which case replication is usually impossible, and they approximate to type (*c*), but have the merit of giving approximate comparisons with other species.

(*c*) *Trials of single species.* As and when plants of rarer species have become available it has been the practice to plant them out in one of the experimental areas as a single plot on a well-defined and common vegetation type. Useful information may be obtained by comparing the growth with that of commoner species in nearby experiments. Similar blocks have been laid down in some cases when small scale experiments showed that a certain species was worthy of more extensive trial.

There is also information to be gained from experiments in which rarer species have been used as indicators in addition to one or more of the seven widely used conifers.

The site factors of the main species trials of types (*a*) and (*b*) are set out below to avoid constant repetition in the notes on the behaviour of the individual species.

Beddgelert Expt. 3.P.27. (Cwm Du.) (Diagram V and Photos 12-15). This trial includes sixteen species, mostly conifers, laid out in single narrow strips. The site, although at about 1,000 feet elevation, is moderately sheltered. The plants were planted on Belgian turfs and received no phosphate The main vegetation types are grass-*Juncus* where the peat is thin, and *Molinia-Eriophorum-Scirpus-Calluna* over peat up to four to six feet in depth ; the proportions of the various species on the two types changing from plot to plot. All measurements given are from the second and poorer main vegetation type. Growth has been steady, with pines growing fastest at first, though some are now dying back, and spruces making slow progress ; *Thuja*, *Tsuga*, *Abies procera* (*nobilis*), *A. grandis* and *Chamaecyparis lawsoniana* are all promising.

Beddgelert Expts. 2.P.27 and 13.P.30. with additions in later years (Y Gyrn reserve). An area at Beddgelert was set aside for trials of species on a larger scale. The range of elevation is 900-1,150 feet and the area is fully exposed to the south-east. A crop of Scots pine and European larch was felled during the first world war and relics of this plantation gave some protection in the early years. There is a great variety of ground types and each species has been planted in the conditions considered most suitable. Many species fall on mineral soil and are not considered here, but there are also areas of *Molinia-Juncus* and *Calluna-Erica-Molinia-Scirpus* with peat up to three feet in depth, on which are located plots of about fifteen species. Growth has been very variable, but the common pines and, spruces and also *Thuja*, *Tsuga* and *Pinus strobus* are growing well on the better peat.

Benmore Expt. 3.P.33. Diagram VI. This trial consists of replicated strips or lines of about fifteen species on shallow peat overlying morainic deposits of mica-schist. Planting was on turfs, and phosphate was used throughout. The vegetation was of *Scirpus-Calluna-Molinia*, and growth of larches and pines has been good, but spruces, hardwoods and hemlock all suffered heavy losses or have grown poorly.

Glenrigh Expt. 5.P.27 and 12.P.28. Diagram VII. These two experiments consist of eight half acre blocks of the commoner species planted on *Scirpus-Calluna* on thin peat over moraine. Half of each block was in most cases planted with seedlings and half with transplants. Individual turfs were used for the first section, turfs and drains for the second. The latter would be expected to give an advantage to the blocks so planted but the top dressing was delayed some years here which may have counteracted this inequality. None of the plants received phosphate at planting. As forest blocks, the crops are broadly comparable, and it can be seen that pines and larches have grown well while spruces are poor.

Inchnacardoch Expt. 36.P.27. (Lon Mor). (Diagram VIII and Photos 11 and 18). This trial was laid down to test shallow turf planting with about twenty species which are arranged in single lines, both seedlings and transplants being included in many cases. A heavy dressing of slag at one ton per acre was applied to certain sections in 1928/29. All figures quoted are for the slagged sections unless noted otherwise. The elevation of the area is 550 feet and the vegetation was dominated by *Scirpus* with abundant *Erica tetralix* and *Eriophorum* over basin peat one to four feet deep. The growth of hybrid larch and Serbian spruce are outstanding on this poor site. Japanese larch has also grown well, and western hemlock, noble and balsam fir are promising. Sitka spruce has recently greatly improved while many other species, including the Norway spruce, are checked or dead.

Inchnacardoch Expt. 46.P.28. (Lon Mor). This experiment is largely a repetition of the above but included nearly thirty species and is mainly on shallower peat, though at one end the peat deepens to over six feet. The vegetation is similar to that in the first experiment with dominant *Scirpus*. Planting was on Belgian turfs, slag was applied to the whole area in 1928 and a top dressing to part in 1939. Growth is much poorer than in the 1927 experiment undoubtedly partly due to the lesser total amount of phosphate and possibly partly to the delayed top dressing. Hybrid larch is the tallest species, with Japanese larch next ; Douglas fir is almost the only other species which is growing even moderately well, apart from a few *Abies balsamea*.

These two experiments together are regarded as the yardsticks of growth on the poorest peat types.

Kielder Expt. 43.P.41. (Photos 16 and 17). This experiment consists of small scattered plots of ten species previously little used on peat, planted on patches selected, within an experimental area, as being the best flush peat types. The peat is black, amorphous and rarely more than eight inches deep ; it overlies a clay loam. The vegetation is of the *Molinia* flush type with grasses and bracken in patches. *Pinus peuce* and *Sorbus intermedia* have grown well here, *Chamaecyparis lawsoniana* and *Abies grandis* are promising, while *Thuja*, *Tsuga* and *Sequoia* suffered heavy losses.

Kirroughtree 6.P.39. Replicated small plots of eight species are situated on a peat flat up to three feet in depth and with the vegetation dominated by *Scirpus* and *Calluna*. The area is exposed though the elevation is only 375 feet. Pines are growing steadily; noble fir and Serbian spruce are healthy but growing only slowly; larches and Sitka spruce are of poor appearance.

The sections which follow give a brief account of the behaviour of all the species which have been planted experimentally, with the exception of the seven common conifers considered in the previous chapter. As far as possible growth rates and losses are always related to those of more widely used species.

ABIES

Abies balsamea Mill. Balsam fir has been planted in three experiments at Inchnacardoch. Where no slag was applied it has failed completely. Growth is best where two year seedlings were used in the first Lon Mor species trial, where with a heavy phosphate dressing, seventy per cent survive and the mean height is eleven feet, after twenty-five years, this result being better than that with either *A. nobilis* or *A. grandis*. In the second species trial growth and survival are rather poorer.

The third plot is a strip of one hundred plants planted on turfs with slag in 1930 on the Lon Mor ; eighty now survive and are growing slowly. In all cases the colour of the trees is good and growth steady although slow. Stems are straight in spite of exposure and the species has been noted as worth more attention.

Abies grandis Lindl. Grand fir. In the first Lon Mor species trial only seven slagged plants survive, and are growing slowly, averaging five feet at twenty years of age. In contrast, on *Calluna-Molinia* at Beddgelert this species had reached ten feet and, on a *Juncus* flush, sixteen feet at the same

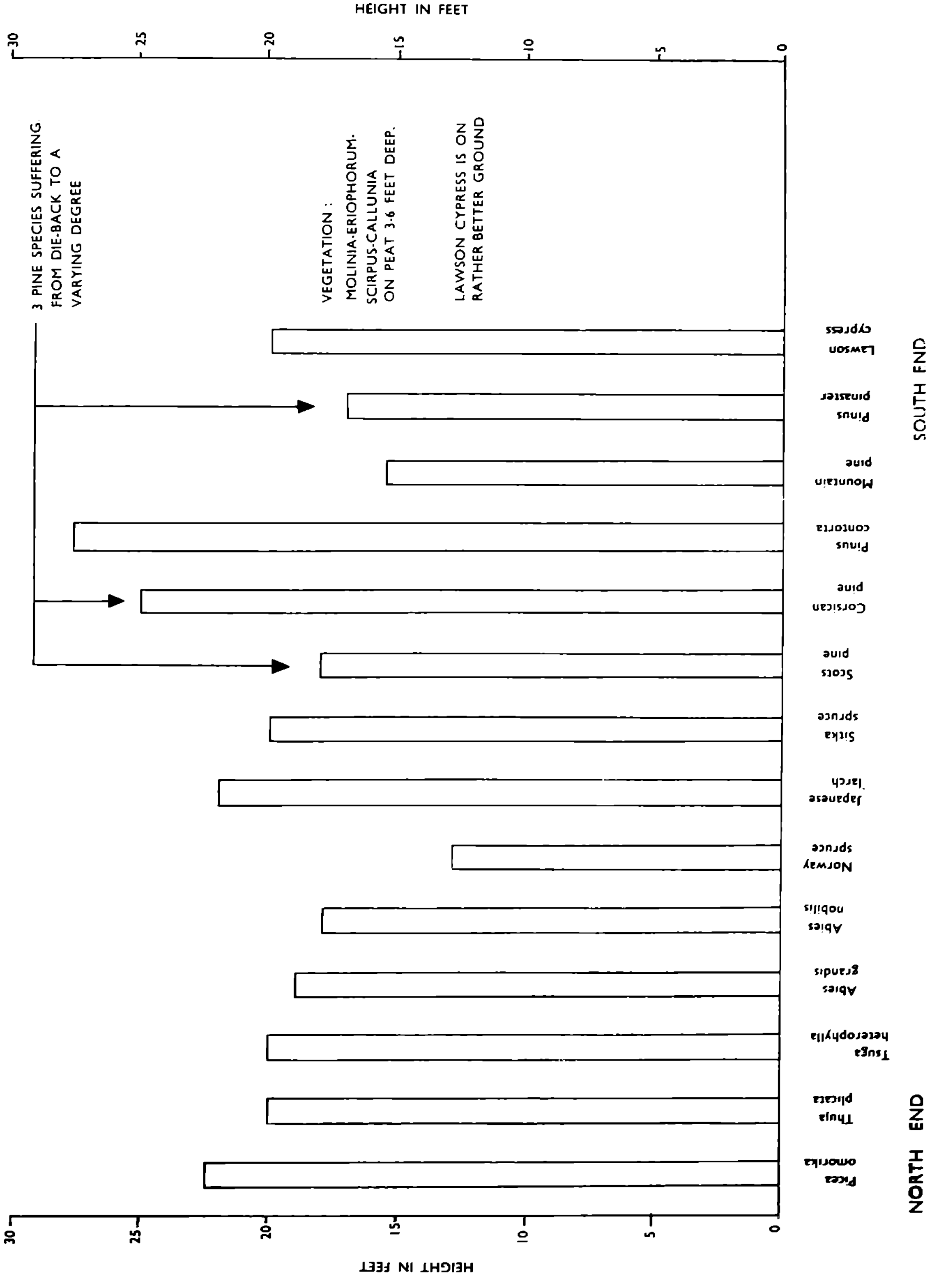
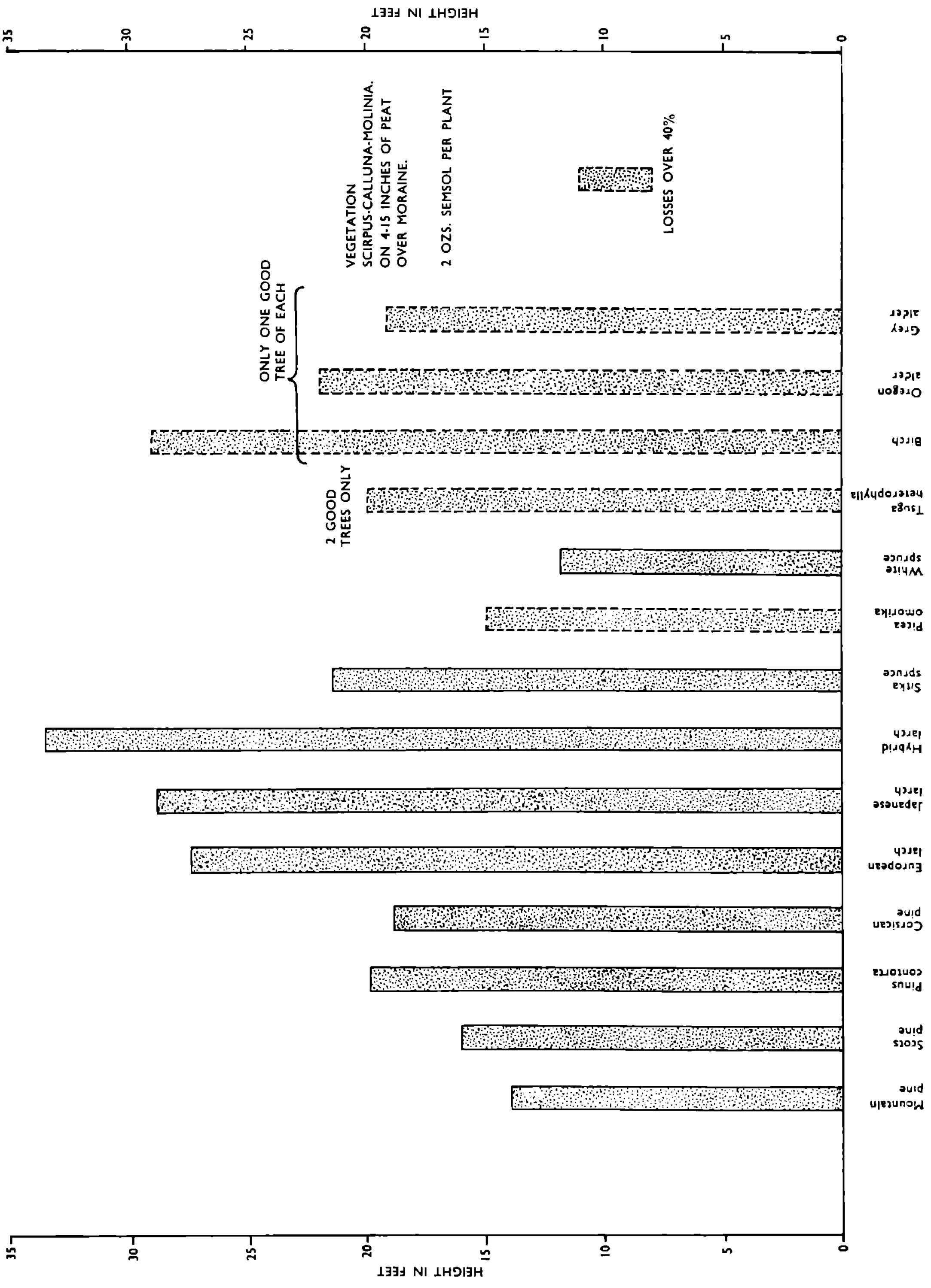


DIAGRAM V. SPECIES TRIAL AT BEDDGELERT EXPT. 3.P.27.
HEIGHTS AT 25 YEARS FROM PLANTING, WITHOUT PHOSPHATE.

DIAGRAM VI. SPECIES TRIAL AT BENMORE. EXPTS. 2.P.32 & 3.P.33.
DOMINANT HEIGHTS AT 20 YEARS.



age, though stocking is not good. In the more recent experiment on good *Molinia* peat at Kielder *A. grandis* has made a good start, reaching four feet after eight years but with losses of thirty per cent

A. grandis was used for beating up eight year old Sitka spruce at the Forest of Ae (4 and 5.P.34). In the early years the plants were affected by the deep shade, and none have entered the canopy, growth falling far behind that of the spruce.

Abies nordmanniana Spach. Caucasian fir has been used in only one trial, that at Kielder, where a plot of sixteen plants was put in. It suffered continual damage from frost and the plants have now all died.

Abies procera Rehder. (=*A. nobilis* Lindl.) Noble fir. (See Photo 15). Seedlings failed completely in the earlier Lon Mor trial while transplants have lost one-third of their number in both trials. Height growth has been slow and erratic, the plants reaching seven feet at twenty-five years. Altogether the performance of this species in these trials is rather better than *A. grandis* but poorer than *A. balsamea.* Very different growth rates have been obtained in a number of experiments of the same age on a range of peat types. At Beddgelert (9.P.29) tenth acre plots turf planted with one ounce of slag, have reached about five feet on *Scirpus-Calluna* peat and double that height where the vegetation changed to *Molinia.* At Kielder (12.P.29) on *Calluna-Molinia-Scirpus* the early growth was slow but after fifteen years rapidly increased, the mean height at twenty years reaching thirteen feet compared to the eighteen feet of nearby Sitka spruce.

Again at Beddgelert, in the species trial, *A. procera* at the same age and planted without phosphate had attained eight feet and sixteen feet on *Calluna-Molinia* and *Juncus* peat respectively. (See Photo 15). For comparison it may be noted that this species may reach thirty feet at twenty years in this area on mineral soil dominated by grass-bracken. The good growth in the younger species trials at Kielder and Kirroughtree has been mentioned above.

Interest was aroused in this species by the reports of good growth in exposed sites in Northern Ireland (Redmond, 1950), and it has been incorporated in a number of trials in exposed areas since then, where it has made the characteristic variable early growth.

All reports on these experiments both old and new speak of the excellent colour and straight growth of *A. procera.* In general the growth is slower than that of Sitka spruce but faster than *Tsuga*, *Thuja* or *A. grandis.*

The trials of this genus show that the capabilities of the various species on peat are by no means fully explored. Owing to their very slow establishment they are not entirely suitable for use in afforestation of poor sites, but the possibilities of introduction into plantations at a later date are promising and are now being investigated.

CHAMAECYPARIS

Chamaecyparis lawsoniana Parl. Lawson cypress. The majority of the plants in the Lon Mor trials at Inchnacardoch failed but the few survivors have reached two to four feet after twenty years.

On *Molinia-Calluna* ground at Beddgelert this species has grown well though often forked. This plot is not exactly comparable with those of other species, being on rather better ground, but the height attained was twenty feet after twenty-five years. At Kielder also, early growth has been good and losses low, in small plots planted in 1941. (See photo 17).

Chamaecyparis nootkatensis Spach. Nootka cypress. This species also suffered heavy losses in the second Lon Mor trial at Inchnacardoch. In an experiment in the "P.22" area (123.P.39) on *Scirpus-Calluna-Molinia*, a small block of Nootka cypress have made a very slow start even where manured with phosphate. The mean height was three feet at twelve years from planting. Unmanured controls are only two feet tall. On rather poorer ground dominated by *Scirpus-Calluna* at Achnashellach (13.P.30) Nootka cypress has reached three to four feet at sixteen years from planting. Part of this experiment fell on a richer grass flush peat and here the height was almost six feet at the same age. The smaller plants in this experiment suffered severely from frost damage in the spring of 1947.

Chamaecyparis obtusa Endl. and **C. pisifera** Endl. Both these species were included in the two species trials on the Lon Mor but failed. The very few plants which remain alive are now generally less than one foot tall after twenty years check.

It would appear that certain species of this genus offer some promise on the better peats and *C. lawsoniana* deserves further trial particularly in mixture, in view of its good growth and the value of its timber.

CRYPTOMERIA

Cryptomeria japonica Don. Japanese cedar. In the second Lon Mor trial twenty-five percent of the plants survive and average three feet in height. In the first trial all the plants died ; the species has not been tried elsewhere until recently.

CUPRESSUS

Cupressus macrocarpa Hart. Monterey cypress. On a *Molinia-Juncus* bog at Beddgelert (2.P.29) two plants survive of a small plot and are growing well, being now seven and ten feet high. Owing to its frost tenderness it is unlikely, however, that this species will be tried elsewhere.

LARIX

Larix decidua Mill. (=*Larix europaea* DC.). European larch was used in several of the early experiments at Inchnacardoch. A number survive in both species trials and are several feet tall, but they are of very poor shape and appearance compared with Japanese and hybrid larches. European larch was also planted at 1,100 feet in a high elevation experiment at Inchnacardoch (25.P.27). Again, though some of the trees are over fifteen feet tall this species cannot be considered to be satisfactory on such a site. About the same period two other trials were planted, at Glenrigh (12.P.28) and at Achnashellach (10.P.28), with in each case the same result, a plantation of twisted stems and unhealthy appearance. These last results and possibly some others were, at least in part, due to the use of unsuitable stocks of alpine origin.

On better quality, shallow peat, European larch has been used only once, in the Benmore species trial ; the plants used were from seed from Cawdor estate in Nairn. They have grown remarkably well and are twenty-seven feet high after seventeen years; as compared with Japanese at twenty-eight, and hybrid at thirty-three feet. In addition the form of the European larch is the best of the three, the hybrid larch being rather roughly branched, and the Japanese having wavy stems. In view of the unsatisfactory state of so many plantations of this species it is worth recording that European larch, when all factors are considered, is one of the most satisfactory of the fourteen species in this plantation. More trials of European larch of proven origin would undoubtedly be valuable.

Larix gmelini (Rupr.) Litvinov (=*L. dahurica* Turcz). Dahurian larch. This species failed completely in the first Lon Mor species trial while the last survivors in the high elevation experiment at Inchnacardoch (25.P.27) are now dying after being continually frosted back for twenty years. The species has not been tried elsewhere on peat.

PICEA

Picea engelmanni Engelmann. Engelmann spruce has been used in the two species trials at Inchnacardoch and there was also a small block at Achnashellach (13.P.30) the major portion of which was burnt in 1942. In the second Lon Mor trial this species, averaging four feet at twenty years of age is taller than any other spruce. However, in the first trial, where most of the species are taller, *P. engelmanni* has practially failed, survivors being only one foot high, the poorest growth of any of the five spruces present.

At Achnashellach, again on poor *Scirpus* peat, the plants were healthy and growing slowly, being about two feet high at ten years of age when burnt.

Picea glauca Voss (=*P. alba* Link). White spruce has been used in six experiments. In the Lon Mor species trials transplants have reached six feet and seedlings rather less ; both failed without slag. This result is similar to that obtained with Sitka spruce, but the height is only one-third of that reached by Serbian spruce in the first experiment. White spruce has checked badly in three other experiments at Inchnacardoch (19.P.26, 25.P.29 and 93.P.31) ; it was also planted in experiments at high elevation (1,600 ft.) at Queen's Forest, where in the absence of phosphate it has failed almost completely.

The only experiment in which this species is still growing is in the Benmore species collection on *Scirpus-Calluna-Molinia*. There the plants now average six feet in height after seventeen years ; this being only one-third of the height attained by Sitka spruce.

Though the appearance of the foliage of this species is often healthy, it suffers severely from spring frosts and it seems unlikely that white spruce can be successfully employed on peat in Great Britain.

Picea mariana Britton (=*P. nigra* Link). Black spruce has been planted in one small trial at Kielder. Results are given in Table 26. The four species were in single blocks and that of *P. mariana* lies on a slightly better vegetation type, grass-rush instead of *Molinia-Calluna* ; this may account for the higher losses due to weed growth, and the better height growth of the survivors. The trial cannot be considered satisfactory owing to the use of old turfs for planting.

Heights and losses of various species of spruce at 15 years from planting in Kielder Experiment, 23.P.35.

TABLE 26

		Losses %	Height Feet
Norway spruce	*Picea abies*	17%	7.5
Serbian spruce	*Picea omorika*	41%	5.5
Red spruce	*Picea rubens*	32%	7.4
Black spruce	*Picea mariana*	51%	9.4

Note.—This experiment was planted on turfs cut five years previously which will have seriously reduced growth rate and increased losses. No phosphate was used.

DIAGRAM VII. DOMINANT HEIGHTS OF VARIOUS SPECIES IN HALF ACRE PLOTS AT GLENRIGH. AGED 25-26 YEARS.

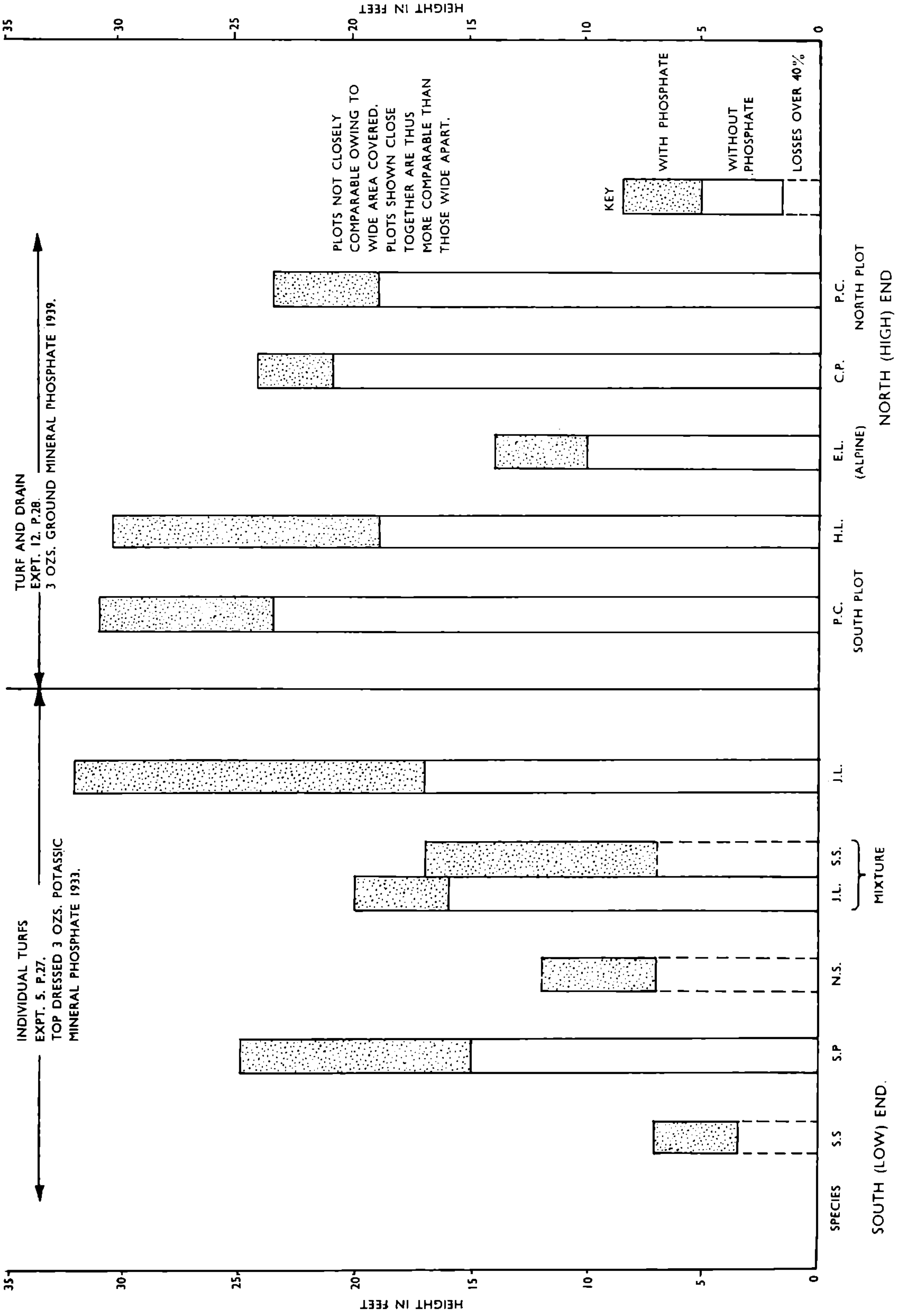


DIAGRAM VIII. SPECIES TRIAL AT LON MOR, INCHNACARDOCH 36.P.27.
HEIGHTS AND LOSSES AFTER 20 AND 25 YEARS.

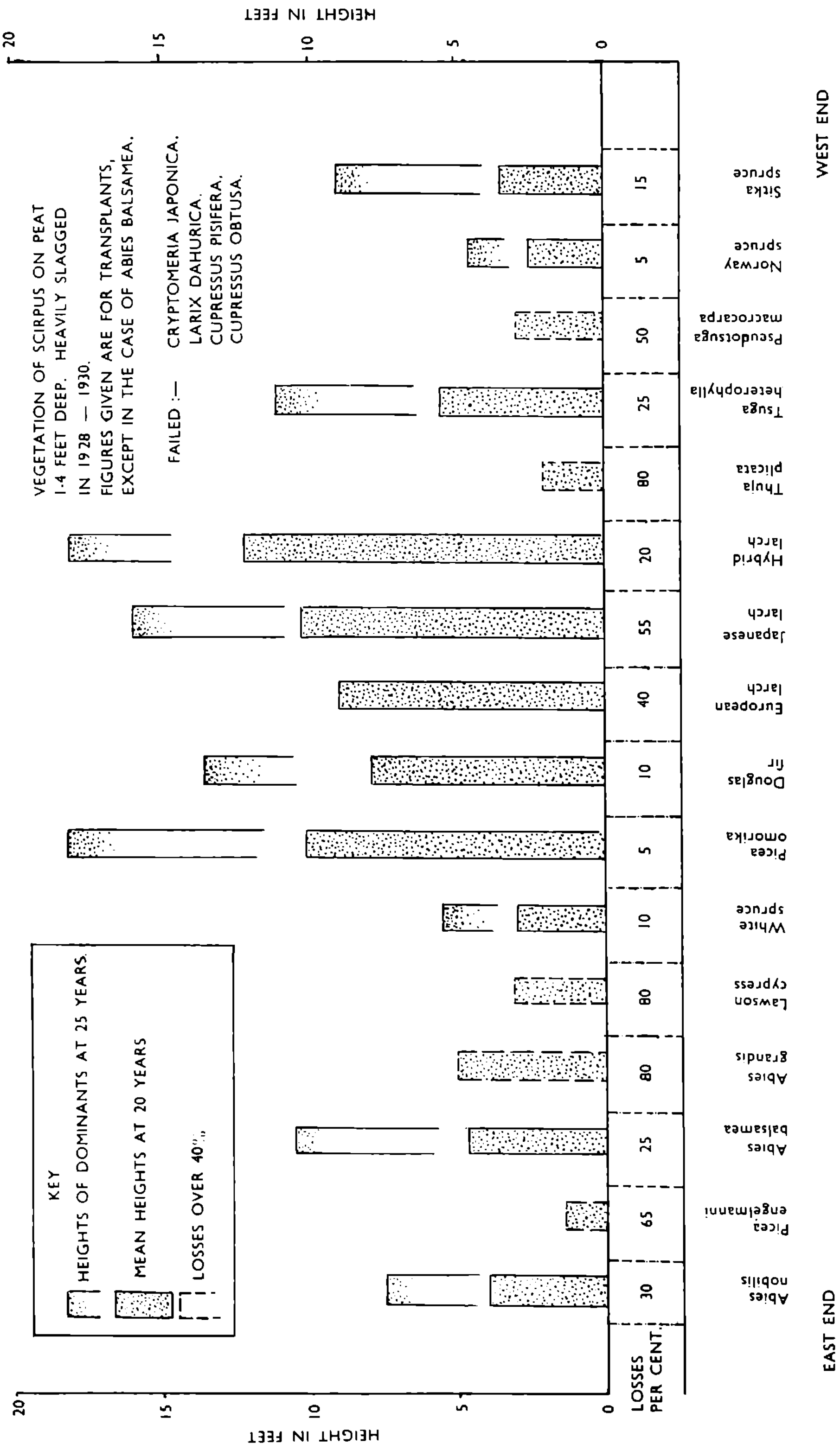


PHOTO 1. Borgie Forest, Sutherland, 1931. Looking south to Ben Laoghal across the main area of the forest. *Scirpus/Calluna* blanket bog.

PHOTO 2. Inchnacardoch forest, Inverness-shire, 1950. Three Sitka spruce, 28 years old, are shown in complete check in the foreground. They were directly notched into the *Scirpus/Calluna* about 1922. In the background is a general view of the P.22 experimental area, showing remnants of the original planting along the flushes and the blocks of trial plantations, planted since 1930.

PHOTO 3. Smales, Kielder Forest, Northumberland. Expt. 5.P.27, photographed in 1943. Variation in growth of 15-year-old directly planted Norway spruce according to the ground vegetation is illustrated. In the background are vigorous spruce on grass/herb/rush vegetation. In the foreground spruce are commencing more vigorous growth after a long period of semi-check in *Molinia/Vaccinium*.

PHOTO 4. Smales, Kielder Forest, Expt. 20.P.32, photographed in 1943. The extreme sensitivity of Norway spruce to minor changes in technique is illustrated. The central row of 2-year seedlings was planted to normal depth on turfs and is flanked on either side by rows deeply planted. All rows 11 years old. The difference shown in the photo was greater than the average, though the result was clear throughout the experiment.

PHOTO 5. Borgie Forest, Sutherland, 1931. "Complete Mock Ploughing". A close view of peat completely turned over by hand tools in 1929/30 to imitate ploughing. The contorta pine is two years planted and shows great vigour.

PHOTO 6. Minard Forest, Argyll, 1948. A *Molinia* peat area ploughed with the single furrow Cuthbertson draining plough at twenty-foot spacing ready for turfing. The plough ridges will be cut up and turfs spread at five feet apart between the drains.

PHOTO 7. Strathy Forest, Sutherland, 1950. Deep *Scirpus* peat ploughed with the double mouldboard Cuthbertson plough, cutting furrows at 10 feet apart and spacing ridges at 5 feet.

PHOTO 8. The Lon Mor, Inchnacardoch, Inverness-shire; Expt. 128.P.46, photographed in 1950. General view of a 4-year-old trial plantation of contorta pine with Sitka spruce planted on deep *Calluna Scirpus* peat single-furrow ploughed at 5 feet. In the background may be seen Anderson groups, and on the skyline the Lon Mor shelter belt 18.P.26. (See Photo 25.)

PHOTO 9. The Lon Mor, Inchnacardoch, Inverness-shire, 1949. Expt. 52.P.28, planted on deep *Scirpus* basin peat after draining to two intensities. View showing the main block of twenty-two-year-old contorta pine with in the foreground Sitka spruce of the same age interplanted with contorta pine in 1940. In the right background may be seen a trial plantation at 850 feet. Inchnacardoch Expt. 96.P.32. Light colouring is Japanese larch and dark pines, mainly contorta.

PHOTO 10. Smales, Kielder Forest, Sample Plot E208, Sitka spruce planted 1928 on turfs; thinned to C D grade; standing volume 1,580 hoppus feet over bark; at 25 years quality class is below IV. Photographed in 1952.

PHOTO 11. Lon Mor, Inchnacardoch Forest, Expt. 36.P.27, species trial. Five central trees of each species received no phosphate. Areas to right and left received heavy dressings. The continuous line of trees is *Picea omorika*, with behind it Japanese and hybrid larches and an occasional Douglas fir. In the foreground noble fir and balsam fir. Photographed in 1949, when 23 years old.

PHOTO 12. Beddgelert Forest, Caernarvonshire, The Cwm Du basin, Expt. 3.P.27 species trial on *Molinia/Eriophorum/Calluna* five years from planting on deep peat. Corsican pine is well clear of the vegetation, whereas Scots pine is hardly showing. Planting was on turfs without phosphate Photo taken in 1931.

PHOTO 13. Scots pine in Expt. 3.P.27, Beddgelert, photographed in 1951 when 25 years old. Thin crowns and some dieback.

PHOTO 14. Corsican pine in Expt. 3.P.27, Beddgelert. Photographed in 1951 when 25 years old. Crowns are thin and some trees are dying back or dead.

Note.—Photos 13 and 14 were taken at the same place as Photo 12.

PHOTO 15. Beddgelert Expt. 3.P.27. Species trial of noble fir, *Abies procera*, age 25 years on deep peat ; photographed in 1951.

PHOTO 16. Kielder Forest, Expt. 43.P.41. Swedish whitebeam, *Sorbus intermedia*, age 12 years on *Juncus* flush peat.

PHOTO 23. Inchnacardoch Forest, general view of Expt. 21.P.26, showing in foreground the area used as a turf nursery on Sir John Stirling Maxwell's system, and in the background the planting-out area, with on the left contorta pine and on the right Sitka spruce. The area lies at 1,300 feet and is of *Scirpus Calluna* on blanket bog. Photographed in 1949, 24 years after planting.

PHOTO 17. Kielder Forest, Expt. 43.P.41, species trial on *Juncus* flush peat showing Lawson cypress 12 years old, and on the left *Pinus peuce*. Photographed in 1951.

PHOTO 18. The Lon Mor, Inchnacardoch, Expt. 36.P.27, trial of species. Controls in foreground in which only *Tsuga*, right, is living. Background: heavily manured section with left to right Sitka spruce, Norway spruce, failed *Chamaecypoaris obtusa* and *C. pisifera*, *Tsuga heterophylla*, and hybrid larch. Photographed in 1949.

PHOTO 19. Whickhope, Kielder Forest. Experiment 25.P.36. An exposed site with vegetation of *Calluna-Scirpus*; Sitka spruce aged 17 years. Turf planted. Section on the left received one ounce of basic slag at planting. Photographed 1952.

PHOTO 20. Lon Mor, Inchnacardoch, Expt. 44.P.28. The best Sitka spruce on the Lon Mor, with a top height of 25 feet at 18 years. The peat was stripped from the planting area in 1928 and between then, and planting in 1933, two crops of potatoes were raised after intensive manuring. Photographed 1949.

PHOTO 21. Whickhope, Kielder Forest, Expt. 25.P.36. Turf planted Japanese larch now aged 17 years on exposed *Calluna/Scirpus*. In foreground control, background one ounce basic slag at planting. Photographed 1952.

PHOTO 22. Golden Valley, Achnashellach Forest, Wester Ross. Expt. 22.P.36, photographed in 1952. Showing effect of slag on the growth of Scots pine planted on peat, 16 years after planting. Trees in background had two ounces of basic slag per plant at time of planting; they are now 16 feet high, healthy, and dark green. Trees in foreground, which received no slag, are only 2 to 5 feet high, unhealthy, with only a few yellowish green needles; a number have died.

PHOTO 24. Inchnacardoch, Expt. 25.P.29., a high elevation plot planted in Anderson groups. Left to right may be seen *Pinus contorta* mountain pine ,*Pinus contorta* again, and Sitka spruce. In the foreground, *Sorbus aria* has failed. Photographed 1952, age 24 years.

PHOTO 25. The Lon Mor, Inchnacardoch, Expt. 18.P.26. The 25-year-old shelter belt of mountain pine, Scots pine and *Pinus contorta* each in a double row. The sections on the extreme left and in the centre received two ounces of slag in 1930. The poorer areas at left centre and extreme right are controls. Photographed 1950.

Picea omorika Bolle. Serbian spruce. This species has been very successful in the first Lon Mor species trial. Only two plants out of fifty have died while the height growth, nineteen feet at twenty-five years, is superior to all other species though individual hybrid larch are taller (Diagram VIII and Photo 11). Elsewhere, good growth has been obtained in two experiments at Beddgelert. In the first (3.P.27) the growth rate on *Molinia-Scirpus-Calluna* has been again faster than in other spruces reaching twenty-two feet at twenty-five years, rather faster than Sitka spruce and only surpassed by Corsican and contorta pines. In the second (3.P.27), on *Molinia-Juncus*, a plot of *P. omorika* has a mean height of fifteen feet and is as tall as Norway spruce though slower growing than Sitka.

At Achnashellach (8.P.28) this species failed when planted without slag, as also did Norway and Sitka spruces. At Benmore and Kirroughtree results have not been as good as those with Sitka spruce, growth being particularly slow at Kirroughtree though the plants are far more healthy in appearance than the other spruces. Finally there is one plot at Kielder for which results are given in Table 26. Clearly more information is needed on this promising species and recently it has been planted on a larger scale in many trial plantations.

Picea rubens Sargent (=*P. rubra* Link). Red spruce. There is only one plot planted on peat, that at Kielder; results are given in Table 26.

The species of this genus have not been widely tried, apart from Norway and Sitka spruces. Serbian spruce shows promise on the poorest peat and in one trial has grown better than some twenty other conifers ; this trial it must be noted, did not include pines. In a second it is only surpassed by two pines out of fourteen species.

PINUS

When the Lon Mor species trials were planted in 1927-28, pines, as already noted, were not included. Blackgame damage to pines was very severe at this time and small numbers of exotic pines were planted nearby, within a wire netting cage. Results are given in Table 27 which shows that the growth of all species has been very poor in the absence of phosphate. The vegetation was dominated by *Scirpus* with much *Erica* and *Sphagnum*, and the thin peat overlies moraine or rock.

Pinus jeffreyi A. Murray and **Pinus koraiensis** Sieb. & Zuc. See Table 27. Virtually failed; not planted elsewhere.

Pinus nigra Asch. & Graeb. (forma *austriaca Pinus laricio*, var. *austriaca* Endl.) Austrian pine. Apart from the small number of plants which failed in the pine species trial on the Lon Mor (Table 27), this tree has only been used in an experiment at an elevation of 1,100 feet at Inchnacardoch (25.P.27) where, again without phosphate, there has been almost complete failure though some grew slowly for many years.

Heights and survival of pines at eighteen years from planting within Inchnacardoch Experiment, 18.P.26.
TABLE 27

	Planted	Alive	Mean Height (feet)
Pinus contorta (inland)	80	50	4.4
+ ,, *jeffreyi*	30	0	—
+ ,, *koraiensis*	10	5	1.0
,, *mugo* (*P. montana*)	32	32	4.2
,, *nigra* var. *austriaca*	30	0	—
,, *nigra* var. *calabrica*	32	9	2.1
+ ,, *ponderosa*	30	0	—
,, *sylvestris*	22	13	2.7
,, *strobus*	30	22	2.2
+ ,, *thunbergii*	10	0	—

Note.—No phosphate applied.
+These species have not been planted elsewhere on peat.

In an effort to take advantage of its known resistance to salt-bearing winds, Austrian pine is at present being tried again in the shelter strips surrounding trial plantations in the far north. Phosphate manuring may increase the survival, and certainly in the first two years the appearance of these plants has been most satisfactory.

Pinus nigra var. **calabrica** Schn. (=*P. laricio* var. *corsicana* Loud.). Corsican pine. This species has been used in eight trials which together cover the major peat types. (See Photo 14). The oldest plantings were made from 1927-33 and results are compared in Table 28.

These results show that in the intermediate and better peat types early growth of Corsican is consistently faster than that of Scots, but rather slower than that of contorta pine. However, serious dieback from frost injury followed by symptoms of *Brunchorstia* has occurred in two experiments, those at Kielder and Beddgelert, where many of the Corsican pine are now dead. In the latter place Scots and maritime pine are also affected.

When the good early growth of the first plantation at Glenrigh was observed, two blocks of this species were planted, those at Glenrigh (34.P.36) and at Inchnacardoch (116.P.35). The latter block as shown in the table, extends over peat of the deeper slope type dominated by *Molinia-Myrica*, and also over peat of the shallow *Scirpus* knoll type, which results in a big difference in growth. These plantations are for the most part healthy, though those at Inchnacardoch show signs of browning at the present time.

Height of growth of Corsican pine in a range of peat types compared with growth of Scots and Contorta pines.

TABLE 28

Vegetation and peat type	Experiment	Age	Mean Heights Feet			Notes
			Corsican pine	Scots pine	Contorta pine	
Knolls :— *Scirpus-Calluna*	Inchnacardoch 18.P.28	18	2.1	2.7	4.4	No phosphate.
Scirpus-Calluna-Molinia	Benmore 2 & 3.P.33	20	19	16	20	
Scirpus	Inchnacardoch 116.P.35	15	3	—	—	
Slope peats :— *Molinia-Myrica*	,, 116.P.35	15	7	—	—	
Scirpus over moraine	Glenrigh 12.P.28	25	24 Blowing	—	23	Phosphate in 1939.
,, ,, ,,	,, 34.P.36	15	8	—	—	
Calluna-Scirpus with *Molinia*	Kielder 8.P.28	20	13 Dying out	13	15	No phosphate. Corsican pine died by 1953.
Basin Peat :— *Molinia-Eriophorum-Scirpus-Calluna*	Beddgelert 3.P.27	25	25 Many dying	18 Defoliated	28	No phosphate.

Note.—All the experiments were turf planted and phosphate applied unless noted otherwise.

It would appear that Corsican pine is worthy of further trial on peat, but the fear of disease and dieback at a later stage in growth must limit its use to small trial plots, until either these setbacks are found to be temporary or else frost resistant races are obtained. All the plantations listed in Table 28 were raised from seed of Corsican origin.

Pinus peuce Gris. Macedonian pine. Several small plots were planted in the Kielder species trial. The plants were very strong yet after seven years in the nursery averaged only eighteen inches. Losses were negligible and at eight years from planting the average height was almost six feet, this species being the tallest conifer in the experiment which however, contains no other pine for comparison ; this pine certainly deserves further trial. (See Photo 17).

Pinus pinaster Ait. Maritime pine has also been used only once, at Beddgelert (3.P.27) where on *Molinia-Calluna* it has suffered heavy early losses and growth is most irregular, averaging seventeen feet after twenty-five years compared to Scots eighteen feet, and contorta pine twenty-eight feet. In recent years dying back has occurred leading to further deaths.

Pinus ponderosa Doug. has been tried only at Inchnacardoch where, planted without phosphate, all died. A number included in the wind belt in this experiment were top-dressed in 1930, but only four survived having reached four feet in twenty years.

Pinus strobus L. White pine has checked in the Inchnacardoch trial though early reports mention this species as among the most healthy in appearance; the addition of slag in this trial would possibly have enabled the good growth to persist.

A recent addition to the Beddgelert plots includes a trial of white pine on *Molinia-Juncus* peat planted in 1942. The plants are now established and appear very promising.

Pinus thunbergii Parl. Ten plants failed when planted without slag on the Lon Mor.

The species in this genus worthy of further trial would appear to be Austrian pine for shelter and Corsican pine and *P. peuce* for production.

PSEUDOTSUGA

Pseudotsuga macrocarpa Mayr. *P. macrocarpa* has been planted only in the two species trials at Inchnacardoch ; in the second it is checked, averaging two feet, while *P. taxifolia* is growing slowly and has reached four feet. While *P. macrocarpa* has grown slightly better in the first trial it is even poorer relative to *P. taxifolia.*

Pseudotsuga taxifolia Britt. (=*P. douglasii* Carr.) Douglas fir is the tallest species after the larches in the second Lon Mor trial, the height being four feet after twenty years compared to the seven feet of hybrid larch. In the first trial growth was more promising, both seedlings and transplants reaching thirteen feet at twenty-five years, but growth has fallen off in recent years and the appearance is unhealthy, so that this species is not as promising as the silver firs and western hemlock, which, though smaller, are healthy and have an increasing growth rate.

Douglas fir was included in the tough peat knoll experiments (Diagram III, page 26) as a result of early good growth at Inchnacardoch. As indicated in the diagram and notes, losses were generally high and growth has been slow. On the knolls at Glenrigh (33.P.35) and Bennan (3.P.35) Douglas fir has grown very well with intensive methods of ground preparation, some individuals stand fifteen to twenty feet at fifteen years, though the average height is less than that of the pines. It is noteworthy that these plantations are now virtually mixtures of a small proportion of Douglas fir with Japanese larch and Scots and contorta pines, but the individual firs show great promise.

More recently Douglas fir has been used in the large trial plantations on ploughing at Inchnacardoch (132.P.46) and Achnashellach (26.P.46) where it has made good early growth. This species is one which might be more widely used in the future on morainic peat types, and trials in mixture with pines and spruces are now in hand.

SEQUOIA AND TAXODIUM

Sequoia sempervirens Endl. Redwood. A plot of sixty plants failed completely on good *Molinia* peat at Kielder.

Sequoia wellingtonia Seeman (=*S. gigantea* Decaisne). Only two survive of a plot on *Molinia-Juncus* at Beddgelert (2.P.27) and though growing only slowly are of healthy appearance.

Taxodium distichum Rich. Swamp cypress. Only a few survive at Beddgelert on *Molinia-Juncus* peat. Their appearance is very poor due to die-back and frosting.

THUJA

Thuja occidentalis L. A single plot was planted at Beddgelert (2.P.27) in 1939. After eight seasons the heights ranged from three to eight feet and the health of the trees was good. At Clocaenog (20.P.37) another plot is growing slowly.

Thuja orientalis L. A plot at Beddgelert adjacent to the above has grown only half as fast while the appearance is also poorer and the stems spindly.

Thuja plicata D. Don. Western Red Cedar. Almost all the plants of this species have died in the Lon Mor species trials. In two experiments at high elevation at Inchnacardoch *Thuja* survives; in the first at 1,250 feet (21.P.25) it is of poor appearance and growing very slowly but in the second at 1,100 feet (25.P.29) a single group of *Thuja* is of good appearance and fifteen feet high after twenty years; partly no doubt this is due to shelter from taller groups of contorta pine nearby.

At Beddgelert, in the intensive trial on *Molinia-Scirpus-Calluna, Thuja* has reached twenty feet at twenty-five years and is healthy and now growing fast, while on the *Molinia-Juncus* peat type in the second trial at this forest (13.P.27) this species has made irregular but good growth. The best parts of the plot were over twenty-five feet high after twenty years. On a similar type in the Kielder species trial the survivors of a plot of this species are now growing well, though in the first few years deaths amounted to eighty per cent, possibly due to insufficient drainage. At Clocaenog a small plot is growing slowly on *Calluna-Vaccinium* (20.P.37).

It would appear that *Thuja plicata* and possibly the other species are worth further trial on peat, particularly in mixture with pine.

TSUGA

Tsuga canadensis Carr. Eastern Hemlock. In the second species trial at Inchnacardoch the growth of this species is much poorer than that of the adjacent *T. heterophylla.* The plants are in complete check and average little more than one foot in height.

Tsuga heterophylla Sarg. Western Hemlock. While in the second Lon Mor trial growth is not good and the plants average less than three feet, in the first, this species has throughout its history been the healthiest and tallest species in the non-manured section, reaching ten feet at twenty-five years. Growth is little greater with manure but the general appearance is such as to encourage the use of the species in recent trial plantations. The pattern of growth of this species here and elsewhere is of interest. For the first few years the top appears to die back annually, but abundant side branches form a thicket within which needles are retained although lost from the leaders. This process leads to the formation of a squat cone-shaped bush and in the Lon Mor species trial this stage lasted for almost twenty years by which time the adjacent bushes closed canopy at a height of five feet. (See Photo 18.) Rapid growth then commenced and the height of the dominants has doubled in the ensuing five years.

Western hemlock was, in 1940, introduced into twelve year old contorta pine on the Lon Mor (Inchnacardoch 52.P.28) and has grown well in groups where the pines have been opened out to admit light ; it has in some cases now reached five feet after ten years growth without any suggestion of 'bush' formation. It was also introduced in 1940 into ten foot high Sitka spruce at Kielder (16.P.30) but here growth has been slower than at Inchnacardoch.

Losses were heavy in the species trial at Benmore but the survivors have grown steadily, reaching twenty feet after twenty years, while at Beddgelert on *Juncus-Molinia* (2.P.27) heights ranged from eight to twenty-three feet at twenty years, being poorest on the wettest areas. In the intensive species trial in the same forest the height was twelve feet at the same age on *Molinia-Scirpus-Calluna*, compared to the nine feet of *Thuja* and ten of *Picea omorika* nearby. *Tsuga* is recorded as one of the best species on the poorer ground in this experiment.

Western hemlock has been used in some twenty recent trial plantations on peat, and in those now three or four years old the process of bush forming is well under way, giving promise that the Inchnacardoch growth pattern will be repeated.

This species obviously shows promise and may be of great value for the second crop on peaty areas.

ALNUS

The history of the planting of this genus on peat is brief but interesting. In 1930 Anderson included *A. oregona* in a trial plantation in the P.22 area at Inchnacardoch. Growth was phenomenal and outstripped all other species, both conifer and hardwood. Thus after three growing seasons many plants were over five feet high and later annual shoots of two feet in length were common. As a result between 1932 and 1938 alders were included in over thirty experiments on peat, six species were tested, and alders were used as indicator species in manuring and draining trials. Then frosting and dieback became prevalent, and planting ceased. Finally the alders died out completely in many experiments. In a few places however, they survive and are growing well.

Alnus cordifolia Ten. This Italian species has made poor growth in two experiments on the Lon Mor and P.22 at Inchnacardoch (107 and 108.P.34).

Alnus glutinosa Gaert. Common alder. Results for two experiments at Inchnacardoch are given in Table 29. These plots are the best of a number of trials and the better growth may be attributed partly to good draining which has turned an original vegetation of *Scirpus* to one with much *Molinia*. Good growth has also been obtained on *Juncus* flush peat at Clocaenog whereas on *Calluna* nearby common alder failed completely (10.P.33). At Beddgelert on *Juncus squarrosus-Sphagnum* peat some plants have reached eleven feet, growth and form being better than either birch or Oregon alder (14.P.30).

Common alder has failed almost completely when planted without a phosphatic dressing (Inchnacardoch 97 and 102.P.32, Clocaenog 2.P.27).

Alnus incana Moench. Grey alder. (Seed used has been of central European origin). This species is generally the most promising of the five species, it grows faster than common alder and does not suffer from frost damage as severely as Oregon alder. Table 29 shows results in two trials on fairly good peat at Inchnacardoch. In two others on poorer peat it is again the best species, being almost the only one still growing out of five alders, even though form and survival are poor (Inchnacardoch 107 and 108.P.34). Grey alder failed however, in two trials at Kielder (13.P.29 and 16.P.30) dying back in the very early years. At Clocaenog (2.P.27) and Queen's Forest (11.P.33) on exposed sites at high elevations this species suffered heavy losses.

Alnus oregona Nutt. Oregon alder. The rapid early growth of this species has already been mentioned and as a result it was for a few years widely used. In the majority of the twenty trials in which it was planted it has failed. In some cases it attained heights of over twenty feet before dying back, as in a trial plantation at Inchnacardoch (93.P.30). Failure has been attributed to frost but this does not seem to be entirely the cause. There are occasional good trees in some of the experiments, usually adjacent to running water, as at Achnashellach (25.P.28). The draining experiments at Glenrigh (33.P.35) and elsewhere also demonstrated the very great beneficial effect on early growth of deep and close drains. The typical dying back of branches which precedes

Heights and losses of Alders in Inchnacardoch experiments at twenty-two years from planting.

TABLE 29 — Feet

	97.P.32 (Lon Mor) Slagged Section	101.P.32 (P.22) Slagged
Common alder	6½*(20%)	12½ (20%)
Grey alder	15 (20%)	15½ (10%)
Oregon alder	Failed	9 (70%)

* Common alder being suppressed by grey.

death may result at least in part from poor soil aeration and the death of the roots.

Alnus sitchensis Sarg. (North American form of *A. viridis*) was tested with other species at Inchnacardoch (107.P.34) on a very poor *Scirpus* slope. Practically all the plants are now dead.

Alnus viridis D.C. Green alder. The European form of this species made at best only shrubby growth in two trials at Inchnacardoch (107 and 108.P.34).

There would appear to be no prospect of establishing alders on poor peat. Common and grey alder could possibly be grown on *Molinia* peat but drainage must be good.

BETULA

Betula japonica Sieb. A plot planted on ploughed ground, and with phosphate, at Inchnacardoch (133.P.46) has failed completely, largely on account of frost damage in the exceptional winter of 1946-47.

Betula pubescens Ehrh. and **B. pendula** Roth. (=*B. verrucosa* Ehrh.). Birch. Much of the birch used in experiments has been of mixed origin and the report on these two species is therefore combined.

At first birch was thought of as a hardy species to be used for shelterbelts and in exposed places. This has proved completely fallacious as it has died out in a number of experiments, at Inchnacardoch in the shelterbelt and at high elevation (18.P.26 and 96.P.32), at Beddgelert in severe exposure (14.P.30) and also at Clocaenog (2.P.32). Usually the birch has grown fairly well for a few years but dieback has then started; the plants became bushy and straggling and often they have subsequently died.

In one or two cases a covercrop of birch has been raised but nowhere even a potential timber crop. Thus at Kielder (13.P.29) and Clocaenog (2.P.32) birch was used with alders and rowan as advance crops for Sitka spruce. In the sites chosen, however, the spruce has so far made better growth than the hardwoods, of which birch alone has formed canopy. In the first of these trials separate plots of the two species were planted, and now after twenty years *B. pubescens* at ten feet is twice the height of *B. pendula*. Birch failed in two other experiments at Kielder (19.P.30 and 30.P.36) partly at least owing to game damage. In a fourth it has grown well in mixture with Sitka spruce (15.P.30), growing faster than the latter until cut back in 1938. This experiment now provides interesting contrasts in litter formation under Sitka spruce/birch and spruce/pine mixtures and also under pure spruce. So far the birch admixture has produced no effect on the growth of the spruce.

In Wales a small number of birch are growing fairly well in the species trial at Beddgelert, where they are planted in a narrow strip between pines.

Birch has been little used in experiments in the last fifteen years. Apart from its possible use for timber, more research is needed on its use in mixture as a soil improving species. Its value in exposure and on poor peat has proved to be very low.

SORBUS

Sorbus aria Crantz. Whitebeam has been used in three trials, all on poor peat and in rigorous conditions. In the second Lon Mor species trial a few survive and are about three feet high after twenty years. Growth has been about the same at 1,600 feet in Queen's Forest (11.P.31) while in the high elevation experiment at Inchnacardoch (25.P.29) the small number planted are all dead.

Sorbus aucuparia L. Rowan has been planted in about ten experiments, and has failed completely in most of them. Several were planted without phosphate and failed quickly (Inchnacardoch 18.P.26 and 66.P.28), but even with slag there was only a postponement of check (Inchnacardoch 75.P.29, Kielder 13.P.30, Clocaenog 15.P.34 and 20.P.37). The history of these plots was similar to that of birch, fair or good growth for a few years, then dieback of the crown followed by death. At Beddgelert in the species trial a few survive and are growing and this is also true at Achnashellach (10.P.28), where rowan was planted by several direct methods and on turfs ; planted on lazy beds of moraine the trees now average eight feet high where slag was applied in 1933.

Sorbus intermedia (Ehrh.) Pers. Swedish whitebeam. This species is probably the most promising of the three, and possibly of all the minor hardwoods. Only used in two trials it is healthy, and growing well in both, being the fastest growing species of the conifers and hardwoods included, having attained ten feet after nine years at Clocaenog on *Vaccinium-Calluna* (20.P.37) and seven feet after eight years in the species trial at Kielder on *Juncus-Molinia*. (See Photo 16.)

QUERCUS AND SALIX

Quercus robur L. (=*Q. pedunculata* Ehrh.). Many of a line of oak planted in the second Lon Mor trial are still alive even where they have never received phosphate. After twenty years they are, however, under two feet high.

Salix spp. Willows too were used in this species trial and in one other experiment at Inchnacardoch (PT 33/5). Few survive and growth is very poor.

SUMMARY OF EXPERIENCE WITH SPECIES LESS COMMONLY USED

Of the fifty species discussed in this chapter few can be said to show promise in the existing established plantations. The most promising on the poorer peat are Serbian spruce, hemlock and the silver firs, particularly noble and balsam firs. On better peat western red cedar, Lawson cypress, Douglas fir and possibly selected European larch should be more widely tried. As regards the remaining species, and in particular the hardwoods, though few of them are likely to be much used in afforestation this is not to say that they may not be employed on peat in the future. It must be borne in mind that the plants in the existing trials, almost without exception, suffer from three separate disadvantages. First, the date of planting of the majority preceded the present technique of ploughing and manuring ; second, the attempt was made to establish these species pure and not in mixture ; and lastly it may be possible to grow many of these species in the second rotation when the inhibiting site factors associated with afforestation will have been modified to a greater or less extent.

The effect of improved technique is seen in the exceptionally early growth made by many species in experiments laid down since the war. A large number of species and mixture plots have been planted in the last five years following the successful demonstration of the effects of ploughing and phosphate on the major species. Four species have been selected for intensive trials on the poorest peat: hybrid larch, noble fir, Serbian spruce and western hemlock. (To these might have been added Macedonian pine (*Pinus peuce*) and balsam fir, but seed supplies of these species have been difficult to obtain). These four conifers, most of which had been planted in fewer than a dozen trials prior to the war, have been used in upward of twenty in recent years. Large numbers of other species have also been employed in addition to these four in the following series of experiments :—

(*a*) *Species blocks on the better peat types.* On *Molinia* peat at Kielder (60.P.51-53) and Glentrool (11.P.53), half acre pure blocks of all the species which have grown reasonably well on any similar site, have been planted out together with interesting but untried mixtures such as spruces mixed with Douglas or silver firs. To complete these areas 100-plant plots of potential species such as the lesser known silver firs with hardwoods—oaks birches and alders—these latter never having received fair trial with modern methods, have been laid out.

The underlying reason for these extensive trials on *Molinia* peat is that these areas carry at present large forest blocks which consist perhaps of ninety per cent spruce. As already made clear the spruces, both Norway and Sitka, were found to be relatively easily established as the first crop while almost all other species were not. For the second crop many of the site conditions will be modified and hence the possibility of employing a larger range of species.

In this second stage the first steps have been taken in a seventy year old plantation mainly of Norway spruce at Buckfell, Kielder, on peat two or more feet deep where the original spruce was below quality class IV. Here windblow has left gaps with a clean forest floor and the progressive replanting with a variety of species was started in 1946. The young crops show great promise and much faster growth than is found in the open.

(*b*) *A further method of extending the range of species.* The introduction of some thirty species, including many hardwoods, into young Norway spruce is under trial (Kielder 58 and 59.P.50). The method employed, not perhaps one that would be used in practice, was to open lanes through the crop, then about six feet tall, by removing two rows of trees, plough down the centre and then plant up. This combines the benefits of side shelter and fresh ground preparation, and probably represents the optimum conditions attainable, in the absence of large mature areas that could be regenerated by planting on a shelter wood system.

(*c*) *The use of secondary species in trial plantations.* The third method by which a greater range of species is being tested is to mix other species into blocks of the well known species of which the trial plantations necessarily mainly consist. These are contorta pine in exposure on poor peat, Sitka spruce on exposed but better peat and Scots pine on poorer peats where exposure is less severe. All these plantations are established by ploughing and generally about five acres is planted at any site in any one year and there is great scope for the use of other species in mixture. Some fifteen to twenty sites have been so employed ; more details of these plantations are given in Chapter 9 (page 86).

In conclusion it may be stated that the present list of seven species for peat planting is possibly about to be extended to ten by the regular inclusion under suitable conditions of Serbian spruce, western hemlock and noble fir. In another twenty years the present experimental plantations may indicate yet further species and it is to be hoped that greater success will be reported with hardwoods than has been attained up to the present. A major task for the forester with this increased selection will be to fit each into its appropriate ecological niche.

Chapter 8

MANURING

MANURING of the young trees at the time of planting was one of the lines on which research started after the failure of the early direct plantings on peat. The first trial employed basic slag, which had been used before the 1914-18 war by Sir John Stirling Maxwell at Corrour, Inverness-shire (Stirling Maxwell, 1925) and also to a small extent at Inverliever, Argyll, when under the control of the Office of Woods. The value of slag was quickly realised and a phosphate dressing, in combination at first with turf planting and more recently with ploughing, has for some years, formed the basis of successful afforestation of the poorer peats. (See Photos 21 and 22). On the poorest *Scirpus* peat phosphate is essential for reasonable growth while on the better quality *Molinia* land application is not normally necessary. Subsequent research in the field of manuring has shown that ground mineral phosphate is a better form than basic slag in which to apply phosphate, but no other fertilizer has given results great enough to make large scale application worth while.

A large number of experiments deal with the practical aspects of applying phosphate and they have resulted in the building up of a technique which is in widespread use. One and a half or two ounces of phosphate in powder form is used, and is applied to the turf around the plant as a top dressing soon after planting. Delay in application for more than a year or two after planting is found to result in a reduction of the benefit obtained. This faces the forester with a dilemma ; manuring is an additional cost in establishment and thus to be avoided where no reasonable benefit results; on the other hand if delayed on an area where the benefit is considerable, the loss cannot easily be made good. Thus it is not normally possible to await results before deciding to employ phosphate. The ideal solution is that from experience the forester shall know which species require phosphate on the various ground types in his area. When there is doubt the safest course would be to apply phosphate since the cost is only about five to ten per cent of the total cost of establishment. In some of the poorest forest areas on peat, such as Borgie, all recent plantations have received phosphate as a normal operation.

In the poorer peat areas of the north and west probably a quarter of the total area planted each year receives phosphate, while in other areas the figures would be considerably less, since the proportion of poor peat is very much lower.

Behind this comparatively clear-cut technique lies a wealth of experimental data from more than one hundred trials ; almost half of which were Preliminary Trials, planted on the Lon Mor and "P.22" areas at Inchnacardoch, consisting of small plots of five closely spaced plants. In this way much labour was saved and many more trials laid down than would otherwise have been possible. The small numbers of trees employed, and the fine differences which often exist between the treatments used, make it very necessary to calculate the significance of the results and this has been done wherever possible. Now after fifteen years the majority of these preliminary trials have been abandoned, since with the closing of canopy, mutual interference of the small plots precludes further impartial observation. Their results may therefore be regarded as final except in so far as re-examination of the data might provide some small amount of additional information.

It is worth noting that in many of these trials the various alternative methods employed make little difference to the cost of the operation, so that even if only a small advantage is found to accrue from a particular point of technique it may be possible to reap the benefit in general practice.

PHOSPHATIC FERTILIZERS

Early experiments at Inchnacardoch.

When work on the Lon Mor commenced in 1925 one of the first experiments laid down (12.P.25) tested various manures, among which was basic slag at the rate of 2 oz. per plant. After two seasons the slag was reported as having a 'marked effect' ; Norway spruce had grown half an inch, Sitka spruce one and a half ! In both cases this was double that of the controls and exceeded any results attained on poor *Scirpus* peat at the time. This improvement in growth continued until the third year but for Sitka spruce fell off slightly in the fourth (Table 30).

The unit in this experiment was a single plant, so that by 1928 the experiment was regarded as completed and used for another purpose. By then however the results were sufficiently clear for basic slag to be used in the majority of the experiments laid down in that year. However until results of this and later trials were forthcoming, experiments on other subjects continued to be laid down without phosphate, and there were at

Height and shoot growth in inches from Inchnacardoch Experiment 12.P.25.

TABLE 30 Inches

Treatment	Height in 1925	Shoot			Final Height
		1926	1927	1928	
Norway spruce Control	7.3	0.3	0.5	0.8	8.5
Norway spruce Slagged	7.3	0.4	1.0	1.3	9.9
Sitka spruce Control	9.7	0.7	0.9	0.9	11.4
Sitka spruce Slagged	9.8	1.2	2.8	2.3	15.0

Note.—Discrepancies between shoot growth and final height are due to damage by blackgame and other agencies.

Inchnacardoch some twenty experiments planted between 1925 and 1929 which gave no result at all owing to this omission, and others which gave indications of results only in the first year or so, after which the plants checked.

In the second experiment which employed slag (17.P.26) Norway spruce grew rather better in the early years than in the first trial. The appearance of birch and rowan was improved by phosphate, though the effect on growth was not large.

After the results of the second year's growth were available from the first experiment, application of manure was costed over half an acre (39.P.27), and was found to represent only a very small proportion, under five per cent, of the time spent in ground preparation and planting. In this and other early experiments the slag was mixed with several times its weight in soil as in the classic 'Belgian system'. Transport might have become a serious problem, but this practice was very quickly abandoned as it became apparent that the part played by the soil in improving growth was negligible. Thus the nett weight of basic slag required being only two to three hundredweight per acre, it was clear that large scale manuring was a practical operation.

In 1928 phosphatic manures other than basic slag were incorporated in a manuring experiment on the Lon Mor (Inchnacardoch 43.P.23). They were Ephos, a proprietary mineral phosphate, and Semsol, also proprietary, consisting of a mixture in equal proportions of superphosphate and mineral phosphate. Plants treated with Semsol made double the shoot growth of those with other phosphates in the second year, but in this experiment different quantities of the various phosphates were employed which made interpretation difficult. A second experiment (87.P.30) compared application of equal weights of Ephos, basic slag and other phosphates. In 1932 the data available were those given in Table 31; and this is the starting point from which developed a series of over thirty preliminary trials on phosphatic manures laid down on the poorest *Scirpus* peat at Inchnacardoch between 1933 and 1937, in all of which Japanese larch and Sitka spruce were used as indicators.

Form of phosphate

Table 32 gives the results of different phosphates trials on the Lon Mor and at the "P.22" area using Japanese larch and Sitka spruce in each of the years 1935 and 1936.

Probably owing to the high losses, height growth of the Japanese larch in the individual trials was extremely eratic, but an average of the four shows remarkable uniformity with the different types of phosphate. Sitka spruce remained semi-checked in the two 'P.22' trials, but the growth on the Lon Mor shows differences which suggest that both ground mineral and mixed phosphates may lead to better growth than basic slag. For both species losses with basic slag and ground mineral phosphate are, with one exception, significantly lower than with any other treatment.

Semsol had been used to a small extent in general practice and in a large number of experiments after early reports of its superiority to basic slag, but within a year or so reports came in of high losses in some areas. This series of experiments demonstrated clearly that Semsol and super-

Results available in 1932-33 on phosphatic manures. Heights of Sitka spruce :—

TABLE 31 Feet

Treatment	Inchnacardoch 43.P.28 5 years from planting	87.P.30 3 years from planting
Control, no phosphate	0.8	0.7
Basic slag 2 ozs.	1.1	0.9
Ephos 1 oz.	1.1	—
,, 2 ozs.	—	1.0
Semsol 3 ozs.	1.7	—
Potassic mineral phosphate 2 ozs.	—	1.1

Form of Phosphate. Mean heights and losses at 10-11 years from planting from eight trials at Inchnacardoch.
TABLE 32

Treatment	Japanese larch Means from four trials		Sitka spruce		
	Height Feet	Losses %	Mean Ht. P.T. 35/1 Feet	Mean Ht. P.T. 36/1 Feet	Mean losses from four trials %
Control. No phosphate	2.4	79	Failed	0.7	59
Basic slag	5.7	41	3.1	4.0	16
Semsol	5.2	82	4.2	4.7	38
Ground Mineral Phosphate	5.7	39	3.9	4.8	16
2 oz. G.M.P. 1 oz. superphosphate	5.4	51	4.3	4.6	15
1½ ,, ,, 1½ ,, ,,	5.7	60	3.7	5.5	21
1 ,, ,, 2 ,, ,,	5.5	64	3.6	4.0	31
Superphosphate	5.6	82	3.4	5.4	39
Difference for significance at 5% level	1.3	6	0.77	1.34	8

Notes.—Japanese larch : P.T.'s 35/2 36/2 (Lon Mor) 35/4 36/4 (P.22).
Sitka spruce : P.T.'s 35/1 36/1 (Lon Mor) 35/3 36/3 (P.22).
3 ozs. phosphate except in control plots.
G.M.P.=Ground Mineral Phosphate.

phosphate may be toxic under certain circumstances. While losses in the controls now equal or exceed those with these manures, the control plants have only died slowly after years in check, for in 1939 the deaths were 41 per cent in the control for Japanese larch, half the present figure, but were already 80 per cent in the Semsol plots. It is noticeable also that the losses of both species increase steadily as the proportions of superphosphate is increased in the mixtures. A further point of interest is that for the 1936 trials nearly all the losses occurred in the year of planting, but this was not true in the 1935 series. The experiments were not assessed every year, but the losses in the 1935 series took place between 1936 and 1938, and on the evidence of the second planting it is reasonable to assume that the majority of the losses in the 1935 trials took place in 1936 also. This association of high losses with Semsol at certain places in certain years was seen at Beddgelert in 1933 (12.P.33) and also in the Tough Peat Knoll Experiments (See Notes on Diagram III, page 27) where heavy losses occurred at Bennan and Leanachan in 1935, but not at Inchnacardoch and elsewhere. These years were reported in local summaries of weather conditions as relatively dry. While no precise data are available, it is a reasonable assumption that in drought years, readily soluble forms of phosphate such as superphosphate, present also in Semsol, form a soil solution strong enough to be toxic to tree roots. After the 1936 losses trials of phosphate which contained superphosphate were discontinued.

Further evidence on the comparison of basic slag with ground mineral phosphate is available from an experiment conducted jointly with the Basic Slag Committee set up by the Ministry of Agriculture (Glenrigh 35.P.37, Diagram IX, page 70). This shows that to the thirteenth year Japanese larch has responded almost identically to high grade slag and to mineral phosphate. Many other experiments bear out this result. During the war some very low grade and even apparently toxic slags were on the market and this naturally created a certain bias against basic slag. Research practice is at present to use ground mineral phosphate, but high grade slag produced by the Bessemer process is also satisfactory.

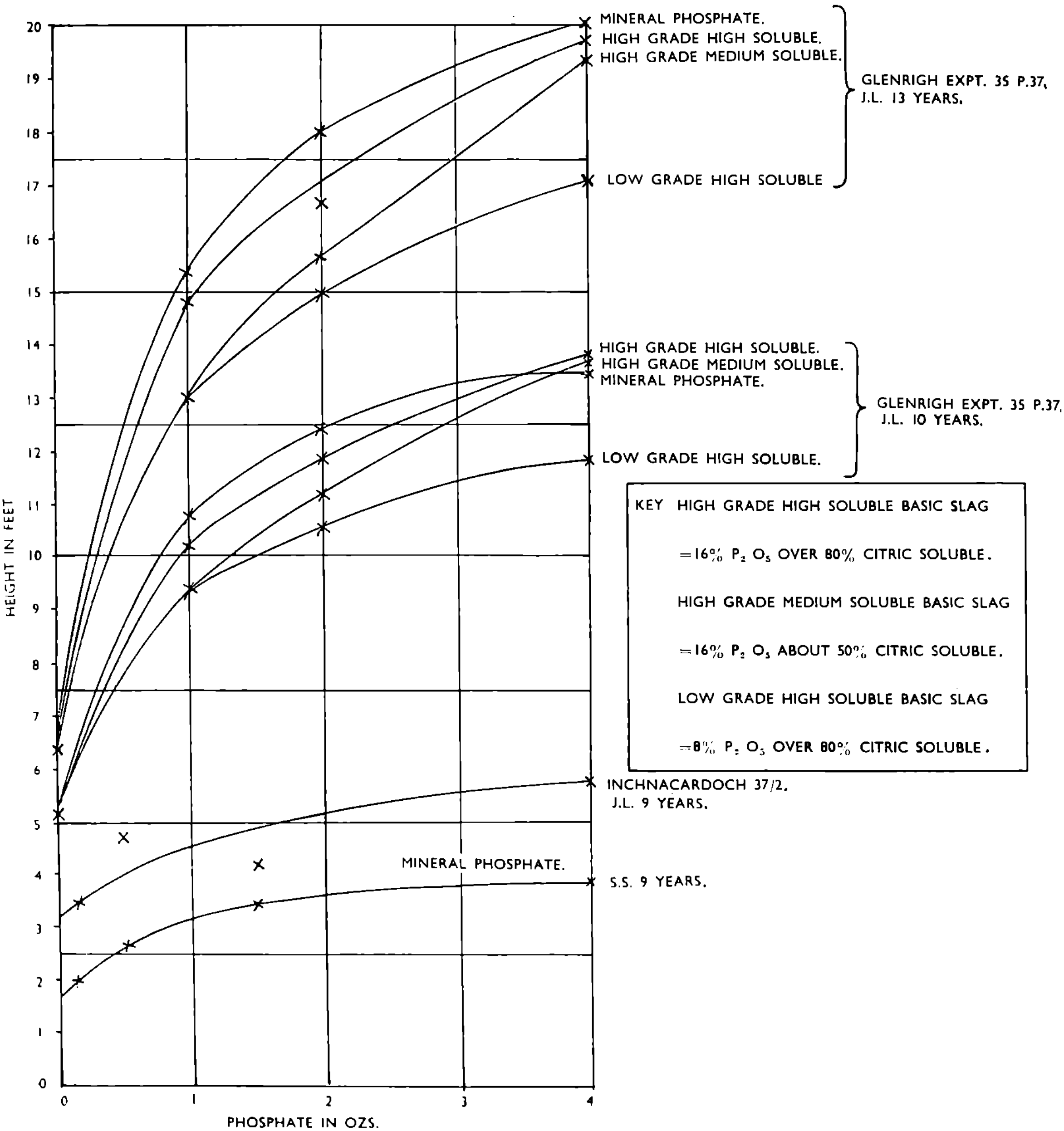
More recently natural phosphates from Fiunary forest and the adjoining estate of Drimnin in Morven, Argyll, have been compared with slag and the imported ground mineral phosphate. That from Drimnin containing 30% P_2O_5 is as good or possibly better than an equivalent weight of ground mineral phosphate but that from Fiunary containing 3% P_2O_5 is of little use. (Inchnacardoch P.T. 42/1.)

Grades of Basic Slag and Ground Mineral Phosphate

In the first experiment on grades of basic slag (P.T. 33/11) Sitka spruce grew very slowly and there is no difference between three grades although other phosphates showed significant differences in growth in the same experiment. A second trial shows a constant trend to better growth with increased phosphate content (Table 33).

The most important experiment is that already mentioned as being conducted for the Basic Slag Committee (Diagram IX). To quote a recent report by Dr. E. M. Crowther of Rothamsted 'low

DIAGRAM IX. QUANTITY AND TYPE OF PHOSPHATE.



Grades of Basic Slag. Height growth in feet at 11 years from planting in Inchnacardoch P.T. 34/2.
TABLE 33

Treatment	% of P_2O_5	Japanese larch	Sitka spruce
Control. No manure	Nil	Failed	Failed
2 oz. Phosphate	13	5.5	3.4
,, ,,	13.5	5.8	3.4
,, ,,	15.5	6.6	3.6
,, ,,	16.5	7.4	3.7

grade high soluble slag is less effective for equal weights of material supplied than high grade high soluble . . . . low soluble slags are known to be relatively ineffective in forestry and should be avoided'.

For ground mineral phosphate various degrees of fineness of grinding have been tested, and fineness is found to have an effect, as shown in Table 34.

Quantity of Phosphate

Early trials with Sitka spruce (Inchnacardoch P.Ts. 33/1 and 33/2) employed basic slag and Semsol in quantities ranging from one half to twelve ounces per plant. In this case there were few losses with Semsol except with the largest quantity, and the growth was half as great again as that with basic slag. Four more similar trials of Semsol with Japanese larch followed in 1935 and 1936. but though a smooth curve is obtained, showing an increase of height with quantity of phosphate, losses were so high that the results are of little interest. The 1937 experiments shown in Diagram IX provided the necessary data for a decision on the quantity to be recommended for employment. It is noteworthy that one-eighth of an ounce of ground mineral phosphate is sufficient to ensure complete survival of Japanese larch and Sitka spruce on the Lon Mor (Inchnacardoch P.T. 37/2). At least for Sitka spruce there is little further increase beyond that given by two ounces of phosphate. In the Basic Slag Committee experiment at Glenrigh, growth of Japanese larch has been much faster than at Lon Mor, but the curves have the same general shape and in three out of four cases the rate of height increase with additional phosphate is falling off rapidly though the maximum absolute increase has clearly not been attained. However it is apparent that between one and a half and two ounces of phosphate provided the optimum dose in these trials when questions of cost of material and transport in the forest are considered. This is the quantity now generally employed and marks a slight reduction from the two to three ounces used in many of the earlier experiments. There are however two trials which employed very large quantities of slag which was broadcast at thirty hundredweight to the acre with striking results on the growth of Sitka spruce. Results for the first at Achnashellach where the slag was applied at planting are given in Diagram XII, page 78, while in the second case at Inchnacardoch (72.P.28) the slag was applied to directly planted and checked Sitka spruce. (See Chapter 10, page 90). Though this rate of manuring could not be economically applied to large areas, it might be practical in a mixture to manure one species more heavily. (See Chapter 6, page 52).

Fineness of Ground Mineral Phosphate. Height in feet at 12 years from planting in Inchnacardoch P.T. 34/4.
TABLE 34 Feet

Treatment	Japanese larch	Sitka spruce
Control. No phosphate	Failed	0.8
2 ozs. High grade slag	9.5	7.0
,, Ground Mineral Phosphate 30% Fineness	9.9	5.9
,, ,, ,, ,, 60% ,, ...	11.6	7.4
,, ,, ,, ,, 90% ,, ...	11.8	7.7
Difference for significance a 5% level....	0.8	1.1

Note.—Fineness means per cent passing a sieve with 100 meshes per inch.

Method of application

The Belgian turf system of planting as evolved in Europe included manuring as occasion demanded. A circular plug of peat was cut from the turf with a Belgian spade and this plug was broken up, mixed with basic slag and soil and replaced in the hole around the roots. Following this practice basic slag and other manures were mixed with soil in the early years. The very high cost of mixing and transport led to the omission of soil from the 1930 manuring experiments. In 1933 this point was checked experimentally (Inchnacardoch P.T. 33/7) ; growth and losses have been identical in the two manurial treatments, in which slag was employed alone and mixed with soil.

Puddling of plants of Japanese larch and Sitka spruce in a mixture of ground mineral phosphate and water immediately before planting was tried at Glenrigh (P.T. 37/1), but results were not as good as with the normal method of application as it was difficult to get more than a very small amount to adhere to the roots. Even minute quantities were shown to improve early growth in this trial.

Placement of phosphate

Interest in the actual position in which the phosphate should be placed relative to the plant and turf was aroused by the first manuring experiment, that on the Lon Mor (Inchnacardoch 12.P.25). Planting was by two methods, Belgian spade and side-notch; in the former the slag was mixed with the plug of peat, but in the latter it was spread beneath the turf. In the second year the plants grew slightly better where planted by the Belgian method but in the next two years the position was reversed (Table 35). A 1928 report suggested this might be of importance since spreading the manure beneath the turf might stimulate production of a more satisfactory root system ramifying beneath the turf, whereas with the Belgian method the manure was concentrated in close proximity to the nursery root system. This latter might give an early advantage but would not necessarily be of such ultimate benefit to the plant.

This question was reopened in the series of preliminary trials at Inchnacardoch and results are set out in Table 36. Placement of phosphate in a lump below the turf gave relatively poor growth with Sitka spruce and to a lesser extent with Japanese larch, and for the latter species this method resulted in much heavier losses even when slag was used. Height growth of Sitka spruce but not of larch was also relatively poor when the lump was placed on the turf at the collar of the plant. Spreading the phosphate gave in every case better growth and also reduced the losses of Japanese larch. With Sitka spruce it made little difference whether the phosphate was spread above or below the turf though in one of the four trials there is bare significance in favour of the top position. For Japanese larch there is conflicting evidence, a twenty-four per cent—ten actual plants—difference with slag in favour of the lower position is however by no means as striking as the forty-four per cent—eighteen plants out of forty—differences in the other direction with Semsol. The evidence is therefore that spreading the manure is advantageous, and that while with Semsol the manure should be as far from the roots as possible, this is not so with slag. The economic aspect must however be taken into consideration. Placement of manures under the turf is an extra expense, and it must necessarily be carried out before planting or the plants will be disturbed ; so that this task would come as an additional operation at the busiest time of the forester's year during the brief planting season. Placement on top of the turf, however may be delayed for a few weeks until the spring planting is completed, since in this case no disturbance of the turf is necessary. Thus the advantages in this respect may outweigh any slight advantage in growth which might be gained from placement below the turf. Top dressing with phosphate soon after planting is now therefore the normal practice.

Time of Application

When it was realised that phosphatic manure was essential to survival and growth on the poorer peat types, experimental top dressing of early

Shoot growth of Sitka spruce in Inchnacardoch Experiment 12.P.25.

TABLE 35 Inches

	Mean Shoot		
	1926	1927	1928
Belgian planting—manure in hole	1.4	2.2	1.9
Side notch—manure spread below turf	1.2	2.8	2.3

Placement of phosphatic manures.
Percentage losses and height growth in feet at 11-12 years from planting in Inchnacardoch P.T.'s 34/5, 36/7 and 36/8.

TABLE 36 — Heights in feet

Placement :— (2 or 3 oz.)	Slag				Semsol			
	Sitka spruce		Japanese larch		Sitka spruce		Japanese larch	
	34/5	36/7	34/5	36/8	34/5	36/7	34/5	36/8
Lump at collar	4.0	—	5.0 (16%)	—	5.1	—	(88%)	—
Spread on turf	4.7	3.1	5.0 (16%)	10.2 (60%)	5.9	5.3	(8%)	(75%)
Lump below turf	2.2	—	4.0 (28%)	—	4.4	—	(76%)	—
Spread below turf	3.7	3.1	4.5 (16%)	8.8 (36%)	5.9	4.8	(56%)	(75%)
Difference for significance at 5% level	1.0	—	2.3	—	1.0	—	—	—

Note.—Losses of Sitka spruce negligible throughout.

direct plantings was undertaken; but as in these cases the plants were by this time in full check, these trials are considered under the heading of "Salvage of Checked Plantations" (Chapter 10, page 90). Many turf-planted experiments, initially without phosphate, were also top dressed but at a relatively earlier age before checking was so general. In the majority of these trials obvious benefit was obtained from late dressings, though the relative effect compared to that derived from manuring at planting is not easy to judge.

One possibility which was examined was that the time of planting was not the best time at which to apply the initial dressing. Semsol was placed under the turfs three years in advance of planting Sitka spruce ; slag and Semsol have been similarly applied one year in advance, and Semsol has been given as a top dressing two years after planting to both Japanese larch and Sitka spruce (Inchnacardoch 76.P.29, 114.P.35 and P.T. 33/10). In no case was there the slightest advantage over the normal application at time of planting, except in so far as the latter gave slightly heavier losses with Semsol. One of these trials (76.P.29) included the use of a heavy phosphate dressing for Sitka spruce transplants in the nursery, as an alternative and in addition to field manuring. No benefit was observed, the plants manured only in the nursery checked, just as all other spruce have done when planted on the Lon Mor without phosphate, similarly the nursery manuring led to no additional growth of plants treated with phosphate at planting in the normal manner.

The growth of the first spruce planted with phosphate started to fall off in the fourth year (12.P.25), and it became obvious that a second dressing would be required, if growth was to be maintained. A very complicated experiment was laid down to assess when and how often top dressing was necessary for a crop of pure Sitka spruce on poor basin peat dominated by *Scirpus*. In this particular experiment there has been little apparent benefit from top dressing ; possibly the controls left were too small and benefitted by shelter or through root interaction or needle fall as they are much better than expected. (Inchnacardoch 74.P.29)

A positive result was obtained from a large scale costing experiment on the Lon Mor used subsequently for top dressing trials. (Table 37).

The original manure has kept the plants alive for twenty years; they grew one inch annually. The heavy dressing in 1930 has produced a growth increase but a far smaller amount would probably have been equally satisfactory, since in 1939 the heights of plots having had only the 1927 or 1930 dressing were about equal. The better plots in this experiment are now forming canopy.

More recently in the Golden Valley area at Achnashellach (17.P.33 and 20.P.34) a heavy top dressing of slag has been applied to plots of Japanese and hybrid larches in which growth appeared to be falling off after an excellent start in the first ten years. No difference has been observed so far between control and top dressed areas. Good results have been obtained in several cases from the late top dressing of the older Sitka spruce experiments on the Lon Mor as shown in Diagram II (page 25) and also in one case with contorta pine (47.P.28). Planted without manure this species had reached seven feet at eighteen years, but the section of the experiment top dressed in 1939 had attained fourteen feet at the same age. Excellent results have been obtained at Glenrigh with pines and larches, but not spruce, again by top dressing six to ten years after planting (Diagram VII, page 59).

Where such results are obtained the trees have usually been growing, even though slowly, previous

Mean height of Sitka spruce at 20 years from planting in Inchnacardoch Experiment 39.P.27.

TABLE 37 Feet

Subsequent top dressings :—	Manuring in 1927: None	Manuring in 1927: 2 oz. Basic slag + ½ oz. Magnesium sulphate
None	2.8 (89% failed)	2.6
3 ozs. Ground Mineral Phosphate 1939	—	4.0
12 ozs. basic slag 1930 3 ozs. Ground Mineral Phosphate 1939	5.1	6.3
12oz. basic slag, 12 oz. potash 1930 3 oz. Ground Mineral Phosphate 1939	6.2	7.1

Note.—Losses negligible except in unmanured section.

to dressing. Where this is not so, late top dressing appears to have only a very small effect ; in certain cases at Achnashellach (7 and 8.P.28) phosphate was applied too late to save the spruces and has had little effect on pines and larches. Generally late application of phosphate takes three or more years to become effective on growth rate, though the colour and general appearance usually improve earlier. In general practice top dressing is an operation only resorted to when it becomes apparent that severe checking is becoming widespread in a particular area.

Interaction of Phosphate with Different Species and Ground Types

The majority of the experiments covered in the previous sections were on the poorest types of peat obtainable. They were laid down on the theory that if a satisfactory technique was established in such sites, then any modifications necessary for better ground were likely to be in the direction of simplification. From the practical point of view one of the main advantages derived from the use of phosphate is the reduction of early losses, and hence of the need for beating up. For the extreme cases the position is clear; without phosphate on the poorest peat complete failure results with almost all species, though ragged pine crops may be raised. In contrast, on the areas dominated by *Molinia* in the Border country, losses are usually below five per cent and phosphate is not normally employed. It is difficult from the experiments to give any figures for the saving in losses on the intermediate types, since they are usually erratic and vary greatly from year to year. In these circumstances any figures would be meaningless unless compiled from a general survey of the experiments, taking into consideration both vegetation type and other site factors and also the climatic conditions of the early years. Phosphate appears to have little effect on first year losses, but by the improvement of foliage and colour and hence growth, losses in subsequent years are reduced. Much more even early growth is also obtained, and for this reason phosphate is employed far more widely in experimental than general practice, since a more uniform material is obtained upon which to gauge the effects of other treatments.

The growth rates of the different species on different vegetation types in the absence of and with slag may be compared in a number of experiments all of which were turf planted. The response varies considerably with the species and is largely determined by the site. It is comparatively easy to generalise as far as the first is concerned; pines, particularly mountain pine, are relatively insensitive, while larches and spruces are relatively more sensitive to phosphate. An attempt has been made to show the effect on the early growth combined with the site interaction in Diagram X, which displays the heights reached at eight years from planting in a number of experiments.

To compare the sites first ; from the original vegetation, those of Kielder 27.P.36 and Inchnacardoch might be expected to give the best growth as included among the dominants was *Molinia* though at the latter *Scirpus* was also abundant. Between the other sites there was little to choose as far as vegetation was concerned ; the site for Kielder 25.P.36 (See Photos 19 and 21) was chosen as relatively exposed and that for 28.P.36 as being a worse peat type than that of 27.P.36. Growth without phosphate follows very much the lines indicated by the site types. With the addition of phosphate the position alters considerably. At Inchnacardoch and at Achnashellach growth was

DIAGRAM X. HEIGHT IN FEET AT 8-9 YEARS, OF VARIOUS SPECIES PLANTED WITH AND WITHOUT PHOSPHATE, IN EXPERIMENTS ON DIFFERENT PEAT TYPES.

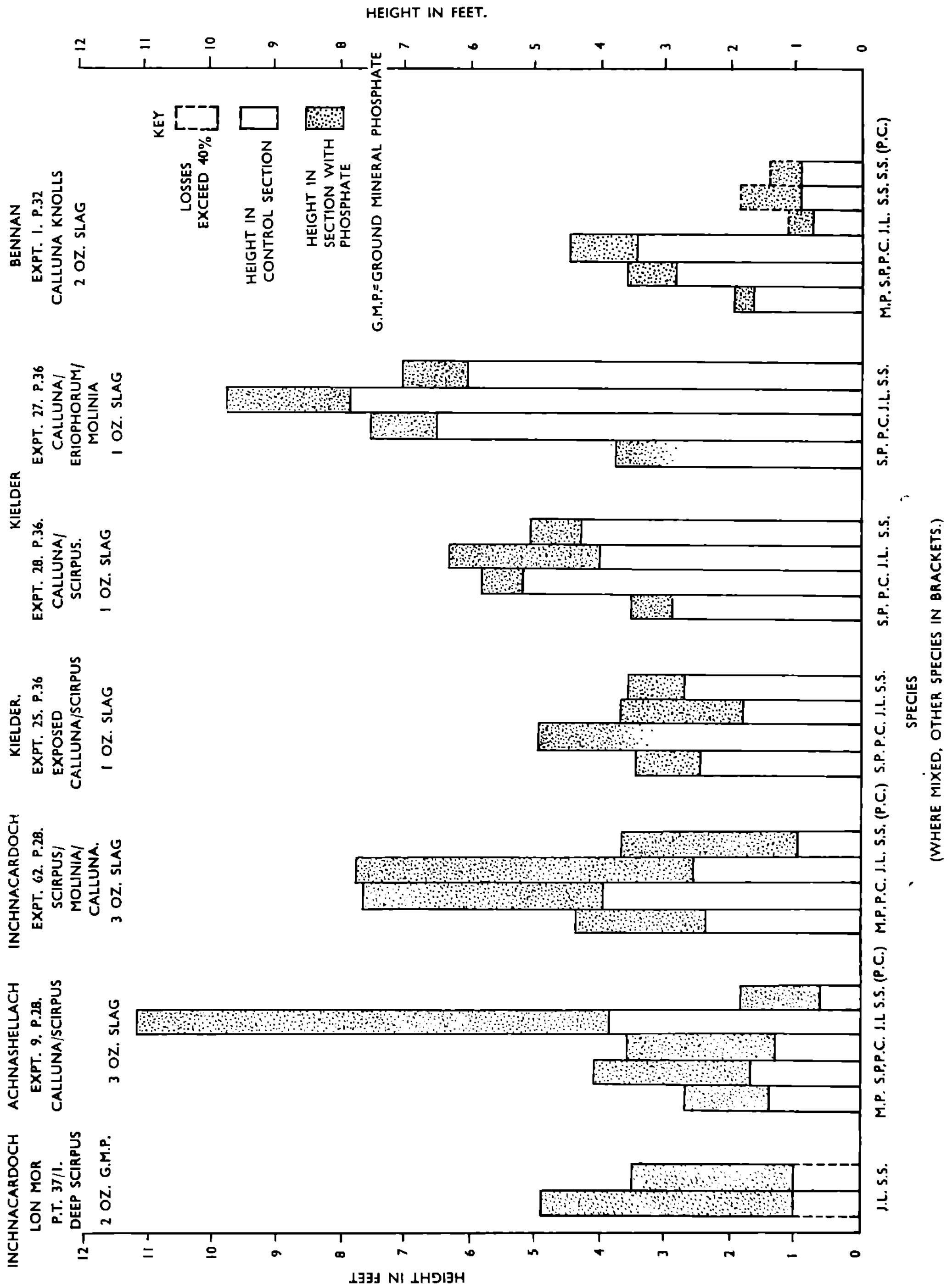
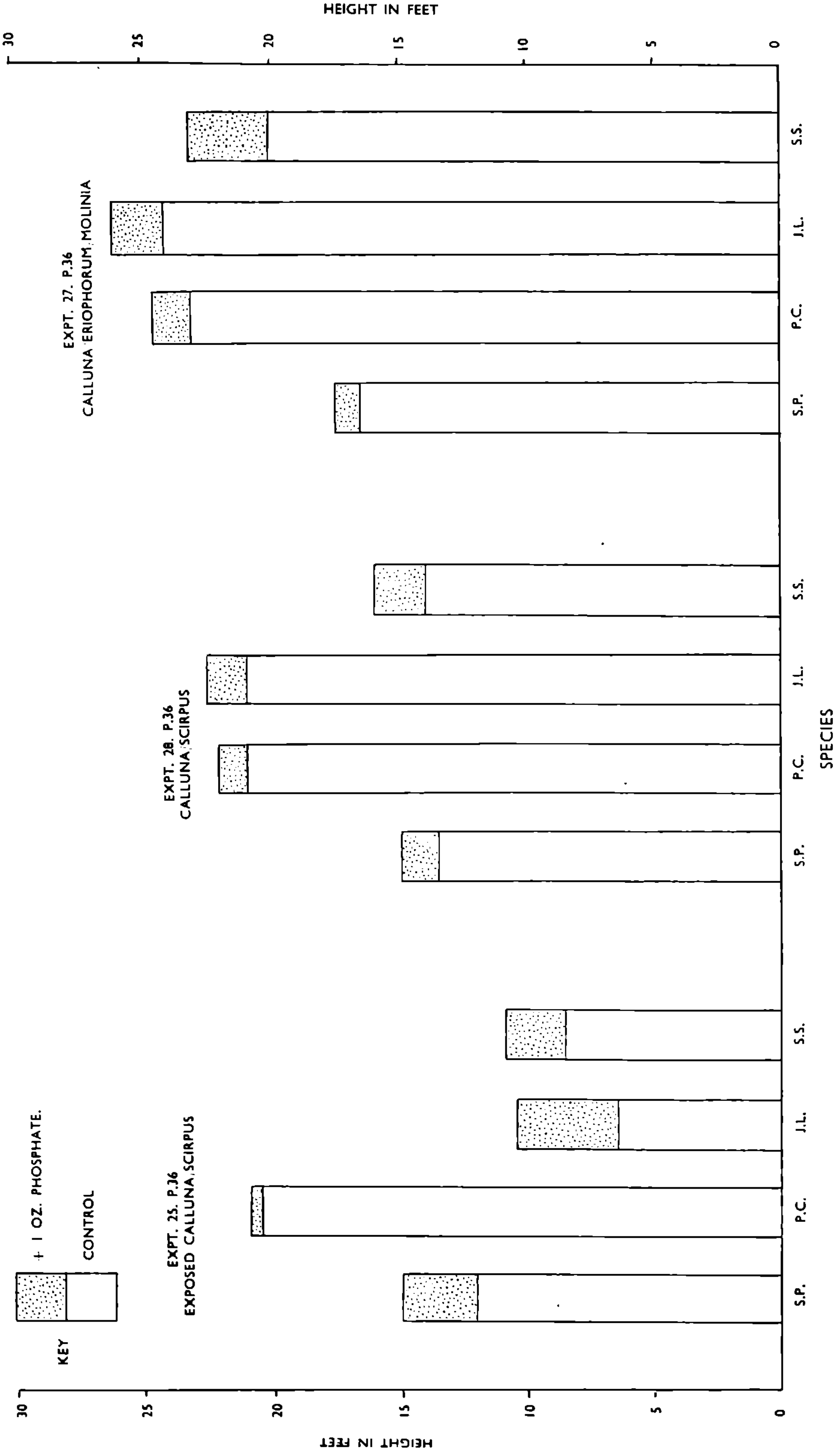


DIAGRAM XI. DOMINANT HEIGHTS AT 17 YEARS FROM PLANTING IN KIELDER EXPERIMENTS, WITH AND WITHOUT PHOSPHATE, ON DIFFERENT PEAT TYPES.



increased by about 60 per cent for mountain pine, and up to 200 per cent for Japanese larch and Sitka spruce, while at Lon Mor the difference was between complete failure and growth. At the other four sites with Japanese larch, only in Kielder 25.P.36 did phosphate increase growth by more than about 20 per cent ; and in two cases with pines there was no effect at all.

The later development of certain experiments of this series is shown in Diagrams XI and XII. In the three experiments at Kielder the differences between control plots and those with phosphate continues to increase, but the proportional effect has remained almost constant. Diagram XI shows interesting contrasts in growth rate and in the effect of phosphate. While contorta pine has grown fairly steadily in all three sites, Japanese larch changes from the poorest to the fastest growing species but in spite of this the effect of phosphate is almost constant though relatively greatest on the poorest site. The behaviour of Sitka spruce follows that of Japanese larch, while Scots pine shows a marked response to phosphate on the poorest site but practically none on the best.

In the experiment at Bennan only Scots and contorta pines have formed a crop and phosphate has continued to give only a small increase. The experiment at Inchnacardoch was burnt in 1942, but enough examples have been given in the preceding chapters to show that phosphate is essential for good growth of all species at Lon Mor or the "P.22 area".

Achnashellach 9.P.28 continues to provide one of the outstanding demonstrations of the effect of phosphate. (Diagram XII). With every species included, but particularly Japanese larch and Scots pine, the plots alternate from well developed and healthy crops to open areas with twisted and often moribund trees, according to whether slag was applied or not. To emphasize the importance of phosphate in this area the results from a second experiment which received heavy dressings are also illustrated. A younger experiment in the Golden Valley at Achnashellach is also most striking. A block of Scots pine was planted from seed of local native pine in Glen Uig (22.P.36). After fourteen years the height of the control section is three feet, while the adjacent section with phosphate is twelve feet high. (See Photo 22).

It has already been necessary to thin twice the manured Japanese larch in 9.P.28 ; the difference in the pines is such that poles will be available at a far earlier date from the slagged plots.

These Achnashellach plots, along with almost all the early experiments, are not large enough to allow a true estimation of the effect of phosphate on production. It is noteworthy that some of the experiments on better types of peat show little or no effect from phosphate now, though in their early years there was perhaps a difference of several feet in height growth (Kielder 14.P.30). Such results have on occasion been cited as indicating that phosphate provided only temporary stimulus on such land. It is however also possible that mutual shelter, root interaction and drifting of litter is in fact responsible for the gradual evening up of the small plots regardless of their original treatment. Accordingly in recent years a series of large-scale phosphate tests have been started on these intermediate peat types, using half-acre plots in order to estimate the effect of the standard phosphate application on production (Kielder 65.P.52, Glentrool 10.P.52).

The second line of experimentation at present in hand is the re-investigation of differential manuring in mixtures on the poorest peat types, using heavy doses for spruce or fir in mixture with pines which receive a minimum application (Watten 2.P.51, Inchnacardoch 140.P.52, Glentrool 9.P.52).

In general practice, phosphate at present is applied mainly to spruces and larches whenever they are planted on poorer peat types, though in certain areas in extreme conditions all species are given phosphate. Differential manuring in mixtures is also a common practice, in so far as applications are made to the spruce or other nursed species, but not to the pine nurse.

USE OF FERTILIZERS OTHER THAN PHOSPHATE

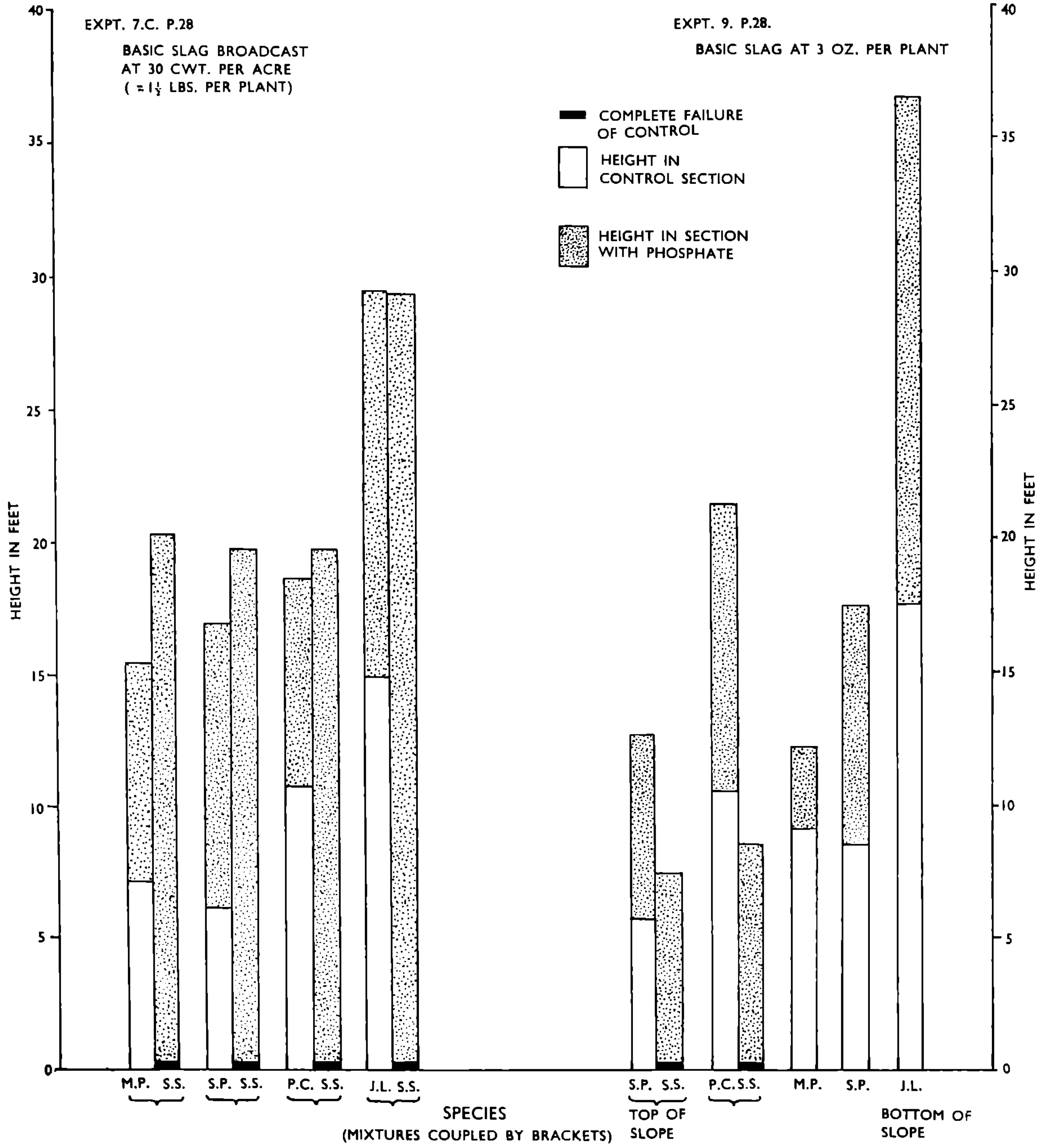
Comparatively little systematic research has been carried out on fertilizers apart from that on phosphates. From time to time trials have been laid down incorporating a variety of sources of nitrogen, potassium and magnesium, and also trace elements such as boron and copper. Since the initial trials have given no such positive effect as was obtained with basic slag, many fertilizers have been used only once or twice. In some cases it is probable that there has been faulty technique in the method of application, particularly before the heavy losses with Semsol had been sustained and the importance of placement realised.

The whole subject of forest manuring is at present being investigated on the heathlands of Yorkshire and Dorset and results obtained there will be considered in the light of possible application on the peatlands.

Potassium

The first application was as kainit; 1 oz. mixed with sand was applied to Norway spruce, rowan

DIAGRAM XII. DOMINANT HEIGHTS IN FEET AT 23 YEARS OF VARIOUS SPECIES AND MIXTURES PLANTED WITH AND WITHOUT PHOSPHATE IN TWO EXPERIMENTS AT ACHNASHELLACH.



Comparison of potassic and non-potassic phosphates: Table of heights and losses from Inchnacardoch Experiments.

TABLE 38 Heights in feet

Treatment : 2 oz. phosphate except where noted otherwise	115.P.35 at 11 yrs. Pinus contorta	115.P.35 at 11 yrs. Japanese larch	P.T. 34/3 at 12 yrs. Japanese larch	P.T. 34/3 at 12 yrs. Sitka spruce	P.T. 33/11 at 12 yrs. Sitka spruce	87.P.30 at 15 yrs. Sitka spruce
Control, no manure	3.4	1.4	—	—	0.7 (44%)	1.0 (30%)
Semsol	—	—	12.2	5.0	2.2 (28%)	—
Basic slag	8.6 (3 ozs.)	4.6	9.9	5.7	1.7 (24%)	3.4 (6%)
Potassic slag	—	—	8.7	4.3	1.1 (64%)	—
Ground mineral phosphate	—	—	—	—	2.0 (32%)	4.4 (14%)
Potassic mineral phosphate	—	—	12.6	5.9	—	4.7 (36%)
1 oz. Superphosphate, 2 ozs. G.M.P.	8.6	5.0	—	—	—	—
1 oz. Superphosphate, 2 oz. Potassic G.M.P.	10.1	4.9	—	—	—	—
Superphosphate	—	—	—	—	2.5 (84%)	—
Potassic superphosphate	—	—	10.6	3.6	3.5 (56%)	—
Lime phosphate	—	—	12.2	5.2	—	—
Difference for significance at 5% level....	3.3	1.0	1.7	1.5	0.7	Systematic layout
	Losses due to deer		Losses negligible			

and birch (Inchnacardoch 17.P.26). Every plant of Norway spruce died the first year where Belgian turf planting was employed and the manure was mixed into the plug of soil ; a few survived where the kainit was below a shallow turf planted by a side notch. The hardwood species also suffered heavily, all the birch dying, but with rowan a few again survived on the shallow turfs.

Potassic phosphates have been used in several trials, often in contrast to the corresponding non-potassic phosphate. Results are given in Table 38. It appears that while potassic slag is probably inferior to high grade slag, potassic mineral phosphate may be as effective as Semsol ; the latter happens in these particular experiments to have had no harmful effects. Potassic mineral phosphate has also given excellent results as a top dressing with Scots pine and Japanese larch at Glenrigh (Diagram VII, page 59). Nowhere however was it intensively compared with ground mineral phosphate of comparable composition.

Sulphate of potash has also been used, alone at Beddgelert for Sitka spruce (7.P.28), and in combination at Inchnacardoch for Japanese larch and Sitka spruce (124.P.39), but in neither case has any positive result emerged.

Nitrogen

Ammonium sulphate was used as a top dressing in early experiments at the Lon Mor, both alone and in combination with basic slag. (Table 39). From the results it is clear that sulphate alone has had no effect on growth but has led to higher losses. In combination with slag there is a slight beneficial effect, shown by shoot measurement to have been effected in the first four years. No such effect was however seen with Sitka spruce at Beddgelert on good *Molinia* in the one experiment where it has been employed (9.P.29).

Nitrochalk in combination with slag was applied below the turf in one experiment; losses were seventy per cent within two years, when in all other treatments they were negligible (Inchnacardoch 87.P.30). This manure has recently been tested for use in direct sowings on peat, but again losses have been high.

Hoof-and-horn manure was employed by itself at Beddgelert (7.P.28) and made no difference to growth either on poor *Scirpus* or better *Molinia* grass vegetation. In direct sowings heavy failures have resulted from the use of three-quarters of an ounce of hoof-and-horn in a balanced fertilizer, and the losses have been shown to be due to failure of germination, or to death in the earliest stages of germination.

Complete Nitrogen-Phosphorus-Potassium Fertilizers

In 1939 two experiments on complete fertilizers were laid down in co-operation with Dr. Stewart

Ammonium sulphate. Height growth and losses of Sitka spruce from experiments on the Lon Mor, Inchnacardoch.

TABLE 39 Height in feet

Manures	43.P.28 after 8 years		83.P.29 after 9 years	
Control, no manure	0.6	24%	0.7	11%
2 ozs. Basic slag (+1 oz. Mag. Sulph.)....	1.2	4%	3.0	10%
1 oz. Ammonium sulphate	0.7	61%	0.7	28%
2 ozs. Basic slag+1 oz. Amm. Sulph.	—	—	3.5	4%
Difference for significance at 5% level....	—	—	0.6	—

Note.—Magnesium sulphate is known to have little effect.

of the Macaulay Institute for Soil Research, using Keronikon, a proprietary hoof-and-horn manure and a granite flour, as slow acting forms of nitrogen and potash respectively, in view of the high losses with readily soluble forms such as kainit and ammonium sulphate. (See Table 40). The complete fertilizers have given a slight improvement on the Lon Mor, but in the "P.22" trial the complete fertilizer using granite flour, but not that using potassium sulphate, has given considerably faster growth. The potassium sulphate appears to be actually harmful since in every case when it is included growth is slower than with phosphate alone. It seems probable that the addition of these substances to phosphate will be economic only in special cases. One such is perhaps in direct sowing operations, and recently a complete fertilizer consisting of ground mineral phosphate, hoof-and-horn and potassium sulphate has been used. The hoof-and-horn, as already mentioned, proving harmful, slower acting plastic waste is now being tried as a source of nitrogen.

Calcium

Ground limestone has been used with the complete fertilizer for Japanese larch and Sitka spruce at Inchnacardoch (124.P.39, Table 40), and magnesic limestone also has been tried with Sitka spruce at Beddgelert (7.P.28); in neither case was there any appreciable effect. Lime phosphate gave good results in one trial (see Table 38), growth of Japanese larch being as good as with Semsol. Trials using lime in combination with phosphatic or complete fertilizers are now in hand.

Magnesium

Magnesium sulphate was used for spruces in the first manurial trial at Inchnacardoch (12.P.25). A slight beneficial effect was obtained in the first three years, though it was only about one-third

Trials of complete fertilizers.
Heights in feet of Japanese larch and Sitka spruce at ten years from planting in Inchnacardoch Experiments 124 and 125.P.39.

TABLE 40 Feet

Treatment	Japanese larch		Sitka spruce	
	124 (P.22)	125 (Lon Mor)	124 (P.22)	125 (Lon Mor)
P	7.8	7.9	4.5	2.8
PK_1	8.5	8.9	3.5	3.2
PK_2	6.9	—	3.2	—
NP	10.2	—	3.3	—
NPK_1	11.0	8.9	5.4	3.3
NPK_2	6.2	—	3.1	—
PK_2+Mg+Ca.	6.0	—	3.3	—
NPK_2+Mg+Ca.	6.9	—	3.5	—
Difference for significance at 5%	3.3	2.4	1.7	0.6

Note.—P=2 ozs. ground mineral phosphate
K_1=5 ozs. granite flour.
K_2=$\frac{3}{8}$ ozs. potassium sulphate.
N =$\frac{1}{2}$ oz. Keronikon.
Mg=$\frac{1}{4}$ oz. Magnesium sulphate.
Ca=$\frac{1}{4}$ oz. ground limestone.

of that obtained with slag. As a result however half an ounce of magnesium sulphate was added to two ounces of slag in several more manuring trials (Inchnacardoch 43.P.28, 83.P.29 and 88.P.29); in no case was increased growth achieved and this result is confirmed in the experiments where magnesium was added to the complete fertilizer (124.P.39—Table 40). Various other salts of magnesium were tested after the early positive result. Applied alone in the first instance (35.P.27) a top-dressing of slag was given in 1930. Again there was no noticeable effect, except that losses were lowest in the control which received only the top-dressing.

Boron

Boronated slag was tested on Japanese larch and Sitka spruce at Glenrigh in comparison with basic slag and ground mineral phosphate. There were no appreciable differences in height growth or losses (P.T. 37/2).

Copper

Trials of this element followed reports of success in application to agricultural crops on acid soils in the United States. Addition of one grain of copper sulphate to the normal two ounces of ground mineral phosphate made no difference to the growth of Japanese larch or Sitka spruce. (Glenrigh P.T.37/1).

Iron

Ferrous sulphate was used in one early experiment without effect on height but losses were increased (Table 41).

Iodine

One trial of potassium iodide resulted in very heavy losses. (Table 41). The iodide was applied as a top dressing after planting, mixed with the ferrous sulphate and sulphate of potash. The improved growth of the few survivors is of interest.

Peat, Composts etc.

Apart from trials of direct sowing (Chapter 10) very little work has been carried out on organic manures. This is largely because the bulk of material which would be required for forest scale work is so great as to make the cost of transport on to the planting areas prohibitive. To supply one pound of compost per plant would require approximately one ton—eighty cubic feet—of material per acre.

In 1923, planting in the forest at Inchnacardoch had included an abandoned peat stack on which it was apparent by 1929 that Sitka spruce were growing remarkably well. In that year a trial planting was laid down in which peat from the stack was placed beneath each turf in a single plot with a surrounding control area (85.P.29). There was a small transitory effect, the treated plants maintaining a better colour for several years, though growth was negligible. A small amount of the same peat was mixed with Semsol in a second trial (Inchnacardoch P.T. 33/3) but has made no difference to growth.

Top dressing with peat and clay from drains was tried at Kielder (12.P.29) and Beddgelert (9.P.29) for contorta pine and Sitka spruce on *Scirpus-Calluna* land. At the latter site there has been possibly a slight improvement in growth as a result of this dressing.

Litter from a stand of Douglas fir was applied in 1933 as a top dressing to checked Sitka spruce in an older experiment (Inchnacardoch 13.P.25). The result was a slight but temporary increase in the growth rate. (Table 42).

Height growth at fifteen years from planting in Inchnacardoch Experiment 13.P.25.

TABLE 42 — Feet

	Control	Slagged
Untreated	1.1	2.5
Top dressed with litter at 8 years	1.2	3.6

Trial of Iron, Potassium, and Iodine. Early losses and height of Sitka spruce 15 years from planting in Inchnacardoch Experiment 88.P.30.

TABLE 41

	Height in feet	Losses to 8 yrs. %
Control	1.0	4
2 ozs. slag	3.1	8
Slag+½ oz. Magnesium sulphate	2.8	10
All above +1 oz. sulphate of potash	3.0	24
,, +1 oz. Ferrous sulphate	3.2	22
,, +½ oz. Potassium iodide	3.9	82

Recent trials have included the use of additional turf as a mulch to semi-checked Sitka spruce; this results in a quick improvement in their colour but the experiments are not old enough to show yet whether this will be followed by an increase in growth. (Kielder 64.P.52.)

Chapter 9

TRIAL PLANTATIONS AND HIGH ELEVATION EXPERIMENTS

From time to time experimental plantations have been established by the Research Branch as a natural sequel to a series of experiments. They combine all the available knowledge at the date of planting and put it to the test on a practical scale. These plantations are located for the most part on the poorer and in many cases high lying areas, considered unplantable for normal afforestation. The few actual experiments involving comparative treatments at high elevations are most conveniently considered here. In the last few years certain similar trials have been laid down in the far north of Scotland to test the possibilities of afforestation in that area.

Experiments generally suffer from several disadvantages compared to full scale plantations. The majority are on land considered originally to be unplantable and therefore are in full exposure. The site occupied is usually small and in addition there may be blanks where a particular species or treatment has failed. Thus the experiments in many cases are unlikely to develop true forest conditions, and as they grow older so their growth will, mainly through exposure, deviate more and more from the growth that would be obtained in a sizeable stand established on the same site. This is the situation which the trial plantations and high elevation plots are designed to overcome. In addition to being essays in afforestation they will provide long-term data on rate of growth on these poor peat lands.

TRIAL PLANTATIONS

The most complete series of these plantations is at Inchnacardoch where there are eleven at the present time, the first planted in 1922 and the latest in 1947. These are considered in chronological order below, those at other sites being referred to in passing.

The first series of trial plantations on poor peat preceded the main body of experiments. They were among the few extensive experimental areas planted by direct methods and were sited at Inchnacardoch (2.P.22 and 5.P.23) and Glenrigh (1.P.24). All were somewhat over-ambitious, lying well outside the land plantable by methods then current, and within a few years attempts at their repair were made by introducing turf planting and phosphatic dressing. The more or less obvious failure of these plantations was thus the stimulus to a great deal of the later work in these forests, and indicated the need to find more suitable methods by small scale trials before embarking on further large scale planting. It was not in fact until five years later that this stage was reached.

The next three plantations at Inchnacardoch are all based on the Anderson group system of planting which has been fully described elsewhere by its originator (Anderson, M.L. 1951 and 1953). In designing this system of group planting Anderson had in mind a number of advantages which might accrue. Of these, those relevant in the present instance for poor peat are that grouping the plants without increasing the number of trees and hence the cost per acre would :—

(*a*) make intensive hand cultivation and intensive manuring feasible ;

(*b*) induce canopy formation at the earliest moment so as to suppress the ground vegetation and thus benefit growth ;

(*c*) facilitate weeding ;

(*d*) allow the best spots to be picked for planting on irregular ground.

Later on in the life of the plantation he hoped that grouping would result in

(*e*) clean stems in the inside of the groups;

(*f*) long lateral extension of roots between the groups to give added stability;

(*g*) freedom of movement through the plantation for inspection and tending;

(*h*) the removal of the need for thinning in remote areas where thinning did not pay.

Anderson also noted the possibility of mixing by groups where species were of unequal growth rate and of mixing within groups to shelter a difficult species. (See Photo 24). He realised that the chief disadvantages were likely to be the risk of the outer trees of the groups becoming dominant or at least becoming so irregular as to give inferior thinnings.

It is too early as yet to estimate the degree of long term success attained by this system but there is no doubt as to its effectiveness in the establishment of these earlier trial plantations on poor peat.

In the first plantation using groups on the Lon Mor (Inchnacardoch 75.P.29), only mountain pine, Sitka spruce and rowan were employed, and growth has been very slow, the groups rarely exceeding ten feet in top height after twenty years, except in the richest flush hollows, where groups of pure spruce average fourteen feet. The groups were widely spaced and closure of canopy between them will not occur for many years.

In 1930 and 1931 two trial plantations of ten and five acres respectively, were planted, mainly by the group system, in the "P.22 area", and have been for the most part successful. The design took into consideration the results of the earliest experiments on the Lon Mor, which included those suggesting the value of shallow turfs, basic slag and close spacing; and the indication that pines, particularly contorta, would grow on such sites, whereas spruce would not, at least when planted pure. Details of the planting prescription and results in the earlier of the two are given in Table 43.

The whole area is of blanket peat over morainic mounds and the intervening hollows alike; it was carefully charted before planting and the crop types laid out according to the site and vegetation. Draining was thorough, girdle drains being cut down to the mineral soil round each of the morainic mounds and linked to the main outfall. The thirteen to fifteen plants in each group were spaced two feet apart with group centres eighteen feet apart. The number of plants used per acre is equivalent to that of a normal plantation with a spacing of four-and-a-half feet. Single turfs were used on the upper slopes but where intensive draining was necessary on the lower slopes and flats, grouped turfs were used for each plant.

The plantation may be rated as most successful. The cost of establishment in 1930 was just under ten pounds per acre. It has received comparatively little attention since then, except for the freeing of the tops of the Sitka spruce in some of the mixed groups. The failure of the Oregon alder has, however, led to the paradoxical result that the poorest crop now stands on the best of the peat types as assessed at the time of planting, the Sitka spruce having made poor growth in the absence of a nurse.

The second plantation of this type (Inchnacardoch 93.P.31) lies near the first but on rather better and more sheltered ground. The prescription was practically identical so that the Orgeon alder and Sitka spruce groups form a larger proportion of the whole, and consequently the general appearance is rather poorer. The various crop types have made almost identical growth to that obtained in the first experiment. This second experiment, however, contains two borders with crops at normal spacing which may be compared with the adjacent Anderson groups ; results of recent assessments are given in Table 44.

From this table it would appear that grouping in itself results in no increase in height of Sitka spruce, nor does grouping Scots with contorta pine lead to any improvement here. Grouping Sitka spruce with Scots pine has, however, been most successful, height growth of the spruce being doubled as shown in Table 25 (page 51). In one section of this experiment the spruce now dominates the mixed groups, and here also is twice the height of adjacent groups of pure spruce.

In the same years 1930-31 similar trials were laid

Summary of Inchnacardoch Experiment 86.P.30 showing the location of the main crop types and their development.

TABLE 43

Site	Vegetation	% of area	Crop	State of crop after 20 years
Knoll tops Knoll sides	*Calluna* ,,	7½%	S.P. directly planted 3 ft. x 3 ft.	7 ft. top of knoll 18 ft. at sides
Slopes above girdle drains	*Scirpus*	32%	Groups of 9P.C./4S.P. on turfs	P.C. 14-20 ft. aver. 18 ft. S.P. 14-20 ft. ,,
Slopes below girdle drains	Intermediate	32%	Groups of 9S.P./4S.S.	S.P. 18-20 ft. S.S. 14-19 ft. aver. 15 ft.
Flats	*Scirpus* *Molinia-Myrica*	20%	Groups of 5.O.A./10S.S.	Oregon alder failed S.S. 5-8 ft.

Notes.—S.P.=Scots pine, P.C.=Pinus contorta, S.S.=Sitka spruce, O.A.=Oregon alder. Groups spaced at 18 ft. between centres.
Heights shown are top heights, being the means of the tallest trees in a number of adjacent groups or in equivalent areas of normal planting (18 ft. x 18 ft.).

Comparison of dominant heights of crops at normal spacings and in adjacent Anderson groups at nineteen years from planting in Inchnacardoch Experiment 93.P.31.

TABLE 44 Height in feet

Normal planting at 4 ft. x 4 ft.		Adjacent group planting	
Crop type	Heights	Crop type	Heights
Pinus contorta/Sitka spruce	19.0 and 7.8	10 Sitka spruce groups	5.0
Sitka spruce pure	9.3	,, ,,	9.0
Scots pine pure	18.4	9 Pinus contorta/4 Scots pine groups	20.1 and 17.3

Note.—Dominant heights are means of tallest trees in each group or in an equivalent area (18 ft. x 18 ft.).

down at Glenrigh and Borgie, both on areas where earlier direct planting had failed. That at Glenrigh investigated costs for different forms of Anderson groups over a total of ten acres. Contorta pine and Sitka spruce were used throughout (Glenrigh 21-26.P.30). The number of plants used in the groups was high, from forty to fifty, so that the number per acre exceeded 3,500. It now appears that this was unnecessary since growth, in particular that of the spruce, has far exceeded expectation, ranging up to thirty feet at twenty years of age. Sections at normal spacing have not grown so fast, but less expensive grouping methods as used at Inchnacardoch would certainly have sufficed.

At Borgie (Expt. 1 P.30) groups of fifteen Sitka spruce planted on *Calluna-Molinia* have grown well, reaching a top height of twenty-five feet after eighteen years, but on *Calluna-Scirpus* growth is much poorer, the height being at most eight feet. This experiment was followed by a seven acre plantation (3.P.31) on a variety of vegetation types and using both normal and group planting, which was burnt in 1942, at which time growth was on the whole promising.

Three further trial plantations laid out at Inchnacardoch in 1932-33 were at normal spacings. Two of them lie above the Lon Mor and were planted to investigate the possibility of afforestation being extended on to an area of steep *Calluna* clad slopes and deep *Scirpus* peat flats with many morainic knolls. (See Photo 9.)

Results are summarised in Table 45.

Summary of two trial plantations at Inchnacardoch showing location of crop types and dominant heights at twenty-two years from planting.

TABLE 45 Height in feet

Site	Experiment 96.P.32: 850 ft. on steep slopes with one flat		Experiment 95.P.32: 900 ft. Mainly flat with deep peat	
	Species	Height	Species	Height
Knolls :—				
Poor *Calluna*	—	—	Mountain pine	6
			Contorta pine	8
Steep slopes :—				
Calluna on 0-6″ peat	Mountain pine	13½	—	—
	{Scots pine	21½	—	—
	Birch	Failed	—	—
	Contorta pine	21	—	—
	Grey alder}	15½	—	—
Blanket bog :—				
Scirpus-Calluna	Contorta pine	22½	Contorta pine	20
Scirpus-Myrica	—	—	{Sitka spruce	5
			Grey alder}	5
Mineral soil types :—				
Pteridium-Calluna	Japanese larch	36	—	—
Calluna-Molinia	—	—	Japanese larch	27

Note.—Brackets link species in mixture.

In spite of the rather poor growth of the hardwoods the general impression is good and there is little doubt that the area could be afforested, using pines as the main species but with a proportion of larch and spruce, these last species being in mixture with the pines on suitable sites.

In the following year a similar plantation was laid down on the "P.22 area" near those of 1930 and 1931 (Inchnacardoch 103.P.33). Japanese larch at this time appeared most promising on the Lon Mor, and it was planted over three-quarters of this trial plantation. This proved most unfortunate as growth has been poor and the trees are misshapen and stunted, the top height at seventeen years being about ten feet, though in a small section by a stream where there is mineral soil it reaches twenty-three feet, and the form here is excellent. Contorta pine was used for the knolls and now averages eleven feet, growth being slow, while Sitka spruce in the flushes has reached four to eight feet. The plantation is very disappointing and contorta pine has recently been introduced into the poorer sections of the Japanese larch. This area serves as a contrast to the nearby plantations using the Anderson group method, and demonstrates the need on these poor peat types for intensive draining and preparation. The cost per acre at £7 10s. 0d. was only three-quarters that in the previous trials, the saving being almost entirely in draining and laying of turfs.

The last trial plantations before the advent of tractor ploughing were those laid down at Inchnacardoch, Achnashellach and Borgie in 1938. They consisted of a mixture by groups at normal spacing of Scots and contorta pines, Sitka spruce, Japanese larch and Oregon alder. The group of each species contained nine plants and a unit of the crop is made up of twelve such groups as shown in Table 46.

Arrangement of species in the 1938 trial plantations

TABLE 46

JL	SP	SS	JL	SP	SS	JL
SS	SS	PC	SS	SS	PC	SS
SP	PC	OA	SP	PC	OA	SP
SS	JL	PC	SS	JL	PC	SS

Notes.—Proportions are :—
Sitka spruce 1/3
Contorta pine 1/4
Scots pine 1/6
Japanese larch 1/6
Oregon alder 1/12
Each symbol represents 9 plants arranged 3 x 3 at 4½ ft.

The plantations were established partly on turfs, where the drains spaced at thirteen feet were to be deepened progressively, and partly on complete mock ploughing where draining was to be carried out when wet spots appeared. There was no great difference between growth on the different types of ground preparation, but results given in Table 47 show that ground variation has resulted in very different growth rates in the early years at Achnashellach. Only on the better flushes are Japanese larch and Oregon alder growing, and indeed these particular alder are the most promising survivors of all those planted in the brief period when this species appeared so promising. A few yards away on *Scirpus* knolls there is the usual complete failure.

The complete failure of the Oregon alder and very poor growth of Japanese larch at Inchnacardoch allowed new species to be introduced in 1950 into the half shelter provided by the pines and spruce. Species chosen include those that have shown promise on the Lon Mor, namely Douglas fir, grand fir, Serbian spruce and western hemlock, with oak and grey alder as possibly useful hardwoods.

The ultimate object of these experiments is that each group should provide one or at most two trees for a mixed final crop.

Finally there are at Inchnacardoch three trial plantations on ground ploughed with the Cuthbertson draining plough at five-foot spacing. Four acres of *Scirpus-Sphagnum* on basin peat up to twelve feet deep were planted in 1946 on the Lon

Growth of various species at 12 years from planting in two trial plantations.

TABLE 47 Feet

	Achnashellach 25.P.38		Inchnacardoch 120.P.38
	Calluna-Mol.-Myrica	*Scirpus-Calluna* knoll	*Scirpus-Calluna*
Scots pine	14	6	10
Contorta pine	16	9	11½
Sitka spruce	15½	9½	6
Japanese larch	13	3½ (poor)	4 (poor)
Oregon alder	19	Failed	Failed

Note.—All plants received phosphate.

Mor, using contorta pine and Sitka spruce in the proportion of three to one. After six years' growth contorta pine averages over four feet in height and many individuals have reached six feet, so that early growth has been exceptionally good (Inchnacardoch 128.P.46). (See Photo 8). In a similar fifteen acres on the "P.22 area" Scots and contorta pines suffered severe losses in the exceptional winter of 1946-47, at which time even the heather was cut back in this area, and over half the plants were killed ; Sitka spruce losses were only fifteen per cent. Though less striking than the Lon Mor trial, this plantation has made a good start in spite of this initial setback.

The next year a further area near the Lon Mor was planted up (Inchnacardoch 135,P.47). The species prescription for each of four sections was laid down separately, one by the then Chairman (the late Lord Robinson) and the three others by officers of the Forestry Commission, each basing his selection upon his experience of peat planting over the previous twenty years. These plantations have started well and should be of great interest as they develop.

In view of the excellent early growth of these recent trials, and the continued steady growth of many of those now twenty years old, it seems certain that a large area of these types in the north-west Highlands could be afforested. The economic aspect however still requires careful consideration, as the cost of establishment is high and growth slow, falling in many cases below the lowest Quality Class of the existing yield tables.

The success so far achieved has however been sufficient to encourage, during the last five years, a considerable extension of the work on trial plantations. A number of blocks have been planted—some of them in co-operation with the Department of Agriculture for Scotland—in Caithness and Sutherland. There the Forestry Commission had hitherto operated only at Borgie, and unfortunately all their work, but not their experience, was lost in the fire of 1942. These new trial plantations are basically of contorta pine or Sitka spruce, according to which species is most likely to grow best on the site, but with an admixture of all the species of conifers and hardwoods considered likely to be worth trial, either for timber or for shelter belts. Early growth has in some cases been most promising. Preliminary accounts of these areas have been given by Bartlett (1953) and Zehetmayr (1953). Another series of trial plantations has been commenced in co-operation with Halifax Corporation on their catchment area near Hebden Bridge, Yorks. In this area however the main problem is smoke pollution of the atmosphere. The peat types, mainly *Molinia* and *Eriophorum* and often rather exposed, would not normally be considered as unplantable with modern techniques.

HIGH ELEVATION EXPERIMENTS

These experiments, as already explained, are of the nature of trial plantations, but for the most part contain definite comparisons of methods. The distinguishing feature of the series is that they have been planted on sites excluded from the areas for afforestation on account of altitude. The main characteristics of the early sites are shown in Table 48. It may be seen that the altitude at which these trials are located increases from the west to the centre of Scotland as the general level of the land rises and exposure to westerly gales decreases.

The history of the earlier Achnashellach experiments has already been described (See Chapter 5, page 17). After the fire of 1942 only the plots of Norway and Sitka spruce remain and are completely checked. Contorta pine turf planted and supplied with phosphate had reached six feet in fifteen years when burnt; mountain pine, slightly behind contorta, was growing much better than Scots.

The 1933 experiment at the same forest includes Japanese and hybrid larches. The two species are not comparable as the Japanese plot is on a poorer

TABLE 48

The main site characteristics of the high elevation experiments.

Forest	Elevation Feet	Exposure	Vegetation type	Experiments
Achnashellach, Wester Ross	900-1,000	Mod. to very Exposed	*Calluna-Scirpus*	1.P.21 & 6.P.28
Achnashellach, Wester Ross	800-900	Exposed	,, ,,	18.P.33
South Laggan, Cen. Inverness-shire	1,300	Sheltered	*Scirpus-Calluna*	7, 8, 9 & 13.P.28
Inchnacardoch, Cen. Inverness	1,250	Mod. exposed	*Scirpus* to *Calluna-Molinia*	21.P.26
Inchnacardoch, Cen. Inverness	1,100	Exposed	*Scirpus*	25.P.27 & 29
Queen's Forest, Cairngorms	1,600	Exposed	*Calluna-Scirpus*	1-9.P.30, 11.P.30

and more exposed site. While the hybrid has made fair growth, reaching twelve feet in fifteen years, the Japanese plot is very poor.

The highest experiment at Inchnacardoch is the plantation formed in 1927-30 from a turf nursery on the plan devised by Sir John Stirling-Maxwell as mentioned in Chapter 5. (See Photo 23.) Contorta pine is generally the most promising species having reached sixteen feet in twenty years. Sitka spruce is poor on the *Scirpus-Calluna* but ranges up to fourteen feet or more on *Calluna-Molinia.* A few *Thuja* which were included are alive but are of poor appearance and growing slowly.

The second plantation at Inchnacardoch (25.P.27) lies above the "P.22 experimental area" and above the old planting limit, and was formed in two stages. In 1927 an area was planted with mountain and Austrian pines, Norway spruce and European larch, all of Swiss origin, turfed or notched according to the depth of peat but without phosphate. This area has for the most part failed, except for some mountain pine and a few spruce on the better ground types. In 1929 a plantation of Anderson groups was added, mainly of contorta pine but with a number of other species and also different provenances of certain species. (See Photo 24). Basic slag was applied here and this area has been most successful, its present state being shown in Table 49 below.

The pines are clearly well established and have received their first thinning, the growth of spruces is also good, while that of the small number of *Thuja* is of interest.

The group of experiments at South Laggan are in rather a different category, as they lie in a corrie which is well sheltered, and parts of the area carried a grass vegetation on mineral soil, the transition to poor *Scirpus* and *Calluna* peat being sharply defined. Contorta pine has been badly damaged by deer as also has Japanese larch used to beat up the area. Scots pine of Scottish origin suffered a little from blackgame ; the foreign lots have failed completely. Spruce are very poor on the peat, though on the burnside they range up to twenty feet.

The Queen's Forest area comprises some seven acres just above the present tree limit of the old natural Scots pine of Glenmore. The area is hummocky with dry *Calluna* peat on the knolls and *Calluna-Scirpus* peat from one to three feet deep on the flats. The trials include the use of different species, methods of planting, and manuring. A large part of the experiment was top dressed with phosphate in 1939, and draining was improved at the same time.

Contorta pine, here of Alberta origin, is the most promising species over the whole area, and after twenty years has reached a top height of about ten feet. The few mountain pine are also healthy and growing well. Scots pine has suffered from exposure at various times and particularly in the winter of 1946-47. Its general appearance is much more satisfactory when in mixture with contorta pine. Norway, Sitka and white spruces have all failed where planted without phosphate. In the sections where Sitka received slag—the only spruce to receive a dressing at planting—it survives but is semi-checked.

All six species suffered heavier early losses where

Height of various species at 1,100 feet, twenty-one years from planting in Inchnacardoch Experiment 25.P.29 Section.

TABLE 49

	No. of groups	Dominant Height Feet	Notes
Mountain pine	10	13	Healthy
Scots pine :—			
Scottish	2	22	Excellent appearance
Finnish & Latvian	3	16	Colour yellowish
Hagenau	1	7	Only 2 plants survive
Contorta pine .... (of 3 origins)	32	25	Excellent appearance. No difference between origins
Norway spruce	9	15½	Condition excellent
Sitka spruce	9	23	,, ,,
White spruce	6	12	Colour only fair
European larch (alpine)	1	18	Form and trees sickly
Thuja plicata	1	15	In fair health

Note.—Groups of Austrian pine, *Larix dahurica* and *Pyrus aria* have failed.

directly planted than where turf planted. Group planting does not seem to be a satisfactory method on this exposed site, as the appearance of pines is poorer than in the normal plantations which were themselves closely spaced at three feet. The grouping appears to increase rather than diminish the effects of exposure.

The additional draining in 1939 has resulted in a marked change in vegetation through the replacement of *Scirpus* by *Calluna*, but this has not yet affected growth ; the top dressing with phosphate carried out at the same time has however increased growth.

It is clear that the original planting prescription did not allow for sufficient draining or manuring. By modern methods of ploughing considerably improved growth could be expected and possibly the expense of close spacing would then be unnecessary. Only contorta pine, with possibly Scots pine in mixture, could be recommended for this area.

The general conclusion for these peat areas at high elevations must be that tree growth is not impossible but may be very slow. It certainly would be possible to produce pitwood and the question of how far such areas should be planted becomes once more very largely a matter of economics. The stage now reached is one where these early plantations are being followed by others established by current methods on ploughed ground, using contorta pine as the main species with some Scots pine throughout the plantation, and mountain pine as a windbelt. In small quantities throughout the plantation are placed the five species selected for intensive work on the poorest ground: hybrid larch, Sitka and Serbian spruces, western hemlock and noble fir. Six such plantations have been planted in the Kielder area, all lying on poor peat types over one thousand feet above sea level ; and it is intended to extend this work to other forests where large areas are still classified as "unplantable". The earliest of these areas, dating from 1950, have made a most satisfactory start.

Chapter 10

OTHER EXPERIMENTS

Direct sowing

Sowing as an alternative to planting on peat has been attempted in small scale trials over a period of twenty years. The main difficulty in the use of sowing for afforestation is the intense vegetation competition, and for this reason there could be little prospect of large scale use of sowing until the introduction of ploughing which suppresses the vegetation to a greater or less extent for a number of years.

The early trials were with one exception confined to the poorer vegetation types at Inchnacardoch where re-invasion of vegetation is slow. The first was on the Lon Mor in 1927 when Scots pine, Norway and Sitka spruce were sown on turfs without phosphate ; within two years very few seedlings remained (33.P.27). A similar failure occurred with alders, birch and rowan at Beddgelert (17.P.30).

In a second trial on the Lon Mor, Scots pine seed was broadcast over turfs in 1928, and then phosphate was applied as a top dressing in 1930 to certain sections (59.P.28). After eighteen years the plants which received phosphate averaged five feet, the controls about half that figure. Growth has been very much faster in the next trial (P.T. 37/3) where phosphate was applied at sowing ; Scots pine reached four feet in ten years, and little faster growth could have been expected in a plantation. Norway and Sitka spruce were also included and are alive but in check, having barely attained one foot in height at the same age.

In 1938 and 1939 two trials were sown in the "P.22 area" on rather better peat with a vegetation of *Calluna-Molinia-Scirpus* and using Scots and contorta pines and Sitka spruce (Inchnacardoch 121.P.38 and 126.P.39). Composts prepared by the late Dr. M. C. Rayner were used, with phosphate and also peat innoculations from vigorous stands of the appropriate species. The latter proved of no value except in promoting survival, but the compost has resulted in a growth rate about equal to that with phosphate. Growth of pines was at approximately the same rate as in the previous trial and compares favourably with that of transplants added two years later. Spruce has grown better than previously, reaching two feet in seven years ; for all species the combination of phosphate and compost has had marked beneficial effect. In a small recent repetition (P.T. 45/3) high losses occurred, largely through birds dusting on top of the turfs. Growth of the surviving pines has been good.

When part of the "P.22 area" was ploughed in 1946 five species were sown with phosphate; Scots and Corsican pines, Sitka spruce, Japanese larch and hemlock, all germinated well but almost the entire crop of seedlings was destroyed in the succeeding very severe winter.

Since this date work has been extended to other peat areas with fair success with Scots pine at a number of sites. The most complete series of trials is at Kielder, where Scots pine and Sitka spruce were used in 1947-9, and the pine shows promise here, though spruce has not been successful owing to continual damage by frost. For pine the first trial shows the value of phosphate; plants average almost one foot high three years from sowing and stocking is complete (46.P.47), this area being now as satisfactory as any planted plot of an equivalent age. The next year's trial brought out the value of sowing in a step cut in the turf or plough ridge for early protection, and also suggested that working-in the manures and covering seed with sand is of value (48.P.48). In this trial the form of nitrogen used, hoof-and-horn, proved lethal, so that in the third year comparison of different nitrogenous manures was undertaken; waste plastic is the most promising at the present time (51.P.49). A further development of these trials was the sowing in 1950 of half-acre plots of Scots and contorta pines (57.P.50) using the best technique developed, i.e. sowing in steps cut in the plough ridge with ten seeds per patch, adding one ounce of a balanced NPK fertiliser and covering the seed with sand. Costs are being kept in detail for these sown areas for comparison with plantation work.

Sowings on similar lines on a good peat type started at Leanachan, Inverness-shire, in 1948 and results have been comparable to those at Kielder for pine, while Sitka spruce is much more promising.

Experience has shown that it is the second year's growth which is crucial; good germination can be expected with the technique employed, but the next year's growth indicates whether the plants will surmount the two main risks involved in direct sowing, frost damage and smothering by vegetation. Since frost is more severe over dense vegetation, especially grasses, the two factors are related and it may be found as a result that sowing is more feasible on the poorer rather than the better peats. The high cost of planting stock which prompted the new enquiry into sowing has been greatly reduced by means of the heathland nursery technique whereby seedlings are produced at low cost. It appears unlikely that sowing costs can compete with those of using 1 + 0 or 1 + 1 stock raised in this manner.

Protection

A small number of experiments on peat deal with the protection of crops, both from physical and biological agencies. The results are summarised below. These experiments have been laid down with one of two objects, either to test some form of protection or to gauge the effect of some injurious agency in order to assess its economic importance.

Shelterbelts. This project is unusual in that the very first experiment on the subject, laid down by Anderson at Inchnacardoch in 1926, has provided what appears to be almost a perfect solution. (See Photo 25). This trial (18.P.26) has already been referred to (Table 9, page 35) in connection with other aspects of its design. The belt consisted originally of two closely planted lines of each of six species, birch on the windward edge being followed in turn by rowan, mountain, Scots, contorta and western yellow pines. The hardwoods and the western yellow pine (*P. ponderosa*) soon failed, so that the belt now consists of mountain, Scots, and contorta pines only. Three different methods of planting were used and in addition sections were topdressed with phosphate in 1930. Thus this experiment was one of the first to include turf planting and phosphate dressing, and it is the sections which received this treatment that at the present time form a striking demonstration of a narrow shelterbelt providing dense cover from ground level to over twenty feet. It is well sited on a brae and, in a wind, the vegetation is seen to be relatively still for a long distance to leeward. In 1950 a plot of Japanese larch was added, part lying behind the belt while part projects beyond and thus is fully exposed. Growth differences in the early years indicate that it will be possible to gauge the effect of the belt on the height growth and the form of the larch, one of the species most susceptible to damage through exposure.

Breaks of this type have been used round certain of the recent trial plantations and high elevation plots. The only modifications which may possibly be worthwhile are to increase the number of rows of each species to three or four. In very severe exposure the inclusion of Scots pine is probably not worthwhile but prostrate mountain pine such as is seen round the high elevation experiment at Inchnacardoch (25.P.29) might profitably be added as the first species on the windward edge, as indeed has been recently done to the original belt.

In two small experiments at Inchnacardoch (8 & 9.P.25) small wooden shelters were placed round young spruce and were shown to have a slight beneficial effect on their growth. This is one of the considerations which led to the widespread use by Research Branch in recent years of the step position of planting on plough furrows. The step is a square or V-shaped ledge cut into the plough ridge by a spade. For small plants this provides a certain amount of shelter in the first year and at the same time places the base of the plant as far as possible out of the reach of blackgame and other browsing or grazing animals.

Blackgame. The large amount of damage inflicted on pines by blackgame particularly from 1925-1933 has already been referred to. Parts of a number of experiments were caged with wire netting during this period so that this damage would not obliterate the effects of the different treatments. A striking example is shown in Diagram I (page 20) of an experiment at Kielder where destruction of the buds by blackgame during the first ten years has resulted in a one-third reduction of the early growth rate of pines. Had the attacks continued with the severity encountered in the early years at Kielder, the planting of pines, particularly Scots, might perforce have been abandoned. However, the numbers of blackgame decreased rapidly from about 1933 onward and many of the pines, which had been reduced to stunted bushes, recovered, formed a leading shoot, and now show little sign of their early malformation.

At present (1953) the population of blackgame appears to be increasing again and may possibly reach the point where the planting of pine in badly infested areas may again become a hazardous proposition. In particular the planting of seedlings would become impossible since such small plants would succumb to damage much more easily than would transplants.

Salvage of checked spruce plantations

The question of how to treat the checked areas of spruce which had been directly planted on peat in the early nineteen twenties was for a time a research problem of some importance.

The *Scirpus* and *Calluna* covered peat areas where the severe check occurred were mainly in the north-west of Scotland, and research work was undertaken at Achnashellach and Inchnacardoch. (See Photo 2.)

It was demonstrated at Inchnacardoch that the recovery of checked spruce was possible ; plants which had been completely checked for six years and were in very poor condition were dug up and re-lined in the nursery. Within three years they had made a complete recovery and were growing well (Inchnacardoch 70.P.28). This experiment served to keep alive after early setbacks, the hope that a suitable treatment could be devised to promote recovery in the forest.

The first suggestion for treatment of these areas was to simulate turf planting by lifting each plant with the surrounding turf and placing it on the peat surface alongside the hole from which it had come (Inchnacardoch 26.P.27, Achnashellach 3, 4 and 12.P.27-28). As is now well known turf planting alone is not enough to ensure the growth of spruce on *Scirpus* peat so that these experiments were foredoomed to failure. Lifting combined with application of basic slag was tried next and here results were variable, no benefit being obtained in some cases and a small increase in growth rate in others. (Achnashellach 15.P.32 and Inchnacardoch 91.P.30 and 100.P.34.)

Heavy manuring with phosphate without prior lifting of the plants provides the one example of a successful outcome of salvage attempts (Inchnacardoch 72.P.28). Basic slag was applied broadcast in 1928 at thirty hundredweight per acre among spruce which had been in check since planting in 1922. In the areas left untouched as controls, all the plants are now dead except for a few planted on *Molinia* flushes, while in the manured areas there is a complete crop, though the height varies from two to thirty feet according to the vegetation type.

A further large trial of manuring with phosphate was undertaken in conjunction with the Basic Slag Committee on deep poor peat at Scootmore (2.P.36) following the lines of that already described at Glenrigh (Diagram IX, page 70), except that the subject here was checked Sitka spruce planted two years previously instead of new planting. This trial has been a complete failure ; the plants which averaged under one foot when phosphate was applied have grown at about one inch per year in all treatments though deaths have been heaviest in the controls. The heaviest dressing employed at Scootmore was four ounces of high grade slag per plant while the broadcast dressing in the successful experiment at Inchnacardoch was equivalent to one and a half pounds per plant.

Another possible remedial measure was draining, and this was usually combined with the introduction of a nurse crop on the turfs so provided. In the first such trial at Inchnacardoch (61.P.28) no phosphate was applied and the Sitka spruce have not benefitted. One experiment at Achnashellach combined draining and all the other methods tried, and results are set out in Table 50.

This experiment demonstrates the futility of lifting, which was an expensive operation. Phosphate has served to keep the spruce alive and it is possible that a small number will come into canopy with the pine. It is now apparent that there was no simple remedy once the initial mistake of direct planting of pure spruce had been made.

Heights and losses of Sitka spruce twenty-five years after planting and seventeen years after treatment in Achnashellach Experiment 19.P.33.

TABLE 50

Treatment of Sitka spruce	% Failed	Mean Ht. Feet	Treatment of Pinus contorta in plot	% Failed	Mean Ht. Feet
Control	94%	—	Notched	50%	2.1
Lifted only	100%	—	Not B.U.	—	—
Drained only	100%	—	Notched	40%	2.6
Lifted and drained	100%	—	Turf planted	15%	5.0
Top dressed only	25%	2.7	Notched+T.D.	Nil	5.5
Drained and top-dressed	33%	1.7	Notched+T.D.	20%	6.0
Lifted, drained and top-dressed	26%	3.0	Turfed and T.D.	Nil	10.3

Notes.—Contorta pine was used to fill blanks in 1933.
B.U.=Beat up. T.D.=Top dressed.

The cheapest solution would certainly have been to replant with more suitable species, mainly pine, using turf planting and basic slag. It should be noted that both turf planting and phosphate had a marked effect on the growth of the contorta pine but the effect of draining was slight.

SUMMARY

THIS Bulletin is in itself a summary of a vast amount of experimental work, but it may be useful to recapitulate briefly the main points covered, and in particular the positive results which have emerged. Many lines of investigation are not included below since the results are either negative or as yet only tentative.

Ground preparation. Some form of turf planting has been shown to be essential on all but the best flush peats. While a single turf is sufficient to induce good early growth on *Molinia* peats, more intensive turfing is desirable on the poorer areas to provide a better planting site for each plant. At the present time, turf is provided either in the conventional form of single turfs from widely spaced ploughing or as continuous ridges at about five foot spacing from single furrow ploughing.

The most successful planting method has been shown to be that where the roots are spread below the turf so as to lie on the decaying vegetation.

A sufficiency of draining for establishment is provided by ploughing or turfing, and while the experiments show that more intensive draining gives better growth, it is not yet possible to say how far it is economic to provide increased drainage beyond that which is obtained with the best modern types of plough.

Species. Only four species have been employed to any great extent on peat, namely Scots pine, Japanese larch and Norway and Sitka spruces. Contorta pine and hybrid larch are in limited use, though more widely planted in experiments, while mountain pine is very little used, though this species was also planted on some scale in the early experiments. The main points which have emerged from work on these species are :—

Mountain pine. The only proven use to which the species may be put is to form the windward edge of shelterbelts. In very severe exposure both the prostrate and erect forms can be employed with advantage. It is a most hardy species and will survive where all others fail, with the possible exception of coastal contorta pine.

Scots pine. Home seed should always be used for this species. Planting sites must be well drained and it is suited for all the drier peat areas, especially the *Calluna* covered knolls which form such a prominent feature of so many peat areas. It is also suited for use in mixture with contorta pine in sites marginal for planting and also in mixture with spruces or other species as a nurse, on sites marginal for these species.

Contorta pine is the most promising species on all the peat areas where conditions are extreme either on account of vegetation and peat type, elevation or exposure. It has replaced mountain pine as the species for these sites since its growth is much faster and its timber is likely to be of more use. Care should be taken to use the correct strain, the coastal type being more suitable for exposed sites. Contorta pine has been widely employed in mixture, mainly with spruce, but its rapid growth is often a disadvantage, which may however disappear with the improved planting conditions for the admixture species now attainable by ploughing and manuring.

Japanese and hybrid larches have grown very well in certain experiments, even in areas of *Scirpus* peat. The extreme sensitivity of Japanese larch to site conditions and the necessity for turf planting and manuring with phosphate has been established. The place of this species is on the thinner peats overlying moraine or mineral soil which occur in many areas of the north-west Highlands. Stock raised from seed of Japanese origin appears to be variable; many extremely poor plantations exist and it is often difficult to assign the cause between site and planting stock. The true hybrid larch shows great promise and is undoubtedly superior to Japanese but care is needed to see that first generation stock is obtained if possible; otherwise stock derived from first generation stands, but not from second or later.

Norway spruce grows well on *Molinia* peat but has proved quite useless on all the poorer *Scirpus* types. The origin of seed has been shown to be of importance, certain central European strains growing fastest while Scandinavian races are particularly poor.

Sitka spruce has been extensively planted on the richer peats and grows well with turf planting. On the poorest peats it showed more early promise than Norway spruce when turf planted and manured with phosphate ; subsequent growth was however extremely slow and checking was widespread. In the early experiments canopy has only formed in a few cases where intensive methods of ground preparation, manuring and admixture with pine were employed. In experiments recently established by improved technique the spruce appears to be escaping the early check and it may be possible at a later date to show that this species can be grown by a practical combination of treatments.

The origin of seed has been shown to be of some importance particularly from the aspect of frost hardiness. The Queen Charlotte Islands are worth mention as one source of proven worth.

Other species. While over fifty other species have been tried on peat areas, early results were so poor that many have been tested only on a very small scale. On the poorer peat, Serbian spruce, hemlock and the silver firs, particularly noble and balsam firs, show promise while to this list might be added on better types western red cedar, Lawson cypress, Douglas fir, and selected European larch. None of these species should however, be planted pure. Others may be added when the results of newer experiments with improved planting techniques become available.

Planting stock

While transplants remain the conventional stock there is hope that seedlings may be employed to some extent in the future ; although probably their use will be more feasible on poorer peats where re-invasion of the plough ridges by vegetation is slower than on the *Molinia* peats. Trials of heathland and specially raised planting stock have shown that considerable advantage may be gained over stock from established nurseries.

Mixtures

Few of the experiments on mixtures are as yet old enough for their value to be assessed. The majority of such trials as have given results deal with the establishment of Sitka spruce by nursing. So far the most successful have been mixtures with pine in Andersonian groups. All the early trials have been outdated by the introduction of ploughing which has altered the relative growth rate of spruce compared to pine so that at least for the first few years after planting the two are now on more nearly level terms.

Manuring

Manuring with phosphate is now an established practice on the poorer peats and full details of the experimental background to this technique are given. Phosphate is essential to the survival of all species other than pines on the *Scirpus* peats, but even with pines growth rates may be more than doubled, so that application to all species is fully justified. On the *Molinia* and better peats phosphate is not necessary, while on intermediate types it is advisable to apply it to all species other than pines, to ensure survival and good early growth.

Other work

An account has also been given of the trial plantations which are 'museum pieces' embodying what was the latest experimental technique at their date of establishment. These may provide long term information on sites considered or proved to be "unplantable" by normal methods at the time they were set up. Similarly the high elevation experiments seek to extend the planting limit upward.

Other research projects include direct sowings, work on shelterbelts and protection, and on the salvage of checked spruce plantations which had been planted in the early years using faulty technique.

Planting Prescriptions

The conclusions drawn may be briefly summarised by means of generalised planting prescriptions which might be considered as applicable to all the peat areas subject to local modification in the light of experience. The peat areas are classified by vegetation type and two exposure classes. Under normal conditions the dividing line between them might be taken to lie about 400 feet on the northern and western sea-board and run upwards to 900 feet in the inland parts of the country. Its exact location will depend on the slope, aspect and relative elevation as influencing the exposure.

Grass-Rush Flushes with Rich Flush Peat. Norway spruce remains the most satisfactory species for such areas unless exposure is severe, where Sitka spruce should be employed. Single turfs will suffice for planting on this type.

Molinia on Amorphous Peat. If the *Molinia* is pure then turf planting of spruces as for the flushes gives entirely satisfactory results, but where a proportion of other species, particularly *Calluna*, *Scirpus* or *Vaccinium* occur, rather more intensive methods are required. Use of continuous plough ridges for the spruce is the first precaution. As the proportion of other species increases, a pine admixture is advisable, using Scots on the less exposed and contorta pine on the more exposed areas. Phosphate may be advisable for the spruce. Where the peat is thin Japanese larch might be used instead of Scots pine here.

Calluna dominant. With other species in mixture, dominant *Calluna* will be found on a variety of types. The luxuriance of the *Calluna* in respect to its age provides a most useful guide to their fertility. Spruce should not be used extensively on any *Calluna* type. The morainic knolls with thin peat and locally drier conditions provide in sheltered conditions a site for Scots pine with Japanese larch and possibly Douglas fir in mixture. In exposure they are recognized as a troublesome feature and should be well broken by ploughing and planted with pines, either contorta pine pure or with some Scots in mixture. Phosphate should be applied here.

Calluna on deeper peat will generally be dominant only where enclosure has prevented grazing and where burning has been restricted. Measures should be taken to keep down the heather, by burning if this is practicable, and also by single furrow ploughing at five feet. Pines are the safest choice but if the heather is very luxuriant some spruce might be added in mixture. Phosphate should be given to spruce but not to pine unless the heather is very poor and stunted. The object must be to establish the crop before the heather regains its full vigour.

Eriophorum Types with Fibrous Peat. These peats have been shown to be plantable if well drained. With close ploughing and phosphate Sitka spruce may be established very quickly. If *Calluna* and *Scirpus* are present the usual precaution of pine admixture should be taken. Pines should also receive phosphate on these transitional types.

This peat type, of *Eriophorum* with many other species in mixture, may be taken to represent the present limit of plantability, though in many areas planting has been extended on a restricted scale into the extreme types listed below. In existing conditions such areas on their own are doubtfully economic but may be justified as part of a large planting programme.

Scirpus-Calluna with Pseudo-fibrous Peats. This description covers a number of types on which lie the most important trial plantations. The deep basin types with *Erica tetralix* abundant (Lon Mor) could now be planted using contorta pine; such basins are not generally in extreme exposure, and Scots pine could be added in mixture. Intensive draining and use of phosphate are essential.

On slope types exposure becomes important and if severe will render the area unplantable, but in contrast if exposure is moderate and the peat is thin, larches particularly hybrid, could be added to the list of potential species, though admixture with pine is advisable.

Scirpus-Calluna Knolls. These are more difficult than the *Calluna* knolls already considered and only contorta pine can be recommended.

Sphagnum Peats. All the *Scirpus* types contain a proportion of *Sphagnum* and often local *Sphagnum* hollows. If, however, *sphagna* are dominant and form large tussocks the area is unploughable and unplantable by any current method.

The above classification may appear optimistic but in the present phase successful establishment is being attained far outside any previous experience of peat planting in this country. Only time will enable an estimate to be made of how far successful establishment can be used as a guide to forecast successful production, and thus allow the economics of the operations to be determined. The series of trial plantations now in hand should provide some evidence on this point within twenty years.

ACKNOWLEDGMENTS

The author, who was entrusted with the task of summarising thirty years experimental work begun by others, would in conclusion like to express his thanks to those who have made it possible. First to the experimental officers who designed and laid down the experiments to meet the conflicting requirements of long and short term information, economy, and scientific exactitude, namely : Dr. (now Professor) H. M. Steven, in Scotland 1921-25 and in England and Wales 1925-30 ; Dr. (now Professor) M. L. Anderson, in Scotland 1925-27 and 1929-30 and in England and Wales 1930-32 ; Mr. James Macdonald, in Scotland 1930-32 and in England and Wales 1932-36 ; Mr. R. G. Sanzen-Baker, England and Wales 1936-47, and Mr. J. A. B. Macdonald, Scotland 1932-51. Until 1948 all the work was carried out under Mr. W. H. Guillebaud as Chief Research Officer and as Director of Research.

With regard to the present summary of the work on peat the author would like to thank Mr. J. Farquhar and Mr. A. Macdonald who as Research Foresters long connected with the peat work have provided much of the data for Scotland, and to Mr. J. Weatherell and Mr. R. D. Pinchin who provided data for Kielder and the Welsh experiments respectively. Finally, Mr. J. A. B. Macdonald, who has been intimately connected with the work on peat since 1925 and who was responsible for laying down the majority of the trials, has constantly guided the work of summarising and, even more important, that of interpreting the results of the experiments.

APPENDIX

ROOT FORM ON PEAT

Report on a survey of Blocks I-VI of Inverliever Forest, Argyll, in October, 1923.

By Dr. H. M. Steven

UNDER this title are given the results of an exploratory survey of the older blocks at Inverliever Forest, Argyll.

These blocks I-VI were planted between 1909-10 and 1913-14.

In Addendum I will be found general notes on the Locality conditions and the species used.

These blocks present the following features :—

1. The failure of Silver fir (*Abies pectinata*).
2. The unsatisfactory condition of European larch on certain sites.
3. The prolonged check period and irregular development of Norway spruce on peat.
4. A similar condition for Sitka spruce.
5. The failure of Scots pine which has also been planted extensively on peat.

The study was concentrated on problems which, as far as has been determined, are not mainly pathological. Hence the failure of silver fir, which is considered to be due chiefly to *Chermes*, was not investigated. Further the condition of larch, although due partly to wind exposure from the south and west, is partly the result of a severe attack of larch canker. (*Dasyscyphia willkommii*). Both tops and branches have been killed by this fungal pest. In some cases it was noted that death had taken place during this summer after the tree had come into leaf, as the result of complete ringing of the stem by the fungus.

The study was directed principally therefore to the irregular development of Norway and Sitka spruces on peat and to the failure of Scots pine.

Norway spruce was selected first, mainly because it has been planted under a wide range of conditions. The study of any plantation is always difficult because of the large number of factors which have operated on producing it. There are always serious gaps in the history of the plantation from the date of planting. The herbage and soil factors at the time of planting may have been entirely different from those present now, while information regarding the type of stock used, the soil conditions under which they were raised, and heredity, is often lacking. One can therefore only weigh up available evidence and keep in mind possible but unknown factors.

A preliminary survey of the Norway spruce plantations was made in order to endeavour to obtain an idea of what were the important factors or groups of factors. The outstanding feature of the growth of this species on peat, which is almost always present except on the steep slopes at the loch side, is the extreme variability in development. Here a group has come away and the trees are growing 12 to 18 inches per annum, while adjoining are trees entirely in the check stage. In other groups the trees are emerging from the check stage while in some cases they are entering into a second check stage. Lastly there are sites where scarcely a living tree is to be found.

As regards the causes, it is considered that the extreme irregularity within small distances makes it improbable that origin of seed, type of stock and method of planting have been important influences. The efficiency of planting can to some extent be determined by detailed examination. No pathological interpretation of this irregular development has as yet been put forward. It is generally agreed that both climatic and soil factors are involved. As regards climatic factors it is clear that wind pressure from the south and west is an important factor. Trees have come away only to have branches deformed and defoliated. The exposure from the prevailing winds was found to vary considerably within short distances due to the topography. As however there are numerous completely sheltered sites where there are trees in the check stage, this factor does not appear to be the principal one involved in the initial check. Immediately trees come away however it is of first importance and is intensified by the irregular development, almost every tree suffering instead of only marginal trees. Secondly there is the influence of the wind on transpiration and evaporation, i.e. the desiccating power of the wind especially at critical periods of the year. Here again the existence of trees in the check stage in fully sheltered sites is evidence that this factor is not of principal importance. It may be however an important one in certain sites. This can only be determined by extended metereological and ecological records.

It must also be borne in mind that very little is known regarding the temperature of peat soils, particularly the range of temperature in relation to tree root activity.

Coming to soil factors a feature of the plantations at Inverliever is the better results when the peat rests on the Loch Awe Grits compared with that on the massive type of epidiorite. In the blocks investigated however the Loch Awe Grits do not cover any extensive area. The second feature is that the growth of Norway spruce is related in a general way to the surface herbage. Within a given herbage, however, there are marked differences in the duration of the check period. In general the tree growth improves in ascending order from *Calluna-Scirpus caespitosus* herbage, where scarcely a live plant is to be found, through *Calluna*-Grasses, Grasses-Bilberry to Rushes-Grasses. This may be due directly to soil factors or, as has been pointed out by G. K. Fraser, to different degrees of protection given by these herbages against the desiccating power of the wind.

Two methods of approach to the problems are possible. First the different climatic and soil factors may be studied. This is an extended but essential investigation. Secondly the trees may be studied in order to get some idea of the response to the resultant of the factors operating. For the purposes of an exploratory survey the second method, especially a study of the root systems of contiguous trees in different stages of check and growth, is considered to be a useful method of approach to the problems.

The general method of survey was to locate plots which had, within short distances, trees in different stages of development, and to study and record the data. In initial operations plots sheltered from the prevailing wind were selected in order to reduce the factors operating. An account of the observations made, classified primarily by species, follows.

NORWAY SPRUCE

Plot 1.

Location : Compartment 10.

Date of Planting : 1910-11.

Elevation : 700 feet.

Aspect : S.E.

Exposure : The topography shelters the ground on the south, south west and west. In additional groups of trees 5-10 feet high shelter the plot on the S.W. and N.E.

General Note : On a moderate apparently well drained slope there is a small patch of trees in the check stage adjoining a patch in active growth. One tree in the check stage and another growing well were studied.

Tree 1. This tree was on the margin of the group of thriving trees—

Vegetation : The herbage is partly killed out. From existing plants and remains it was as follows :—

Molinia caerulea, Vaccinium myrtillus, Potentilla tormentilla and *Galium saxatile.*

Soil : 2-3 inches decayed plant remains and needles, 4 inches dark brown peat with some mineral matter through it. Over 18 inches brown gritty loam with some epidiorite fragments.

Shoot Analysis : Colour of needles—green. Average length of 1922 needles 8-10 mm.

1922	shoot	—18 inches
1921	,,	15 ,,
1920	,,	11 ,,
1919	,,	8 ,,
1918	,,	4 ,,
1917	,,	1 inch
plus		14 inches to top of roots.

Period of check—7 years.

Root System : The root system was dissected out. It was noted that the plant had been put into the peat at normal depth amongst tufts of *Molinia.* The original root system is large and bushy or has developed to some extent after planting. The depth penetrated was however only 4 inches, i.e. just reached the soil. Above the original surface a number of adventitious roots have developed. These grow out laterally along the original surface, that is amongst the plant remains formed since the date of planting. Rootlets developing from these penetrate into the peat but not through to the soil. Some rootlets in the decayed herbage bear bunches of small roots.

The longest of the lateral roots is 3 ft. 6 ins. long and has a maximum diameter of 1½ ins. It was considered that the age of this lateral would be interesting. It was cut up, therefore, and rings counted. The following is the analysis with corresponding shoot development.

	Number of Rings	Date of Development	Length of Leading Shoot
At Junction with main stem	7	1917	1 in.
,, 2 inches out	6	1918	4 in.
,, 4 ,, ,,	6	1918	4 in.
,, 8 ,, ,,	5	1919	8 in.
,, 14 ,, ,,	4	1920	11 in.
,, 20 ,, ,,	3	1921	15 in.
,, 24 ,, ,,	2	1922	18 in.
,, 42 ,, ,,	0	1923	incomplete

It is thus seen that when this lateral first developed the plant was still in the check stage. The following year the tree began to emerge from the check stage and developed steadily thereafter.

Tree 2. This tree in the check stage was 4 yards from Tree 1.

Vegetation : The two dominant plants are *Vaccinium myrtillus* and *Molinia caerulea.* Other plants present are *Potentilla tormentilla, Galium saxatile, Erica tetralix, Nardus stricta, Aira flexuosa* and *Scirpus caespitosus.*

Soil : 6 ins. decayed plant remains and living roots, 4 ins. dark brown peat with some mineral matter. Over 18 ins. grown gritty loam with some epidiorite fragments.

The two soil pits indicated that the soil conditions under Trees 1 and 2 were identical at the time of planting. The greater accumulation of plant remains around Tree 2 has taken place since planting.

Shoot Analysis : Colour of needles yellow green : average length of 1922 needles 6-7 mm.

1922	shoot	1¾ inches
1921	,,	1¼ ,,
1920	,,	1¼ ,,
1919	,,	1¼ ,,
1918	,,	½ ,,
1917	,,	½ ,,

plus 5 ins. to top of present root system. The tree is still in the check stage, but an improvement began in 1919.

Root System : The plant was originally planted amongst *Molinia* tufts and bilberry. The original root system is small and shows little or no development. The roots were put into the peat but reached to the gritty loam. The planting was thus rather deep. Four inches above the original root system, in a region where there are still living branches, two adventitious roots have grown out. The number of the rings at the stem, including the current year's, was 4 in one case and 3 in the other. These roots have grown out laterally into the decaying herbage. They are short, 9 ins. long, and there are bunches of numerous short rootlets which bind together the plant remains. The high point on the stem at which these roots have come off can be explained by the accumulation of plant remains between the date of planting and date of development of the roots.

Observations : The following are the main points brought out by the study of these two trees.

(*a*) The original root system has not developed to any extent.

(*b*) Adventitious roots have developed above the original system. These grow out laterally not in the peat but in the decayed and decaying surface herbage.

(*c*) The duration of the check period appears to depend on the development of these laterals.

(*d*) The later and weak development of laterals in Tree 2 may be due to the original plant being less vigorous and to less efficient planting.

Plot 2.

Location : Compartment 10.
Date of planting : 1910-11.
Elevation : 700 ft.
Aspect : N.E.
Exposure : Sheltered on S.W., and N. by topography. There are groups of thriving trees all around.

General Note : This is a patch partly of thriving trees and partly of trees in the check stage. The site is a hollow and there is an actively functioning drain through it. On one side of the drain there is a patch of thriving trees and on the other the trees are partly thriving and partly in the check stage.

Tree 1. This tree is about 3 feet from the drain.

Vegetation : The principal plants are *Juncus communis, Myrica gale, Molinia caerulea and Aira caespitosa ; Galium saxatile, Potentilla tormentilla* and *Carduus palustris* are present.

Soil : 2-3 ins. Plant remains. Over 36 ins. almost black, well decomposed almost amorphous peat.

Shoot analysis : Colour of needles, dark green. Average length of 1922 needles 10-12 mm.

1922 shoot	13 inches
1921 ,,	8 ,,
1920 ,,	8 ,,
1919 ,,	4½ ,,
1918 ,,	6 ,,
1917 ,,	4½ ,,
1916 ,,	1½ ,,
1915 ,,	2 ,,

plus 12 ins. to top of existing roots—period of check 4 years.

Root system : The plant had been put into the peat amongst *Juncus* and bog myrtle roots. From the region of the original root system roots grow out. These do not now, however, constitute the main root system. Two inches above the original root system two adventitious roots grow out laterally. One of these divides into 3 main branches. These laterals run along the original surface amongst the decaying vegetation. They run through *Molinia* tufts, rootlets come off which penetrate into the peat. There are numerous bunches of small rootlets which are in the decaying plant remains. The longest lateral is 4½ ft. The unbranched lateral give 6 rings at the stem including the 1923 ring. The development of the laterals is not mainly in the direction of the drain. Figure 1 illustrates the branched lateral root.

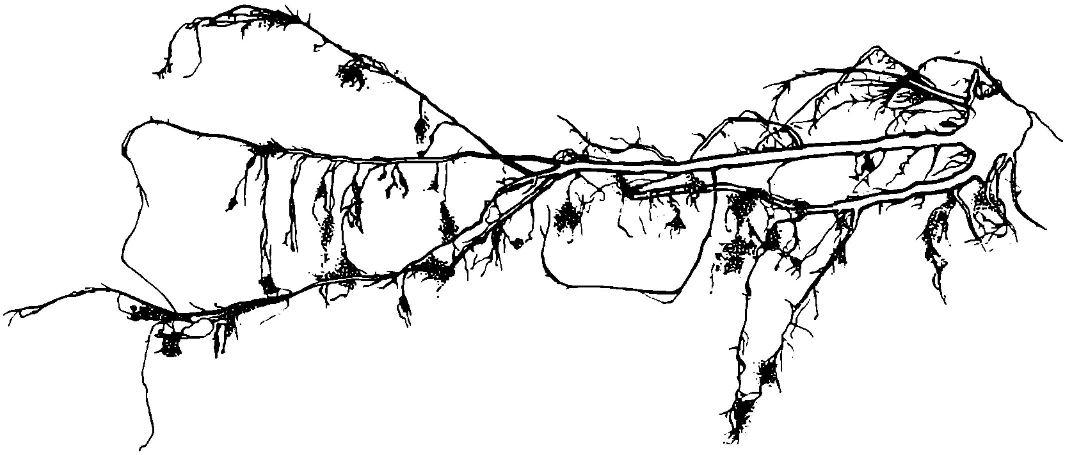


FIG. 1. PLOT 2. TREE 1. Norway spruce. An adventitious root with many bunches of small rootlets in Rush-Bog Myrtle – *Molinia* – *Aira caespitosa* – decayed remains.

Tree 2. This tree is beginning to emerge from the check stage. It was growing 4 yards from Tree 1 and at about 4 ft. from the drain.

The vegetation and soil is as for Tree 1.

Shoot analysis : Colour of needles green. Length of 1922 needles 8-10 mm.

1922 shoot	4 inches
1921 ,,	3 ,,
1920 ,,	3 ,,
1919 ,,	2 ,,
1918 ,,	1 ,,
1917 ,,	1 ,,

plus 13 ins. to top of roots—period of check 8 years.

Root System : The original root system shows some development. 1 inch above it, 2 lateral roots come off, the longest of which is 24 ins. These laterals are running in the plant remains. They bear a few branches with bunches of many small rootlets. The strongest lateral has 5 rings at the stem including the 1923 ring.

Tree 3. This tree is adjoining Tree 2 and 5 ft. from the drain. It is just at the point of emerging from the check stage.

Vegetation: As Tree 1 but no *Carduus palustris* plants near, and a small hummock of *Sphagnum* 3 ft. away.

Soil : As Tree 1.

Shoot analysis: Colour of needles green. Length of 1922 needles 8-10 mm.

Shoot length	1922	2 inches
	1921	1½ ,,
	1920	½ ,,
	1919	½ ,,
	1918	½ ,,
	1917	½ ,,

plus 8 ins. to top of roots—period of check: 10 years.

Root System: The original root system was put into the peat amongst *Juncus* and bog myrtle roots. This root system is now small and poorly developed, although a few new growing tips are present. Two inches higher 2 adventitious roots have come off. These show dead tips while some of the living ones are black. They bear bunches of small rootlets.

Observations: The following is a summary of the characteristics of this plot.

(*a*) The original root system shows some development in the peat on this site. It appears to have been sufficient to enable Tree 1 to begin growing.

(*b*) The main root system is the secondary laterals running in the layer of the herbage remains and roots. Some of the rootlets of the laterals of Tree 1 penetrate into the peat. The bunches of small rootlets are in the plant remains.

(*c*) The black tips of certain of the roots of Tree 3 present a feature which has been noted also by Mr. Laing in sites where bog myrtle was present.

Root Development of Norway spruce on a Normal Site

It was considered desirable before proceeding further to investigate the root system, etc. of a Norway spruce growing in soil. A tree in the interior of an established plantation in Compartment 3 was selected. It was a sub-dominant tree.

Date of Planting: 1909-10.

Elevation: 600 feet.

Aspect: E.

Exposure: Sheltered by topography on S., W. and N. and surrounded by as high or higher trees.

Vegetation: None. Remains of *Aira caespitosa*, *Holcus* sp., and rushes were found.

Soil: 3 ins. spruce needles and plant remains on a deep brown loam.

Shoot analysis: Needles dark green. Length of 1922 needles 12-15 mm.

Shoot length	1922	16 inches	probably due to partial shade (1922–1920)
	1921	6 ,,	
	1920	8 ,,	
	1919	15 ,,	
	1918	19 ,,	
	1917	18 ,,	
	1916	11 ,,	
	1915	8 ,,	
	1914	3 ,,	
	1913	3 ,,	
	1912	2 ,,	
	1911	2 ,,	

It is notable that there was no period when shoot length was 1 inch and under, such as was met with on peat soils.

Root System: The original root system was put into the soil. It shows development. A number of strong roots have developed from it. They bend round and up into the superficial layers of soil. Above the original system a number of adventitious roots have come off—some run in the superficial layers of soil, others penetrate in the deeper layers. They could not all be followed out owing to the presence of roots of other trees. Some of the laterals have branches which come up into the layer of humus and have bunches of small rootlets in that layer.

Observations:

(*a*) The original root system has developed and has bent up into the superficial layers.

(*b*) A system of adventitious lateral roots has developed as in case of trees in peat. They run through the soil however and not in the herbage layer. Bunches of rootlets are developed in the spruce humus layer.

(*c*) The check stage of shoot growth is not so marked and of shorter duration than in the case of the peat sites.

Plot 4.

Location: Compartment 4.

Date of Planting: 1909-10.

Elevation: 600 ft.

Aspect: N.W.

Exposure: A hollow sheltered in all directions by topography and thriving trees.

General Note: A patch where the trees are entering a second check stage. There are thriving trees on 3 sides. The slope is running down to a drain, and there would appear to be good natural drainage. The site is sheltered.

Tree 1. This is a tree which after coming away has entered a second check stage.

Vegetation: The predominant plants are *Vaccinium myrtillus*, *Sphagnum* and *Polytrichum*. The two mosses show luxuriant growth forming clumps. There are also some plants of *Molinia caerulea* and *Aira flexuosa*. An examination of the herbage showed that *Molinia* was more abundant at the time of planting, there being numerous dead tufts on the original surface.

Soil: 6-12 ins. of plant remains, largely mosses above with layer of *Molinia* below.

2-3 ins. black peat.

9-15 ins. dark brown loam on epidiorite.

Shoot analysis: Needles yellow green. Length 8-10 mm.

Shoot Length:	1922	1 inch
	1921	3 inches
	1920	3 ,,
	1919	5 ,,
	1918	9 ,,
	1917	7½ ,,
	1916	10 ,,
	1915	4 ,,
	1914	4 ,,
	1913	2 ,,
	1912	1½ ,,
	1911	2 ,,

plus 6 ins. to top of roots.

The initial check period was thus not severe.

Root System: The original root system is small and undeveloped but appears to be alive still. One inch above it, is a thickened piece from which go off a number of adventitious roots which are short, namely 12-24 inches long and less than ¼ in. in diameter. These roots run through decomposed plant remains of which *Molinia* leaves are a constituent. These roots have bunches of small many branched rootlets. Above these come off the main lateral roots which are 5 in number, up to 5 feet long and with a maximum diameter of 1 in. The thickest of these laterals is 10 years old. These roots are running through living roots and undecomposed remains of the herbage plants noted above. Except near the stem where there are small bunches of small rootlets these roots are almost bare of rootlets.

Tree 2. This is also a tree which has entered a second check stage.

Vegetation: Sphagnum, Polytrichum, Vaccinium myrtillus, Empetrum nigrum and a few plants of *Molinia caerulea.*

Soil : 6 in. plant remains as above but more *Molinia* at base.

2-3 in. black peat, well decomposed.

9 in. yellow brown loam.

6-12 in. reddish brown loam on rotten epidiorite.

Shoot Analysis : Colour of needles yellow to whitish green. Length of 1922 needles 5-8 mm.

Shoot Length :	1922	¾ inches
	1921	¾ ,,
	1920	1¼ ,,
	1919	2 ,,
	1918	3 ,,
	1917	4 ,,
	1916	2 ,,
	1915	2 ,,

plus 15 ins. to top of roots.

The first check stage does not appear to have been long or well marked.

Root System : The original root system is very small and bent to the side in the peat. Immediately above it is a thin lateral 30 inches long. It ends in a small bunch of fine rootlets. Above it are two adventitious lateral roots. The longest is 3 ft. 6 ins. long. It ends in a large bunch of small rootlets in partially decomposed plant remains containing *Molinia.* The other lateral ends in a small bunch of rootlets surrounded entirely by decomposed *Sphagnum.* Another lateral root comes off 2 inches higher and divides into three. Five inches higher a small lateral comes off.

Tree 3. This is a thriving tree a few yards further down the slope.

Vegetation : Sphagnum, Polytrichum, Vaccinium myrtillus and a few plants of *Molinia caerulea.* There are dead tufts of *Molinia* in the lower layers of plant remains.

Soil : 6-9 in. plant remains.

1-2 in. blackish well decomposed peat.

9 in. yellow brown loam.

6 in. reddish brown loam in epidiorite.

Shoot Analysis : Colour of needles dark green. Length of 1922 needles 10-12 mm.

Shoot Length :	1922	16 inches
	1921	6 ,,
	1920	3 ,,
	1919	7 ,,
	1918	8 ,,
	1917	6 ,,
	1916	5 ,,

plus 18 in. to top of roots.

The check period was therefore not of long duration.

Root System : A part of the original root system has grown round and up into the plant remains. This root divided several times and has at least one bunch of small rootlets. Three inches above the lowest point of this curve the adventitious lateral roots come off. They are 4 in number, one divides immediately in to 3, another twice within a foot of the stem. The smallest lateral has been damaged by voles. One of these lateral roots has a total length of 8 ft. 6 ins. It ends in a loose bunch of rootlets. Two feet from the stem is a large bunch of rootlets on a side rootlet. The main lateral is 6 ft. 6 ins. long. Its first branch is 2 ft. 6 ins. long. Along it are a number of small bunches of rootlets. It ends in a festoon of long brown roots most of which were dead. Its second branch was 18 ins. long ending in a number of branches with small bunches of rootlets. The main root goes on sending off branches with small bunches of rootlets. 1 ft. 6 ins. from the end the root divides. One branch has a large bunch of rootlets. The other branch gives off several branches with small bunches. A large bunch finishes the root which is however still growing in length. This lateral runs through the plant remains, sometimes penetrating the peat for short distances. The herbage plants above it are *Polytrichum* dominant with *Sphagnum* and bilberry subsidiary. There are many dead tufts of *Molinia* at the bottom of the remains. The bunches of small rootlets are developed in layers of almost black well decomposed plant remains in which *Polytrichum* and *Molinia* were identified.

Observations :

(*a*) The conditions at the time of planting appear to have been a thin layer of peat with *Molinia,* bilberry and some *Sphagnum* and *Polytrichum.* The trees did not suffer a marked check but gradually came away. Adventitious lateral roots were developed and grew mainly in the decomposed plant remains. During this period the mosses increased from some undetermined cause, killing out much of the *Molinia.* The lateral roots of Tree 1 grew into layers of undecomposed remains, while laterals were developed at higher points in the case of Tree 2.

(*b*) Both Trees 1 and 3 have strongly developed laterals. The outstanding difference between them is that while the laterals of Tree 1 are almost bare of bunches of small rootlets, Tree 3 has a large number of them. This appears to be related to the physical condition of the humus surrounding the roots. The roots of Tree 1 were surrounded by living and undecomposed bilberry, *Sphagnum* and *Polytrichum* remains, while those of Tree 3 were in decomposed layers of humus of these plants and *Molinia.*

(*c*) The development of laterals on Tree 2 is weaker than in the two other cases, partly due probably to less initial vigour and partly to the development of laterals at more than one level arising from a rapidly increasing level of herbage. A few bunches of rootlets were developed, one notably in pure decomposed *Sphagnum.*

(*d*) The fall off in Trees 2 and 3 appears due either to their roots coming into layers of undecomposed plant remains which inhibited the development of bunches of fine rootlets or to the bunches of rootlets developing on remains deficient in available food.

Plot 5.

Location : Compartment 12.
Date of Planting : 1910-11.
Elevation : 750 ft.
Aspect : E.
Exposure : Sheltered by topography in all directions.

General Note : This patch shows poor results with good herbage conditions. This site is in a flat bottomed valley with very little fall and the natural and artificial drainage is sluggish.

Tree 1.

Vegetation : Molinia caerulea predominates with *Potentilla tormentilla, Erica tetralix, Eriophorum vaginatum* and *Scirpus caespitosus.*

Soil : 6 in. living roots and decomposing plant remains mostly *Molinia.*

Over 3 ft. dark brown fairly well decomposed very wet peat.

Shoot Analysis : Colour of needles yellow green. Length of 1922 needles 7-8 mm.

Shoot Length :	1922	½ inch
	1921	1 ,,
	1920	1¾ ,,
	1919	1¼ ,,
	1918	1 ,,
	1917	1 ,,

plus 12 ins. to top of roots.

It is clear that the tree is still in the check stage.

Root System : The original root system was put into the peat but not too deep. It is small and undeveloped. Immediately above it come off a number of thin adventitious roots. These roots run first in the wet peat, then bend up into the drier layer of decomposing vegetation. They run amongst and through *Molinia* tufts and end in some bunches of rootlets. The longest root is 24 inches. Immediately above these come off 2 stronger roots. These also start in the peat. One bends up into the layer of *Molinia* remains, running through and amongst the tufts and occasionally amongst *Potentilla* rootstocks. It is 5 ft. long and has no bunches of rootlets until near the end when there are few small ones. Figure 2 illustrates this tree with its root system.

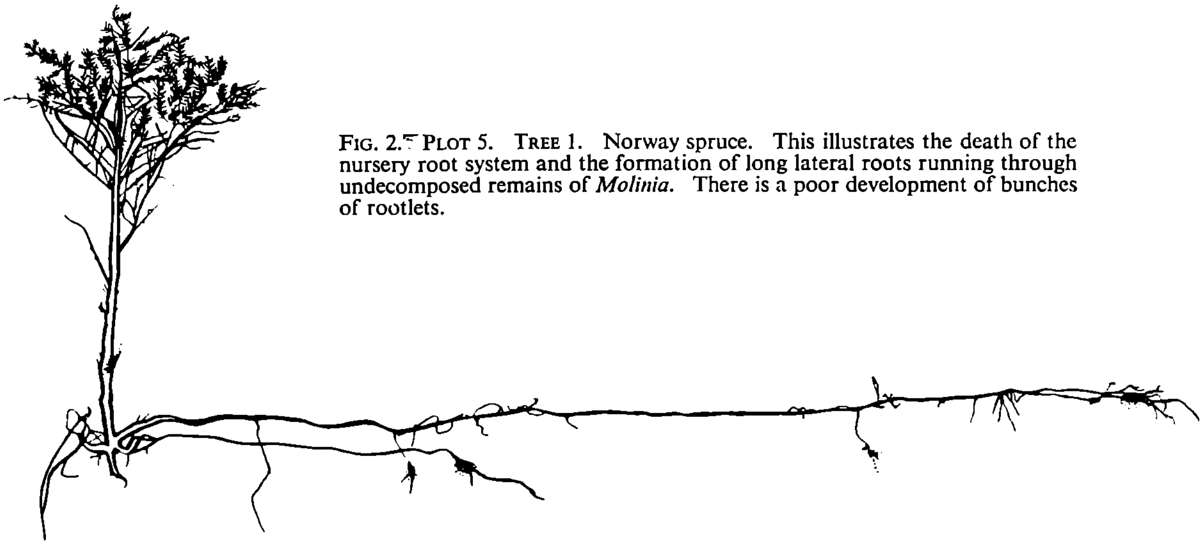


FIG. 2.—PLOT 5. TREE 1. Norway spruce. This illustrates the death of the nursery root system and the formation of long lateral roots running through undecomposed remains of *Molinia.* There is a poor development of bunches of rootlets.

Tree 2. An adjoining tree with the same vegetation and soil.

Shoot Analysis : Colour of needles yellow green. Length of 1922 needles 8-10 mm.

Shoot Length :	1922	½ inch
	1921	½ ,,
	1920	½ ,,
	1919	½ ,,
	1918	½ ,,
	1917	¾ ,,
	1916	¼ ,,
	1915	1 ,,
	1914	¼ ,,
	1913	½ ,,

plus 12 ins. to top of roots. The plant is still in the check stage.

Root System : The original root system is fairly large and shows some development. Immediately above it several adventitious roots come off. They are in the peat. They branch but show little development the longest being 12 ins. Two inches higher up one strong and several small lateral roots come off. They run amongst living *Molinia* tufts and remains. The longest one is 2 ft. 6 ins. long and ends in a small bunch of small rootlets. It is 8 years old.

Observations :

(*a*) The adventitious roots beginning in the superficial layers of peat, then bending up into the layer of vegetation, together with the development of lateral roots higher up suggests a rise in the water level some years after planting.

(*b*) The layer of herbage, consisting largely of living tufts of *Molinia*, does not appear to have been suitable to the development of bunches of small rootlets.

Plot 6.

Location : Compartment 18.

Date of Planting : 1910-11.

Elevation : 850 ft.

Aspect : N.E.

Exposure : The topography shelters from the S., W. and E. The site is exposed from the N. and N.E.

General Note : This slope where heather predominates has trees in different stages of development, the maximum height however is 2½ ft.

Tree 1. This is one of the better growing trees.

Vegetation : Calluna vulgaris is dominant. *Scirpus caespitosus, Eriophorum vaginatum, E. polystachion, Potentilla tormentilla, Vaccinium myrtillus. Molinia caerulea, Sphagnum* and *Hypnum* sp. are present also.

Soil : 3-6 in. plant remains, mainly heather and mosses tending to black peat on lower layers.

Over 3 ft. brown moderately fibrous wet peat.

Shoot Analysis : Colour of needles yellow green, length of 1922 needles 10 mm.

Shoot Length :	1922	3 inches
	1921	3 ,,
	1920	2¼ ,,
	1919	2½ ,,
	1918	2 ,,
	1917	1 ,,
	1916	½ ,,

plus 12 ins. to top of roots. The marked check stage lasted 6 years.

Root System : The original root system was put in the peat. It shows little development One inch above it an adventitious root comes off, bends up and divides into 3, the branches going different directions. Two of them are 5 ft., one 3 ft. long. They run entirely in the layer of living and dead herbage consisting mainly of mosses and heather remains. One of these branches has 5 rings. These lateral roots have side rootlets, and branch, but have no bunches of small rootlets.

Tree 2. This is a tree entirely in the check stage.

Vegetation : Calluna vulgaris predominates, with *Scirpus caespitosus, Potentilla tormentilla, Molinia caerulea, Vaccinium myrtillus* and *V. vitis-idaea, Carex* sp., *Sphagnum*, and *Hypnum* sp.

Soil : As Tree 1.

Shoot Analysis : Colour of needles yellow. Length of 1922 needles 5 mm.

Shoot Length :	1922	⅓ inch
	1921	1 ,,
	1920	1¼ ,,
	1919	1¼ ,,
	1918	1¼ ,,
	1917	¾ ,,
	1916	½ ,,

plus 6 ins. to top of roots.

This tree has not emerged from check stage.

Root System : The original root system is in the peat. It is dead. One to 3ins. higher are a few small adventitious roots in the top layer of peat. Three inches higher 2 adventitious lateral roots come off, one 2 ft. long and the other 1 ft. long. There are also several small adventitious roots coming off at this level. These lateral roots run mainly through recent heather remains, but go down also into the half decomposed heather, moss and *Molinia* remains of the original surface, one runs through a *Molinia* tuft. They have many small rootlets but none of the characteristic bunches of small rootlets, although in one or two cases the development approaches this type. Fig. 3 illustrates this tree with its root system.

Observations :

(*a*) The type of root developed in the heather remains differs from these examined before in having many small side rootlets but no bunches of rootlets developed at the top or on side roots. When the roots get into *Molinia* remains the rootlets are more in bunches.

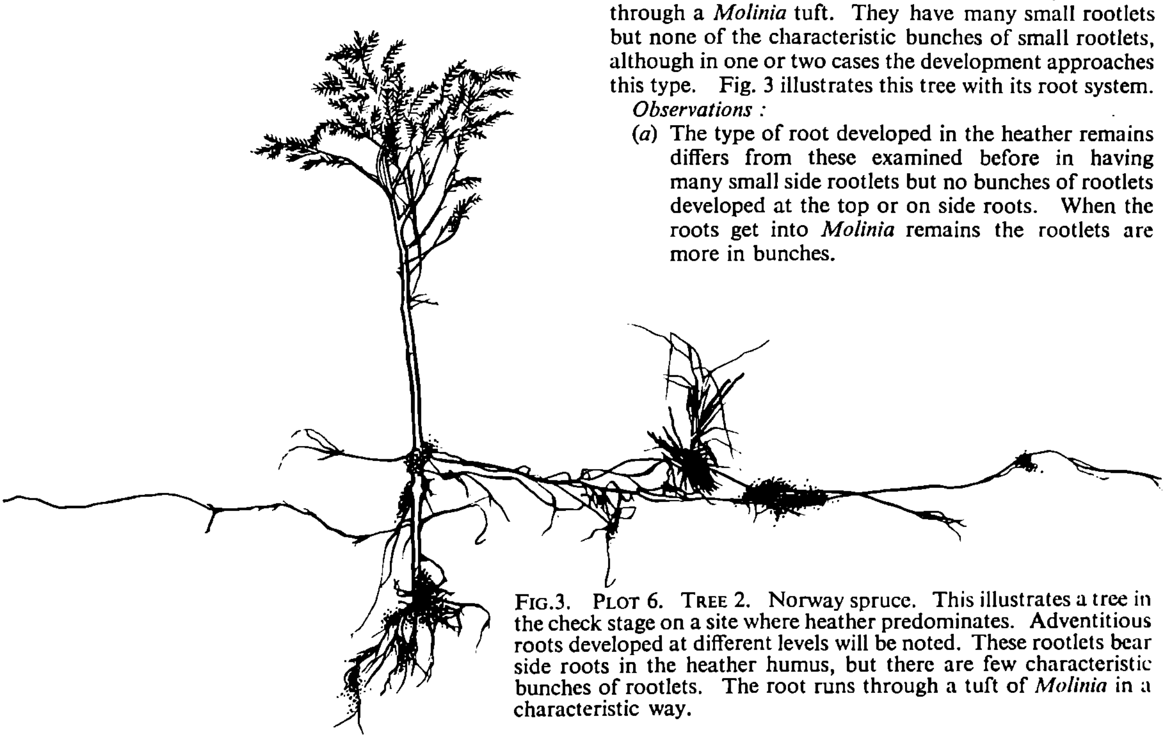


FIG.3. PLOT 6. TREE 2. Norway spruce. This illustrates a tree in the check stage on a site where heather predominates. Adventitious roots developed at different levels will be noted. These rootlets bear side roots in the heather humus, but there are few characteristic bunches of rootlets. The root runs through a tuft of *Molinia* in a characteristic way.

Plot 7.

Location : Compartment 19.
Date of Planting : 1910-11.
Elevation : 800 feet.
Aspect : S.W.
Exposure : The site is moderately exposed in all directions. Trees nearby show wind pressure damage from S.W.

General Note : It was found impossible to locate a sheltered place where *Scirpus* predominated, further most trees had died on these sites except where other herbage plants came in.

Tree 1. This plant adjoined a drain.

Vegetation : *Calluna vulgaris.*

Soil : 6 in. heather remains.

Very deep over 6 ft. wet yellow brown peat consisting largely of *Sphagnum* with *Scirpus*, *Eriophorum vaginatum* tufts.

Shoot Analysis : Colour of needles yellow, Length 5-6 mm.

Shoot Length :	1922	¾ inch
	1921	¾ ,,
	1920	½ ,,
	1919	1 ,,
	1918	1 ,,
	1917	1 ,,
	1916	1 ,,
	1915	½ ,,
	1914	¾ ,,
	1913	1½ ,,
	1912	¾ ,,
	1911	½ ,,

plus 9 ins. to top of roots. The tree is completely in the check stage.

Root System : The original root system is in the *Sphagnum* peat. It shows some development. Immediately above a single adventitious root has developed. It branches several times and runs through the upper layer of the *Sphagnum* peat. It is 18 ins. long and has developed no bunches of small rootlets.

The root systems of several dead trees were examined on sites with *Scirpus caespitosus* predominant, with heather present also. The peat was similar to that already described. In most cases no adventitious roots had developed, the original root system showed little development. In one case a short lateral root had developed 4 ins. above the original system. It was less than 12 ins. long and showed no special feature.

Observations :

(*a*) Root development is poor under these conditions.

SITKA SPRUCE

This species has not been planted extensively in Blocks I-VI. There is enough to indicate, however, that the duration of the check period of this species also varies under different conditions. This variation was studied in the same way as that of Norway spruce.

Plot 9.

Location : N.W. corner of Compartment 16.
Date of Planting : 1910-11.
Elevation : 750 ft.
Aspect : E.
Exposure : Sheltered from S., S.W., N.W., W. and N. Exposed from N.E. and E.

General Note : This is a small block of Sitka spruce which is doing well (Trees 6-10 ft. high) at N.E. and S.W. sides, while trees are in a partial check in the middle of the block. The slope is moderately steep, sufficient to give natural drainage. The difference in the growth of Sitka spruce appears due to soil factors.

Tree 1. This is a tree in the check stage on a heather herbage site.

Vegetation : *Calluna vulgaris* is the dominant plant. There are also small amounts of *Vaccinium myrtillus*, *Juncus squarrosus*, *Scirpus caespitosus*, *Potentilla tormentilla* and *Molinia caerulea.*

The mosses are *Sphagnum* and *Hypnum* sp.

Soil : 3-6 in. plant remains consisting mainly of heather and mosses.

12-15 in. dark brown moderately fibrous peat on a few inches of gritty loam with Loch Awe grit fragments on epidiorite.

Shoot Analysis : Colour of needles yellow green. Length of 1922 needles 8-12 mm.

Shoot Length :	1922	3½ inches
	1921	1½ ,,
	1920	¾ ,,
	1919	1½ ,,
	1918	¾ ,,
	1917	1½ ,,

plus 8 ins. to top of roots. Duration of check period 10 years.

Root System : The original root system is in the peat. It shows little development with the exception of 2 thin horizontally running roots. Immediately above, an adventitious root comes off which is 2 ft. 9 ins. long. It is blackish in colour and has small rootlets along the last foot of its length. There are no characteristic bunches of small roots. One inch higher another adventitious lateral root comes off 1 ft. 9 ins. long. Two inches higher two laterals come off, one 3 ft. 9 ins. and the other 1 ft. 9 ins. long. These are also blackish in colour; the tops are dying in the case of the longer and dead in the case of the shorter one. All the adventitious roots were running above the peat in plant remains consisting mainly of heather and moss remains.

Tree 2. This is a tree emerging from the check stage in a Bilberry-*Molinia*-Cotton Grass herbage.

Vegetation : *Vaccinium myrtillus*, *Molinia caerulea*, and *Eriophorum vaginatum* are dominant. *Calluna vulgaris*, *Potentilla tormentilla* and *Aira flexuosa* are subsidiary. *Hypnum* sp. is also present.

Soil : 3-4 in. plant remains. 12 in. black slightly fibrous peat. 6 in. clay loam with fragments of Loch Awe grit on epidiorite.

Shoot Analysis : Colour of needles green. Length of 1922 needles 10-12 mm.

Shoot Length :	1922	4 inches
	1921	5 ,,
	1920	5 ,,
	1919	2 ,,

plus 3 ins. to top of laterals (add 7 ins. to top of original root system). Duration of check period probably 8 years.

Root System : The original root system now consists of only a bare tap root. Two inches higher a number of short adventitious roots come off. Two inches higher 2 adventitious lateral roots come off, one 6 ft. 3 ins. long and the other 3 ft. 9 ins. long. The longer is the principal lateral root. It is reddish brown in colour and has side branches and rootlets, including small bunches of small rootlets. Three inches higher a short lateral (15 in.) comes off. All the lateral roots are in the plant remains consisting of the moss and the plants noted above.

Tree 3. This is a thriving tree 10 ft. from Tree 1 and 20 ft. from Tree 2. It is surrounded on three sides by thriving trees.

Vegetation : It is beginning to die off. *Aira caespitosa* predominates with a little *Vaccinium myrtillus, Luzula sylvestris* and *Potentilla tormentilla.* The only moss present is *Polytrichum* sp.

Soil : 2-4 ins. decaying *Aira caespitosa* and Sitka needles. 12 ins. dark brown loam to clay loam with grit fragments in epidiorite.

Shoot Analysis : Colour of needles bluish green. Length of 1922 needles 17-22 mm.

Shoot Length :	1922	24 inches
	1921	3 ,,
	1920	18 ,,
	1919	10½ ,,
	1918	6 ,,
	1917	6 ,,

plus 18 ins. to top of laterals. The check period was short.

Root System : The original root system has developed but not downwards. A number of roots come out from it through the soil, but bending up in most cases into the humus layer. They are short and in the humus have small bunches of rootlets. Immediately above the original system the main lateral roots have developed. The longest and thickest one runs out from the soil site through a gap in the thriving trees on to a peat site similar to that of Tree 1. This root is 13 ft. long. It has rootlets after 3 ft. from the stem but no bunches of roots have developed. The next lateral runs through the upper layer of soil, then into that of *Aira caepitosa* remains. This root branches several times in the humus layer and has many small rootlets. It was noted that there were many small bunches of rootlets of this and other trees in the *Aira* humus. This root was 9 ft. long. The next lateral is 6 ft. 6 ins. long. It first of all runs several inches into the loam, then bends up the *Aira*-Sitka spruce remains. (The herbage has been killed out). It divides frequently and has many small rootlets. The terminals are long bare brown roots with white tips. It was noted that both the last two laterals while in the soil send roots deeper into the soil and also into the humus layer above where they form small bunches.

Observations :

(*a*) In general form, the root system of Sitka spruce is the same as Norway spruce. The original root system does or does not develop depending on the soil conditions. The main root system however is formed by adventitious roots developing above it. They run partly through the soil, when present, but come up into the humus layer to form small bunches of rootlets. On peat sites they run through the plant remains.

(*b*) As in the case of Norway spruce the lateral roots of Sitka spruce are poorly developed where heather predominates in the plant remains.

(*c*) There are 2 Norway spruce in this plot; one is completely in the check stage, the other is emerging from it. Both compare unfavourably with the surrounding Sitka spruce in size and vigour.

THE INFLUENCE OF TURF PLANTING ON ROOT SYSTEMS

It was considered useful to investigate the influence of turf planting and screefiing on the root system.

Plot 8.

This is a site where Norway spruce and Sitka spruce, mixed irregularly, have been planted by the Belgian System.

Location : Compartment 26.

Date of Planting : 1911-12.

Elevation : 900 ft.

Aspect : N.E.

Exposure : The site is in a "through" valley and is exposed in practically all directions. Both species show evidence of wind pressure from the S.W. but Sitka spruce has retained its foliage to a greater extent than Norway spruce.

General Note : The records regarding the treatment are meagre. The drains appear to have been cut and turfs were laid out in the usual Belgian method. This probably was done the year before planting. Some mineral soil was added at the time of planting. There is a considerable difference in the size of individual trees, those selected being of average height. The Sitka spruce were more vigorous than the Norway spruce.

Norway Spruce

Vegetation : On the turf dominant plants are *Calluna vulgaris* and *Molinia caerulea.* Surrounding *M. caerulea* predominated with *Calluna vulgaris, Potentilla tormentilla, Erica tetralix* subsidiary. There is some *Sphagnum.*

Soil : The turf is black fairly well decomposed peat and moderately dry. On the natural surface there are 3 in. plant remains mostly undecomposed *Molinia,* 3 in. black peat similar to turf but wet, over 3 ft. yellow brown fibrous peat consisting largely of decomposed *Sphagnum* with tufts of *Scirpus.*

Shoot Analysis : Colour of needles yellow green. Length of 1922 needles 5-8 mm.

Shoot Length :	1922	½ inch
	1921	½ ,,
	1920	½ ,,
	1919	1 ,,
	1918	1½ ,,
	1917	2 ,,
	1916	2 ,,
	1915	2 ,,
	1914	1½ ,,

plus 7 ins. to top of roots. There has thus been a fall off in growth since 1917 due either to soil factors or exposure.

Root System : The original root system is not clearly defined. From the region of it a root comes off which runs through the peat of the turf out into the herbage of the natural surface and ends in a pocket of decayed *Sphagnum* and *Molinia* where a small bunch of rootlets has developed. A short adventitious root runs out through the peat to the edge of the turf where there is a small bunch of rootlets in the decaying peat. Several other short roots penetrate the peat. The two strongest adventitious roots run out of the turf through tufts of living *Molinia* into a pile of drain turfs and were lost after 4-5 feet.

Sitka Spruce

Herbage : *Calluna vulgaris* and *Molinia caerulea* on the turf. Surrounding *Molinia caerulea* predominates with a little *Scirpus caespitosus*, *Potentilla tormentilla* and *Erica tetralix*.

Soil : The turf is black fairly well decomposed peat. The natural surface is 6 in. plant remains and black peat on over 3 ft. of yellow brown fibrous peat similar to that under the Norway spruce.

Shoot Analysis : Colour of needles green. Length of 1922 needles 10-12 mm.

Shoot Length :	1922	6 inches
	1921	8 ,,
	1920	5 ..
	1919	3½ ,,
	1918	8 ,,
	1917	6 ,.
	1916	3 ,,

plus 12 ins. to top of roots. The actual check period was thus short, the tree is not however getting away.

Root System : The original root system is not clearly defined and probably has developed to some extent. The original roots appear to have reached the natural surface at the time of planting. Two short roots come off from the region of the original system and penetrate into the peat off the turf. Higher up 3 adventitious roots come off and run out of the turf amongst the *Molinia* turfs of the natural surface, occasionally dipping into the black peat for short distances. There are a few small bunches of rootlets on side roots. The main lateral shows 8 rings and was dissected to a length of 13 ft. 6 ins. It runs towards a drain, then along the drain side. It was lost at the length mentioned. It had no notable bunches of rootlets.

Observations :

(*a*) Planting in the upturned turf enables the original root system to develop to some extent in the peat. The adventitious lateral roots also grow through the peat of the turf. The main lateral roots however quickly pass out of the turf and grow through the herbage as previously noted.

(*b*) On this site Sitka spruce is more vigorous than Norway spruce. Further it retains its foliage to a greater degree under wind pressure.

SCOTS PINE

Scots pine was studied by the same methods as were used for the spruces.

Plot 10.

On this site a tree growing on soil was studied. The growth on this site was considered the best at Inverliever.

Location : Compartment 16.

Date of Planting : 1910-11.

Elevation : 450 feet.

Aspect : S.E.

Exposure : This is a sheltered hollow on the slope at the loch side. A ridge and thriving trees protect the site from the S.W.

Vegetation: Bracken and *Holcus lanatus* predominate; *Carduus palustris*, *Digitalis purpurea* and *Potentilla tormentilla* are present.

Soil : 1-2 in. plant remains, principally *Holcus*, over 18 in. clay loam with fragments of epidiorite on that rock.

Shoot Analysis : The colour of the needles is bluish green. In common with all Scots pine at Inverliever the needles remain only 1-2 years on the shoot. The cause of this has not been determined. Length of needles 40-60 mm.

Shoot Length :	1922	8½ inches
	1921	10 ,,
	1920	8 ,,
	1919	11 ,,
	1918	12½ ,,
	1917	12 ,,
	1916	9½ ,,

plus 15 ins. to top of roots. There was thus no prolonged check period.

Root System : The tree like most others is bent over slightly to the N.E. at the root. In view of the sheltered site this may have been caused by the bracken falling over in winter.

The original root system has developed. From it numerous roots have grown out. One penetrates into the soil of the hill side. Another goes along the surface down hill but in the soil. The others bend downwards into the soil. There is no marked tap root. The roots are all healthy.

Plot 11.

This is a knoll on which the Scots pine has failed partially and was interplanted with Norway spruce.

Location : Compartment 4.

Date of Planting : Scots Pine—1909-10. Norway spruce—1912-13.

Elevation : 550 feet.

Aspect : S.W.

Exposure : The plot is in a sheltered hollow which is protected on all sides by the topography and by thriving trees on the S.W. side.

Scots Pine (Tree 1.)

Vegetation : *Calluna vulgaris* is principal plant. *Vaccinium myrtillus*, *Juncus squarrosus*, *Molinia caerulea*, *Aira flexuosa* and *Potentilla tormentilla* are present also. The mosses are *Sphagnum* and *Hypnum* sp. An examination of the plant remains indicates the *Molinia* was more abundant previously.

Soil : Up to 12 in. plant remains mostly *Sphagnum* where deep. 3-4 in. black wet moderately fibrous peat. 6-9 in. yellow brown fibrous peat on stony loam probably boulder clay.

Shoot Analysis : Colour of needles green. Very few of last years needles remaining. Length 25 mm.

Shoot Length :	1922	2 inches
	1921	4 ,,
	1920	5 ,,
	1919	7½ ,,
	1918	12 ,,
	1917	10 ,,
	1916	8 ,,

plus 14 ins. to top of roots. There is evidence of damage, possibly blackcock during 1916-17. *Chermes pini* is present but does not appear important.

Root system : The original root system is in the peat. All the present roots come from the region of the original system. From it numerous roots run out horizontally. mainly through the wet black peat layer. The longest root was followed to a distance of 8 ins. when it was lost. This root runs near a spruce and the dissection showed that the Scots pine root is under the lowest lateral of the spruce. This Scots pine root also passes through the root system of another Scots pine. The roots of the Scots pine have a number of rootlets throughout but no characteristic bunches of rootlets or coral-like mycorhiza growths were formed. The root system was extensive and healthy. The dissection of the roots of several other Scots pine showed that the roots were all mainly in the peat.

Norway Spruce (Tree 2.)

The adjoining tree of this species was studied also. Vegetation and soil as before.

Shoot Analysis : Colour of needles green. Length of needles 10-15 mm.

Shoot Length :	1922	5 inches
	1921	3 ,,
	1920	2 ,,
	1919	1 ,,
	1918	1¾ ,,
	1917	3½ ,,
	1916	1½ ,,

plus 8 ins. to top of roots.

Root System : The original root system is in the peat. From it 3 roots come off and bend upwards into a *Sphagnum* clump. There are *Molinia* remains in this layer. The roots have small bunches of rootlets near their tips. One inch higher there is a whorl of adventitious lateral roots. There are 3 principal ones, the longest being 3 ft. 9 ins. These roots are mainly in a layer of dead decaying *Sphagnum* and *Molinia*. Numerous bunches of small rootlets were developed in this layer. Three inches higher 2 laterals come off, partly in *Sphagnum* but stretching out into a layer of heather and *Hypnum* remains. They were severed in dissecting out the Scots pine root system. Fig. 4 illustrates this tree.

Observations :

(*a*) The plantation root system of Scots pine develops from the region of the nursery root system and not above it as in the case of the Spruces.

(*b*) The roots grow mainly in the peat and not in the herbage remains as do the spruces in peat sites.

(*c*) No evidence was obtained relating the failure of the Scots pine to the root development. The shedding of all but the current year's needles was a characteristic of both soil and peat sites, sheltered and exposed.

(*d*) The Norway spruce studied was notable in its root development in decayed *Sphagnum* with some *Molinia*.

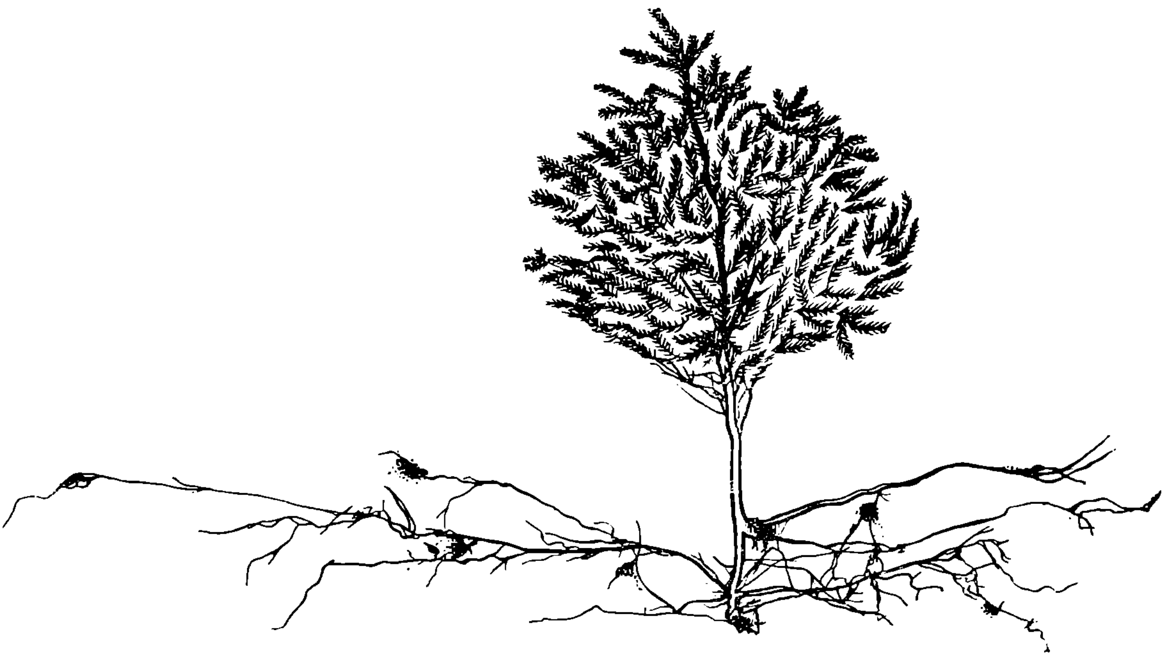


FIG. 4. PLOT 11. TREE 2. Norway spruce. This shows a tree emerging from the check stage. Small roots bend up from the original nursery root system. Adventitious roots are developed from different levels. All are in herbage remains of which *Sphagnum* is the notable constituent. Small bunches of rootlets are developed in decayed *Sphagnum-Molinia* remains.

MOUNTAIN PINE

The dwarf form of mountain pine, *Pinus montana* var. *pumilio* has been planted occasionally on peat in Blocks V and VI.

Plot 13.

Location : Compartment 43.
Date of Planting : 1913-14.
Elevation : 650 feet.
Aspect : S.E.
Exposure : Sheltered in all directions except the east.

Tree 1.

Vegetation : *Calluna vulgaris* and *Molinia caerulea* predominate. *Myrica gale, Eriophorum vaginatum, Scirpus caespitosus, Erica cinerea* and *Potentilla tormentilla* are present also. *Sphagnum* is the principal moss.

Soil : 2-3 in. *Sphagnum* and plant remains. 6-9 in. brown fairly well decomposed peat on deep yellow brown fibrous peat, almost pure *Sphagnum.*

Shoot Analysis : The colour of the needles is bluish green. The main shoots are 2-3 inches long.

Root System : The original root system is in the peat at a normal level. From it a number of horizontally running roots come off. One is 2 ft. 6 ins. long and runs through *Molinia* tufts and plant remains. It bears a number of the characteristic whitish mycorhiza tubercles near the tip, which is long and white. The main lateral is 6 ft. 11 ins. long. It runs through the herbage. When not penetrating *Molinia* tufts it can be seen by turning back the herbage. It branches near the end and both branches bear white tubercles and end in long white tips.

Tree 2.

Vegetation : *Calluna vulgaris, Molinia caerulea* and *Myrica gale* predominate. *Scirpus caespitosus, Eriophorum vaginatum, Erica tetralix, Potentilla tormentilla* and *Narthecium ossifragum* are present also. *Sphagnum* is the principal moss.

Soil : 1-2 in. *Sphagnum* and plant remains. 9-12 in. brown wet fairly well decomposed peat; deep yellow brown fibrous peat largely *Sphagnum* remains.

Shoot Analysis : The colour of the needles is green. the current year's shoots are 1-2 ins. long.

Root System : The original root system is in the surface peat. From it come off a number of bare roots not exceeding a foot long. These run in the surface peat. There are no tubercles.

Observations :

(*a*) The roots of mountain pine appear to develop normally from the region of nursery root system. They run either in the peat (Tree 2) or in the herbage (Tree 1). The mycorhiza tubercles of Tree 1 were developed in the surface vegetation and could be seen by turning back the herbage.

CONCLUSIONS

Norway Spruce

(1.) In a normal soil site the nursery root system develops after planting. Roots from it bend up into the superficial layers of soil. The principal plantation root system is however an adventitious one developing above the nursery system. These roots run laterally in superficial layers of soil sending branches deeper into the soil and also up into the humus layer where bunches of small rootlets are developed, presumably for feeding purposes.

Further studies on such sites are desirable especially for younger trees than those investigated, namely 13 years.

(2.) In a peat site the nursery roots may or may not develop. On the upturned turf they grow to some extent and in other cases roots have come up into the superficial layers from the region of the nursery root system, e.g. Plot 11. As in the normal soil site however the principal part of the plantation root system originates adventitiously above the nursery root system. Where the conditions inhibit the development of the nursery root system the check period continues until this adventitious root system develops (Plot 1). These adventitious roots develop laterally not in the peat but mainly along or above the land surface at the time of planting, i.e. amongst living herbage and remains of surface vegetation. They are found frequently penetrating tufts of living *Molinia.* Where the level of the herbage is rising rapidly, adventitious roots are developed at higher levels (see Figures 3 and 4) so that whorls of adventitious roots are formed. The development of this adventitious lateral system does not necessarily mean the successful establishment of the tree as is seen in the case of Tree 1, Plot 4. This appears to depend on the development of bunches of small rootlets presumably for feeding purposes. Before the tree branches meet and needle humus is formed, these feeding rootlets can only develop in the humus of the herbage plants. The evidence collected indicates that the species of herbage plant and the degree of the decomposition of its remains are the important factors concerned in the development of the bunches of feeding roots. Thus these roots were frequently developed in a decaying layer of *Molinia.* Where there were rank growing tufts however the lateral roots passed through without forming bunches of rootlets. Notably decayed *Sphagnum* is frequently a constituent of the humus surrounding the bunches of roots. Heather remains do not appear favourable for the production of the feeding rootlets. When the herbage conditions are not suitable for the development of these rootlets the lateral roots continue growing, giving the long bare roots. The irregular development of Norway spruce on peat sites would therefore appear to be due first of all to the small development of the nursery root system in the peat causing a check stage until the adventitious roots develop in the herbage layers. The time required for this development varies and requires further investigation. Secondly the value of these laterals to the plant depends on their ability to form bunches of feeding rootlets, which appears to be only possible in layers of vegetation of particular species and state of decomposition. This opens up several lines of research and experiment in treatment. It appears therefore that the herbage plants are important not only as indicators of quality of peat but directly as potential tree feeders until the canopy closes.

Sitka Spruce

(3.) The form and development of the root system of Sitka spruce in peat is similar to that of Norway Spruce. The nursery root system normally shows little development. The main plantation root system arises from adventitious roots above the nursery root system. On peat sites these roots run mainly through the herbage plant remains. Bunches of small feeding rootlets are developed amongst decayed herbage of particular species, generally mosses and grasses.

(4.) Plots 8 and 9 indicate that on these sites Sitka spruce is more vigorous than Norway spruce. Sitka spruce has not been planted sufficiently widely in the Blocks in question to enable a critical comparative study of the two species for a range of conditions to be made. Plot 8, and a study of ridges in Compartments 14 and 21, indicated that although Sitka spruce suffers similar branch deformation to Norway spruce under wind pressure, it retains its foliage better.

Scots pine

(5.) In a normal soil site the plantation root system of Scots pine develops from the nursery root system. The roots penetrate through and down into the soil.

(6.) On peat sites the plantation root system also develops from the nursery root system. The roots run in the upper layers of the peat and not in the herbage layers. No definite evidence was obtained that the failure of Scots pine at Inverliever was related to the root development in peat.

Mountain pine

(7.) This species appears normally to develop its plantation root system from the region of the nursery system. The roots bearing mycorrhiza tubercles were located in the herbage layer, but roots were also found in the superficial layers of peat.

ADDENDUM I.

LOCALITY CONDITIONS, BLOCKS I-VI.

Topography

The altitude of Loch Awe, which runs N.E. and S.W., is 118 ft. and the highest point in Blocks I-VI is Dun Corrach, 951 ft. The ground rises steeply from the loch to Dun Corrach, while from the N.E. and S.W. limits of the blocks the slope of the land is more gentle and undulating to the summit. From the ridge of Dun Corrach to the fence on the N.W. there is a plateau with a mean elevation of about 850 ft. This plateau is traversed by several valleys which run N.E. and S.W., i.e. transverse to the present drainage system. These valleys are narrow and bounded by rock ridges. The outstanding feature of them is that they are flat with a very low gradient. As they approach the N.E. and S.W. limits of the blocks the gradient increases and they drain into the loch either directly by bending round or into streams running transverse to their direction. The three main features of the topography are thus :—

1. The poor natural drainage of the plateau resulting from the direction of the valleys traversing it being at right angles to the main drainage direction and to the low gradient of the bottoms of these valleys.
2. The valleys traversing the plateau, by running in the same direction as the prevailing wind namely S.W. (see Addendum II) greatly increase the wind pressure exposure of the land. They act as wind channels.
3. The ridge of Dun Corrach is one of the highest points in the neighbourhood and is thus almost fully exposed.

The exposure from wind acts in two ways from a forestry point of view namely :-

Exposure

(*a*) The direct effect of wind pressure on the trees
(*b*) The indirect effect of the desiccating power of the wind.

The direct effect of wind pressure is from the direction of the prevailing wind namely S.W. It therefore sweeps the slopes on the loch side, the S.W. side of Dun Corrach, and the plateau, where its effect is increased by the topography as has been noted. As the sea is less than 10 miles distant on the S.W. the salt spray may be an adverse factor.

How far the desiccating power of the wind acts on this site has still to be determined. The high rainfall and high relative humidity are counteracting influences.

Geology

The principal underlying rock is epidiorite. It retains its original igneous characteristics, being a massive andesitic basalt. Its massive nature must impede drainage downward. Below the road round Kilmaha there are patches of Loch Awe grits and limestone traversed by basalt dykes. There are also patches of grit up the Allt Mor burn near the Arichamish march and on some ridges towards the fence. Superficially however they are not of great extent.

There are few glacial deposits marked on the one inch O.S. Drift map, on the area under consideration. They do not appear to be important.

Soil

Normally the epidiorite weathers into a reddish brown loam or clay loam. It is found on the steep slopes on the loch side. Elsewhere peat is present to a greater or less extent. It usually rests on soil on the slopes and on rock on the ridges. The hollows usually have a deep deposit of peat.

General Notes on Species and their Distribution

The following species were planted in Blocks I-VI in order of their importance :—

(i) Norway spruce
(ii) European larch
(iii) Scots pine
(iv) Silver fir
(v) Douglas fir
(vi) Sitka spruce
(vii) Japanese larch
(viii) Dwarf mountain pine
(ix) *Thuja plicata*
(x) *Abies nobilis*

On the steep slopes with soil, carrying bracken and grasses, European larch was planted. On the more sheltered bracken slopes Douglas fir was used and where the soil was shallower Silver fir.

On ridges with shallow peat on rock Scots pine was planted and also on other peat sites especially in Blocks I & II.

On wet soils and in many of the peat sites Norway spruce was used. Sitka spruce was used to a much smaller extent on such sites.

Dwarf mountain pine was used mainly on exposed rocky knolls in Blocks IV and V but also to some extent on peat sites. The other species only occur in small patches mainly in Block VI.

The principal planting method used was by semi-circular spade. A small area was planted by the Belgian turf method.

3. TABLE SHOWING DIRECTION OF WIND AT FORD BY AVERAGE No. OF DAYS IN 3 YEARS—1918 TO 1920.

Direction	No. of Days
N.	20
NNE.	6
NE.	38
ENE.	7
E.	40
ESE.	8
SE.	20
SSE.	8
S.	18
SSW.	19
SW.	89
WSW.	16
W.	23
WNW.	4
NW.	30
NNW.	6
Calm	13

Note.—Ford lies 4 miles south-west of Inveriiever Forest, while Cruachan lies 14 miles north-west of it.

ADDENDUM II.—METEOROLOGICAL DATA.

1. TABLE OF RAINFALL, RAIN DAYS, AND TEMPERATURE (AVERAGE OF 5 YEARS 1916 TO 1920) AT FORD AND CRUACHAN.

	January		February		March		April		May		June	
	Ford	Cru.	Ford	Cru.	Ford	Cru.	Ford	Cru.	Ford	Cru.	Ford	Cru.
Rainfall (Ins.)	7.19	8.45	6.0	7.55	4.28	5.0	4.58	5.13	4.55	4.78	3.68	4.08
Rain Days	24	25	20	20	20	19	21	18	19	19	20	18
Max. T. (F.)	41.27	40.1	45.06	41.16	45.06	43.57	52.02	49.6	60.76	60.91	64.43	63.7
Min. T. (F.)	31.29	30.84	31.2	30.3	31.24	30.14	33.15	32.91	40.63	40.63	42.44	42.42
Mean T. (F.)	36	36	37	36	38	37	43	41	51	51	53	53

	July		August		September		October		November		December		Whole Year	
	Ford	Cru.	Ford	Cru.	Ford	Cru.	Ford	Cru.	Ford	Cru.	Ford	Cru.	Ford	Cru.
Rainfall (Ins.)	4.1	3.76	6.21	6.27	6.4	7.45	8.58	9.31	10.3	12.96	8.07	8.99	73.94	83.73
Rain Days	19	17	23	23	25	23	23	22	23	23	25	24	262	251
Max. T. (F.)	67.1	67.29	65.93	63.34	58.7	57.55	52.53	51.67	46.16	44.34	41.54	40.69	53.40	51.99
Min. T. (F.)	44.52	44.13	46.23	46.65	41.75	40.69	37.84	37.0	34.22	33.93	31.3	35.51	37.15	37.10
Mean T. (F.)	56	56	56	55	51	49	45	45	40	39	37	36	45	44.5

2. Table showing distribution of ground frost, snow and sunshine, throughout the year at Ford, Inverliever Forest, Argyll. (Average of 3 years, June 1918 to June 1920).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.	Total
Nights on which grass minimum thermometer showed 30 degrees F. or less	12	12	13	11	4	1	1	1	1	9	14	15	100
Days on which any snow either fell or was lying	5	5	8	3	—	—	—	—	—	—	3	2	26
Days on which 0.6 or less of the sky was covered with cloud	9	9	7	12	13	11	11	7	8	11	10	9	117

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