FORESTRY COMMISSION

BULLETIN No. 32

AFFORESTATION OF UPLAND HEATHS

By

J. W. L. ZEHETMAYR, B.A.

FORESTRY COMMISSION

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE

PRICE 17*s.* 6*d.* NET

FORESTRY COMMISSION
BULLETIN No. 32

AFFORESTATION OF UPLAND HEATHS

By
J. W. L. ZEHETMAYR, B.A.
FORESTRY COMMISSION

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE
1960

FOREWORD

The upland heaths considered in this Bulletin comprise wide stretches of heather-clad land among the hills along the eastern side of Scotland and Northern England. They are distinct from the peat-covered lands situated farther west, which were dealt with in an earlier bulletin, No. 22, entitled *Experiments in Tree Planting on Peat* (H.M.S.O. 1954). They may also be distinguished from the lowland heaths found farther south in England.

Having little or no value for agriculture, the upland heaths form a substantial reserve of land suitable for afforestation, and as such they attracted the attention of the Forestry Commission soon after its formation in 1919. Considerable technical problems were encountered when afforestation commenced, and in 1921 the first experiments were set out by the Commission's Research Branch in order to study and develop the best techniques for this difficult ground. Research has continued ever since, and the stage has now been reached when certain of the main problems have been solved. Operations such as ploughing and manuring have been extended from the experimental areas to the normal large-scale planting operations, and a good appreciation has been obtained of the most suitable species of trees to grow on heather-clad uplands.

This bulletin reviews all the experimental work carried out over a period of thirty-six years, from 1921 to 1957. Many methods tried out in the early years have long since been discarded, while others have become general practice. The object of this work is to present a complete record of all that was attempted, with an assessment of the results so far achieved.

This publication has been compiled, from the extensive records of the Research Branch, by Mr. J. W. L. Zehetmayr, one of the Commission's forest officers.

FORESTRY COMMISSION,
25, Savile Row,
London, W.1.
March, 1960.

CONTENTS

PHOTOGRAPHS

Page

FIGURES

Chapter 1

THE CHARACTERISTICS OF THE UPLAND HEATHS

The upland heaths are one of the principal types of hill land in Great Britain which have not in the recent past been used to their full potential. They thus form one of the main reserves of land available for afforestation, and almost a tenth of the national afforestation programme, which began in 1919, has been located on such land. The purpose of this bulletin is to describe the work of afforestation over the first thirty-eight years, that is, until 1957, and in particular to summarise the large programme of research and experimentation, which accompanied the extension of afforestation from relatively easy to progressively more difficult sites.

Definition

Tansley (1939) was fully aware of the inadequacy up to that date of the descriptions of the section of the heather-covered land or Callunetum of Great Britain termed 'upland heath'; he fell back on the definition that 'these Calluneta are the typical grouse moors'. He divides the community Callenetum into upland heath and lowland heath, the latter occurring on sandy soils in the English lowlands, while the occurrence of the former is on the eastern sides of Ireland, Wales, and northern Britain. While a complete synopsis is given of the lowland areas, the ecological descriptions of upland heath then available came from outliers in Ireland, Somerset, and on the Welsh Marches, and also from the Cleveland Hills in Yorkshire; Tansley recognised the almost complete lack of data from Scotland, where in fact the largest areas occur.

He was undecided whether to distinguish 'heath' (the *Heide* of German authors) on acid soils, with their peat usually much less than a foot in depth, from 'heather moor' (*Heidemoor*) on deeper peat. He noted that the floristic differences listed by various authors are very small, residing chiefly in the frequency of the less common species, and concluded that 'the vegetational distinction between upland heath and heather moor is very slight'. For the purpose of afforestation, however, the difference in the substratum is important. The afforestation of peat areas, including those dominated by *Calluna*, has been described by the present author (Zehetmayr, 1954).

Though important ecological investigations have been carried out on the upland heaths since 1939, there has been no reassessment of the status and inter-relationships of the various types of Callunetum. Before afforestation the areas of heath which are described in this bulletin were expanses of heather-covered land, usually treeless, on strongly podsolised very compact soils, with a thin layer of raw humus, and typically with a thin iron pan. This combination of soil and vegetation types is generally found on sandstones, or boulder till derived from sandstone, at altitudes over 500 feet, and under rainfalls of 30 to 40 inches per annum. The heaths have been maintained in this state by deliberate burning, and to a lesser extent by grazing, without which they would ultimately in many places revert to forest. The characteristics of the heaths are more fully described in the sections which follow, while the factors which distinguish these heaths from others in the British Isles and Western Europe are summarised in Chapter 2.

Location and Topography

Heaths of the type defined are found in the eastern half of Scotland and in parts of north-east England; there is a break in their distribution in southern Scotland, where more fertile rocks have in general given rise to grasslands. Much of the heath is on gently sloping hills, and it is under these conditions that the typical soil profile is developed. Heath is also found on steeper slopes especially on the colder north faces, whereas with other aspects the steeper slopes often bear grassland or bracken. At altitudes below 500 feet, or rather less in the north of Scotland, land of the heath type has long been broken in for agriculture; while above 1,200 feet, hill peat has generally formed.

Geology

Siliceous rocks predominate below the heathlands, and in particular large areas are underlain by Devonian Old Red Sandstone in Scotland, and Carboniferous Millstone Grit or Jurassic Calcareous Grit in northern England. Other areas lie on metamorphic rocks of the Highland series. In most cases the rock is overlain by glacial boulder tills, sometimes of considerable depth. The glacial drift is generally very stony and extremely compact; less often drift is replaced by glacial wash, while frequently on the lower slopes thin wash covers the drift. The main exception is that the Cleveland Hills of the North York Moors are destitute of glacial drift, except in the valleys.

Climate

The upland heaths lie to the east of the main mountain masses, and have a climate cool enough and wet enough to cause podsolisation; yet the rainfall is not sufficient to give rise to peat formation, except in particularly favourable topographical conditions. The annual precipitation is usually between thirty and forty inches evenly spread over the year; comparatively little falls as snow below the 1,000-foot contour. Where heaths occur in higher rainfalls, this is compensated by increased slope or a freely draining subsoil; otherwise peat formation would occur.

The humidity on the heaths is lower than on many other hill areas, ranging from 70 to 75 per cent (Bilham, 1938). The occurrence of destructive fires on these heaths is however not nearly so frequent as on the lowland heaths, for although both are largely maintained by burning, the grouse moors are deliberately burnt at definite intervals and thus the severity is controlled, while the lowland heaths usually burn from accidental causes.

The generally flat topography and absence of shelter allows free play to the winds, which in these regions average sixteen miles per hour in July and twenty-one in January. (Tansley: 7 to 9 and 8 to 12 metres per second respectively). In fact the winds blow steadily over the heaths and still days are rare, though some coastal areas in Yorkshire have up to twenty days a year of fog. In consequence of the general windiness, temperatures are low, but on the other hand damaging frosts are unusual on the plateau, though they may be severe in the intersecting valleys. The actual mean annual temperatures given by Tansley of 42 to 46°F are well below average conditions in Britain. This is to a lesser extent true of the insolation also; the heaths receive 25 to 30 per cent of the possible duration of bright sunlight.

Exposure is not unduly severe, except in the far north where wind speeds are greater, or at the higher altitudes, or else where the hills slope to the east and north near the sea. At altitudes ranging from 800 to 1,200 feet according to local conditions, wind speeds increase, as do the snowfall and total precipitation, while temperatures and insolation fall. Under these circumstances exposure becomes the dominating factor and Tansley considered that here heath became the "climatic formation", in that wind at this level prevented the dominance of trees.

Soil

The soils of all the Calluneta are podsolised. A main difference between the soils of the lowland and upland heaths is in their degree of compaction. While the lowland soils are mainly of coarse sand, the upland are of mixed stones, sand and clay, so compacted that they cannot be dug with a spade, and this is usually attributed to the pressure exerted by the ice in the last glacial epoch, which ended only 12,000 to 14,000 years ago. In these compact soils percolation is slower, and the depth of the profile is much less; usually the subsoil lies at about a foot on the upland heaths, as compared with three feet in the profile given by Tansley as typical of the lowland heath. Podsols of the normal type do occur on the upland heaths, but the typical soil is the iron podsol, in which the raw humus layer thickens until true peat forms on the mineral soil surface, and the B horizon develops as a sharply defined and very hard iron pan, very different from the soft peat pan and broad iron-stained band of the typical lowland podsol.

The soils of certain of the upland heath forests have been described and analysed by Jacks (1932), Muir (1934) and Muir and Fraser (1940). The last authors recognised three types of podsols at Clashindarroch, namely normal podsols, concealed podsols, and peaty podsols. Brief descriptions of typical profiles from these authors are set out opposite and the features exhibited may be discussed in general terms.

Peat Layer, A_0 Horizon. The peat layer is very acid and usually well decomposed, dark brown or black in colour; the presence or absence of a raw humus layer above the peat is generally dependent on the time that has elapsed since the area was last burnt over. Jacks attributes local variation in peat depth to past burning having destroyed varying amounts of the peat. The question as to what depth peat may accumulate over a podsol, and the latter still remain part of the active soil, is still open, but in general the depth in the areas concerned does not exceed six inches and exceptionally one foot. Typically the peat is formed principally of *Calluna*, but in wetter areas other species such as *Eriophorum* play a part also.

On hill tops and in basins, blanket bog and basin peats may have developed to greater depths over a fully differentiated podsol profile with a pan, but for the purposes of afforestation these are regarded as peat areas. Such areas with deeper peat exist in almost all the heath forests, and are usually readily attributed to local topography or increasing altitude and rainfall.

DESCRIPTIONS OF TYPICAL SOIL PROFILES

Allerston Forest, Yorks. (Jacks, 1932)

The typical Wykeham profile

Horizon	*Depth in cm.*	*Description*
A_0	0 – 8	Black decomposed peat, matted with heather roots.
A_1	8 –19	Light grey, sandy, with occasional grey pebbles. Roots frequent, especially in the lower part.
A_2	19 –19¾	Moist black peat, from decomposing roots.
B_1	19¾–20	Brown hard-pan, black on upper surface.
B_2	20 –30	Red-brown, compact, with a laminar structure and dark horizontal streaks.
C	30 –50	Yellow, changing to orange; hard and compact.

Teindland Forest, Moray. (Muir, 1933)

A Normal Podsol

A_0	0 – 6	Surface root mat with slightly decomposed material in lower portion.
A_1	6 – 7	Dark grey humose sand, friable and free, stony.
A_2	7 –23	Light grey, in places almost white, sand. Somewhat variable in depth. Coarse platy structure; roots numerous.
B_1	23 –45	Dark grey-brown sandy stony layer, slight rusty mottling; loose; roots penetrate.
B_2	45 –55	Rusty brown slightly cemented gravelly sand. Stones numerous; roots occasional.
C	55 –70	Gravelly sand with occasional pockets of pure sand. Loose and free.

Peaty Gley Podsol with Hardpan

A_0	0 – 5	Mat of *Calluna* and *Scirpus* roots
A_1	5 –11	Well-decomposed peat, with many live roots; spongy when wet, but cracks on drying.
A'_2–G.	11 –17	Grey sandy layer, structureless; contains many stones which are somewhat bleached. Roots penetrate.
A''_2–G.	17 –27	Dirty olive-brown, silty fine sand in texture; structureless; many stones; slight signs of gleying.
B_1	27 –27½	Iron pan, not quite continuous but extremely hard.
B_2	27½–40	Purplish red with slight iron staining, especially along old root channels; very compact.
C	40 –90	Purplish red boulder till, looser than previous layer.

Clashindarroch Forest, Aberdeenshire (Muir and Fraser, 1940)

Normally podsolised soil found over small areas only

A_0	0 – 5	Brownish-black raw humus.
A_1	5 –15	Dark grey light loam. Underlain by slight pan.
B_1	15 –30	Brown light loam with slight humus staining.
B_2	30 –45	Light brown light loam.
C	45	Fawn light loam.

Peaty Podsolised Soil

A_0	0 – 5	Largely moss litter.
A_1	5 – 20	Brownish peat.
B_1	20 – 28	Dark grey sandy loam, lightens on drying.
B_2	28 – 45	Thin hard pan overlying fawny-brown silty loam.
C	45+	Fawn light loam. Fairly compact.

Concealed Podsol, where the evidence of podsolisation is not directly obvious in the profile

A_0	0 – 5	*Calluna* raw humus.
A_1	5 – 15	Blackish-brown humose loam; crumbly structure; loose.
B_1	15 – 35	Fawny-brown gritty loam; structureless; more compact.
B_2	35 – 95	Drab-brown gritty loam; structureless; very compact.
C	95+	Rotten rock.

The surface peat is generally waterlogged, and in many places burning has produced a felted surface on which algae and lichens develop. Both these features help to prevent downward percolation of water, and prior to afforestation many areas carried surface water, at least over the winter months. In addition, on account of the impermeability of the peat, much of the run-off was over the surface between the slightly raised peat areas, on which stood the heather plants.

The peat layer was the main rooting zone of the original vegetation and is bound together by an extensive network of roots, mainly those of the ericaceous shrubs which dominate the heaths.

Leached A Horizon. This is generally grey in colour, sometimes dark grey, owing to the presence of humus carried down from the peat above, which stains the bleached silica sand and stones of which this horizon is mainly composed. The bleached layer is usually not as compact as the subsoil, and is permeable and fairly easily penetrated by roots. Jacks found the maximum thickness of this layer to be twelve centimetres (five inches) at Wykeham; Muir and Fraser found this the average thickness at Clashindarroch, while in the normal podsol described by Muir at Teindland the A horizon was seventeen centimetres thick. At the bottom of the A horizon there was commonly a thin layer of black humus formed by the decomposition of roots which had failed to penetrate the pan and then ran along on top of it. The lower layers of the leached horizon may also show gleying, particularly when underlain by an iron pan.

The Pan, B Horizon. The normal podsol with a broad layer of iron deposition occurs to only a limited extent and Muir's description shows a very wide, slightly cemented, rusty layer. In contrast, the typical pans described are only a few millimetres in thickness, red brown in colour, very hard and almost impermeable to water and impenetrable to roots.

Yeatman (1955) carried out extensive investigations on tree rooting on these soils, and found the subsoil was only reached at points where the pan was broken or absent. The pan also causes a marked impedance in drainage and there is evidence that water moves laterally along it. The hard pan however, is by no means universal being a characteristic of the poorer heaths.

Vegetation

The status of the heath formation has already been outlined, but it must be reiterated that with elimination of grazing, and freedom from burning, much of the upland heaths would in time revert to forest, though owing to soil degradation only very poor stands could be expected to result over the majority of the areas. In places, particularly in the north of Scotland, there are still areas where semi-natural pine forests occur in comparable sites, while much larger areas now acquired for planting had carried a crop some time previously. Birches, *Betula pubescens* and *B. pendula* (=*B verrucosa*), rowan, *Sorbus aucuparia*, and Juniper, *Juniperus communis*, are other characteristic tree species of the heaths, but growth is generally poor and often the tree vegetation is no more than scattered individuals or scrub. Further south, denudation began much earlier and there are few traces of the original tree vegetation. The pre-history of the heaths has only been investigated in Yorkshire where Dimbleby (1952a) concluded that the broadleaved woods of several species which followed the retreat of the ice were cleared for grazing, and to a lesser extent for cultivation by Bronze Age man, and that the heath vegetation and podsol have developed in the last 2,500 years. Not many other areas of heath are likely to have been cultivated, and clearing was more usually for grazing or for the timber.

Heather, *Calluna vulgaris*, is the dominant species over the vast majority of the heath, but it is only luxuriant under conditions of free drainage, which in fact rarely exist on the upland heaths in their waterlogged state occasioned by the impermeable layers of peat and pan. Thus growth of the heather is slow, flowering poor, and a purpling of the leafy shoots in winter is characteristic; all these conditions can be relieved to a large extent by soil disturbance and phosphatic manuring. Nevertheless in spite of poor growth the heather dominates all but the poorest heaths, and some years after a fire it will, on the more fertile areas, exclude most other species of flowering plants; the lichens *Cladonia sylvatica* and *Parmelia physodes* being almost its only associates. Burning eliminates some species, particularly bryophytes, but on the other hand the regular destruction of the heather offers opportunity for the establishment of a much wider variety of species for a limited period. It must be remembered that the areas becoming available for acquisition by the Forestry Commission tend to be the poorer ones where the heather is of poor quality, since more fertile areas with strong healthy *Calluna* are still today profitably used for the rearing of red grouse (*Lagopus scoticus*) for sport.

Tansley lists undershrubs and herbs which distinguish the more northerly upland heaths from those of the lowlands. The herbs are mostly rare species, but much more important are the undershrubs:

Arctostaphylos uva-ursi, Bearberry
Betula nana, Dwarf birch
Empetrum nigrum, Crowberry
Rubus chamaemorus, Cloudberry
Vaccinium vitis-idaea, Cowberry
Vaccinium myrtillus, Blaeberry
Vaccinium uliginosum

The most complete description of the vegetation to date is that of Muir and Fraser (1940) which was unfortunately not available to Tansley. A synopsis adapted from that given in their work is set out opposite. In the absence of detailed examination, it is impossible to say how far their scheme would cover other heath forests, but Clashindarroch is undoubtedly more varied than most, and the range of types given is wide enough to suggest its use as a basic scheme.

In practice the indicators most commonly used for determination of fertility and soil condition are:

(a) The vigour and abundance of flowers of the *Calluna* rather than its presence or frequency. The form of the heather is a useful guide to the exposure.

SYNOPSIS OF HEATH VEGETATION AT CLASHINDARROCH
(After Muir and Fraser, 1940)

DRY HEATH TYPES

Calluna-Erica cinerea

Adult	Burnt over
Calluna with abundant *Erica cinerea* forming the ground cover, subsidiaries not very frequent and usually suppressed.	The following subsidiaries become temporarily co-dominant with *Erica cinerea:—* *Deschampsia flexuosa*, *Vaccinium myrtillus*, and locally *V. vitis-idaea* and *Empetrum*.

Calluna-Vaccinium myrtillus

Adult	Burnt over
Calluna dominant, with abundant *V. myrtillus* co-dominant. *V. vitis-idaea* generally frequent.	*V. myrtillus* dominant for some years, with *V. vitis-idaea* the commonest subsidiary.

Calluna-Arctostaphylos

Adult	Burnt over
Calluna dominant but open. Undergrowth of *Arctostaphylos*. Many subsidiaries.	*Arctostaphylos* dominant, with increased vigour of subsidiaries.

Calluna-Deschampsia-Vaccinium myrtillus

Adult	Burnt over
Calluna dominant but open; subdominant or locally co-dominant *Deschampsia flexuosa* and *Vaccinium myrtillus*.	*D. flexuosa*, *V. myrtillus*, *Anthoxanthum*, etc., forming mixed growth, with *D. flexuosa* tending to dominate in later stages toward adult form.

MOIST HEATH TYPES

Calluna-Deschampsia flexuosa

Adult	Burnt over
Calluna dominant, with occasionally flowering, partly suppressed *D. flexuosa* abundant. Turf usually quite covered.	*D. flexuosa* vigorous and dominant for several years.

Calluna-Vaccinium

Adult	Burnt over
Calluna dominant, with suppressed or poor growth of *V. myrtillus* and *V. vitis-idaea* abundant. Turf exposed and showing growth of encrusting lichens.	Short, open growth of *Vaccinium* spp. *E. tetralix*, etc. *Nardus* tends to colonise bare patches; recovery of *Calluna* slow.

Calluna-Nardus

Adult	Burnt over
Calluna normally dominant, with *Nardus* sub-dominant or co-dominant. *Hypnum schreberi* the chief moss, along with patches of *Sphagnum*.	*Nardus*, with *Empetrum*, *Erica tetralix*, *Juncus squarrosus*, etc., as subsidiaries.

Submoorland types

Variable subtypes characterised by the presence of peat; subsidiary and co-dominant plants such as *Erica tetralix*, *Eriophorum vaginatum*, *Trichophorum caespitosum*, *Carex* and *Juncus* spp. abundant or locally abundant. *Sphagnum* spp. and *Hypnum schreberi* usually the most frequent mosses.

EXPOSURE TYPES

Dry Eroded *Calluna: Calluna* pruned short by wind and showing grey-brown because of dead twigs and leaves; cover as a rule not close; in more extreme form *Calluna* in discontinuous patches on bare or lichen-encrusted soil.

Wet *Calluna-Cladonia*; *Calluna* short but not so definitely pruned by wind. Soil surface less bare and carrying abundant *Cladonia* and *Cetraria* as well as local encrusting lichens. Subsidiary plants varied and may be quite frequent.

(b) Drier and richer soils are indicated by increased frequency of bell heather (*Erica cinerea*), whin (*Ulex europea*), grasses, and herbs.

(c) Poorer conditions, generally associated with impedance and water-logging, are indicated by cross-leaved heath, *Erica tetralix*, and deer grass, *Trichophorum caespitosum*.

(d) Wetter flush areas, generally more fertile, are indicated by rushes, *Juncus* spp., and grasses, especially by the purple moor grass, *Molinia caerulea*.

(e) Thin peat areas likely to be rather infertile are shown by heath rush (*Juncus squarrosus*) and mat grass (*Nardus stricta*).

Faegri (1952) has listed indicators on heathlands which are considered to mark land in West Norway suitable for the growth of Norway spruce. The most important are *Lotus corniculatus* and *Lathyrus montana*, others include *Arctostaphylos*, *Antennaria dioica* and *Succisa pratensis*. No such indicators have been identified on the British upland heaths.

When cultivation is carried out, a remarkable change takes place in the heather. Once the ground is drained or ploughed, the *Calluna* grows taller and denser than before and flowering is greatly increased, this effect being intensified by the use of phosphatic fertilizers. After about five to ten years the heather reaches its culmination before being gradually suppressed by the young tree crop. In the thicket stages the heath forests become almost completely denuded of ground vegetation, and until thinning has continued for some years only mosses and lichens occur. Too heavy thinning can lead to an invasion of waved hair grass, *Deschampsia flexuosa*, which is very undesirable; this is commonest under larch crops. We may look forward however to the gradual establishment of a coniferous forest vegetation probably not dissimilar to that in existing Scots Pine and birch woods of north-east Scotland, with an open sward, largely of bryophytes; but with typical herbs such as *Pyrola* spp. and *Trientalis europaea*, together with ericaceous species and possibly an understory of juniper. Certainly no chance should be lost of accepting birches and other broadleaved species into the canopy, since these old woods are often also characterised by the development of a raw humus layer.

Woods and Plantations

Scots pine, *Pinus sylvestris*, is the only native timber-producing species to be found on the heaths, or on comparable sites which have never degenerated to heath. The position when reafforestation began may be best illustrated from growth statistics of this species. The records of stands available when work began in 1921 are somewhat scanty, though many other crops then standing and available for observation have since been felled. Such records as exist, supplemented by new measurements of old crops still standing, and early plantings of the Forestry Commission made under comparable conditions, are given in Table 1. In general the Quality Class is low, and where a fully differentiated podsol is recorded the average is about Q.C. IV. This might be taken as the average for the whole heath forests if this species had been planted "direct"—that is, without ploughing; for over many of the poorer higher areas such planting as had been made had failed to form an economic crop, though where there are normal podsols the quality class may rise to III or even II. The average production to be expected from stands of Quality Class IV is sixty Hoppus feet per acre per annum (5.5 cubic metres/hectare), and large areas of the heath could not be expected to reach this figure. The only other crops recorded on the heaths were of European larch and here the quality class was only IV-V.

This then is the problem as it appeared to the staff of the Forestry Commission about 1925: large areas of upland heath were available, part had carried tree crops previously, but the production was low and in some cases the crop was so poor as to be not worth felling. If measures could be taken to improve growth and increase production, then a substantial increase could be made in the potential forest area and ultimately in the national forest resources.

TABLE 1: SCOTS PINE PLANTATIONS ON THE UPLAND HEATHS

Stand data from felled sample plots, old stands, and certain of the oldest experiments in the heath forests.

Location and National Grid Ref.	*Age*	*Top Ht. Feet 100 largest trees per acre*	*Main Crop*			*Quality Class*	*Site*	*Notes*
			Stems per acre	*Basal area sq. ft. q.g.*	*Volume Hoppus feet*			
Harriets Wood, Sutherland								
Plot 346.NH/766925	69	64	305	219	6,040	III	350 ft. S face } Podsolised. On Old Red Sandstone boulder clay.	Now part of Dornoch Forest, replanted 1932-33. The ridge top is at 500 ft.
366.NH/765927	67	52	450	225	4,610	IV	400 ft. ,, }	
356.NH/780929	65	40	665	190	2,840	V	350 ft. E face }	
Black Isle, Ross, Kilcoy Forest Bellton Wood NH/633556	85	62	195	112	2,820	IV (High)	400 ft. 3 in. humus, hard pan at 12 in. Old Red Sandstone till.	Acquired plantations. Area drained at 20 foot intervals. Undrained parts are very poor.
Allanglach Wood NH/632507	80	68	275	146	4,020	III	100 ft. 3 in. humus, iron staining at 18 in. Old Red Sandstone till.	No draining. The best old plantation standing in the area.
Findon Forest Expt. 1.P.29 Plot S. 245 NH/612588	29	38	700	72	1,120	II	350 ft. Grass heath on podsolised moraine, no pan.	Best of plantations made without ground preparation.
Wood of Ordiequish, Moray Plot 291 NJ/355564	78	47	490	150	2,760	V	650 ft. on plateau; heavily podsolised on Old Red Sandstone till.	Now part of Speymouth Forest, replanted c. 1930
Wood of Orton, Moray								
Plot 24 NJ/308530	111	75	220	255	6,500	c. III	550 ft.	Crops planted 1800-10, felled c. 1920, replanted 1950 as part of Teindland Forest.
25 NJ/302535	117	68	180	172	3,750	c. IV	650 ft. 'Sandy loam'. Almost certainly podsolised.	
Teindland Forest, Moray Expt. 30.P.28 NJ/295566	28	37	1,180	124	1,890	II	425 ft. Normal podsol on Old Red Sandstone till. Thin peat, no hard pan.	Lowest and most fertile part of the forest.
Strathdearn Forest, Inverness NH/795318	72	58	330	162	3,900	III-IV	970 ft. Podsol with iron pan at 9 to 10 in.	An acquired plantation.
Beedale, Wykeham, Yorks. Plot 233 SE/954876	47	44	625	148	2,920	III-IV	560 ft. 'Sandy heath'. On edge of plateau probably not strongly podsolised.	Now part of Allerston Forest.
Wykeham, Allerston, Yorks. Expt. 3.P.28 SE/947889	28	26	895	71	735	III	650 ft. on typical Wykeham iron podsol; 2 to 3 in. peat, pan at 8 to 10 in.	A 'direct-planted' control to the experimental area.

Notes: All were planted without ground preparation except for the one case specially noted.
Soil descriptions from the felled sample plots are sketchy and their exact location is unknown.

Chapter 2

COMPARISON WITH OTHER WESTERN EUROPEAN HEATHS

The heath formation extends far beyond the British Isles to Denmark, north-west Germany, Holland, Belgium and north-west France. On none of the afforested continental heaths, however, does the silvicultural picture closely resemble that on the planted upland heaths of Britain, since the climatic and site factors are different. Some account of the silviculture of certain of these areas is however worthwhile, in that these Continental heaths have a considerably longer history of systematic afforestation than our own, and thus the problems which lie in the future in Britain are already being encountered abroad. These problems are related to the perpetuation of the forests created on areas marginal for tree growth and particularly susceptible to the effects of storm, insect and fungal attack. At the present time one of the main tasks is the replacement of uniform areas of relatively slow growing pioneer crops by more valuable species. This account therefore deals mainly with the principles of afforestation on the more northerly Continental heaths.

Site Factors

The heaths of north Jutland lie on the same latitude as Aberdeenshire and a belt of heath stretches south through the Jutish peninsula into Schleswig, covering the same range as the British upland heaths (54 to 58°N). Scattered heath areas extend to the southwest into the province of Drenthe in northern Holland and Brabant in the south on the same latitude as London (51°N). The fundamental difference between the British heaths and these Continental areas is that the former lie mainly to the east of the country, in the rain-shadow of the western mountain ranges, while the latter lie on the western shore of the continental mass on the fringe of the great European plains. The resultant difference in rainfall is considerable. The British upland heaths generally receive 30 to 40 inches, while the lowland and continental have 24 to 30 inches per annum. Temperature differences are greatest in winter, when (as noted by Tansley) the isotherms run north and south in north-west Europe; in January east Britain lies on that for 37°F. and Jutland on that for 32°F.

The direction of the prevailing winds are comparable, being south-west in January and February with a velocity of 9 to 12 metres per second in Britain and north Jutland, but falling to 7 to 9 metres per second in south Jutland. In summer the prevailing direction is more westerly, with velocities uniform at 7 to 9 metres per second; while in Holland the average over the year is only about 5 metres per second. The average daily duration of sunshine in Denmark is 4¾ hours, on the upland heath areas in Britain 3½ to 4 hours. The prevailing westerly winds lead to higher humidity on the coastal heaths of Jutland.

The climatic differences may be summed up by saying that the British upland heaths are wetter, receive less sunshine, are considerably warmer but windier in winter, and may be less humid. Bilham (1938) notes that winter is quite definitely the season of greater contrast between the British Isles and the climates of the land areas which lie to the eastward.

The geology of the areas is very different; the upland heaths as already shown lie on boulder clays or siliceous rock often greatly compacted and overlying paleozoic or mesozoic rocks. In Jutland the underlying rock is chalk, but this is covered by a great depth of quaternary glacial deposits, much of it in the form of outwash plains of fluvio-glacial sand. In Holland also, the heaths lie on recent sand deposits, sometimes with a high water table. A nearer approach to the soil conditions of our upland heaths is seen on the 'hill islands' of Jutland, where older morainic deposits from the Riss glaciation project through the outwash sands from the later Würm. Here the soil is more stony, and contains more clay and is generally more fertile, though it must be noted that this difference is accentuated because on the moraines the steeper edges and hills are available for afforestation, while on the outwash plains it is the least fertile areas which are planted.

Almost all the soils show podsolization, but this is of the normal type and the peaty podsol with indurated iron pan is almost unknown. Blowing of the sand into surface dunes, and the consequent loss or burying of the original surface profile, is another feature common to the Breckland of East Anglia and to the Continental heaths, but not seen on our upland heaths. In the most extreme cases soil deterioration has been accentuated by burning of the vegetative cover and destruction of the humus. When followed by blowing of the exposed sand, this may have sterilized the area to such an extent that only pioneer protective crops have been raised up to the present time.

In conclusion it may be stated that, while there are several points on which the continental heaths resemble our lowland heaths in altitude, rainfall, the sandy soil and type of podsol profile, there is much less similarity between them and the upland heaths of northern Britain.

Silviculture

Work in Denmark up to 1939 was summarised by Flensborg (1939), though this book is now somewhat out of date, while a comprehensive account of work in Germany has recently been given by Jüttner (1954). The latter distinguishes the coastal heaths 'geests' from the main mass of inland heaths of Luneburg. The present author visited in 1955 Jutland, the coastal heaths of Schleswig, and heaths in Drente and Brabant, Holland, under the guidance of the officers of the state forest services concerned, of the Danish Heath Society and of the Danish Dune Service. The following brief account summarises observations made in some forty forests and discussions with some twenty forest officers on their silvicultural methods.

The differences in the climatic and edaphic factors are reflected in the overriding silvicultural difference in that while afforestation of the majority of heaths in Britain, upland and lowland, is dominated by the use of Scots pine, this species is of little use in Jutland, Schleswig and Drenthe. Scots pine has been widely planted on all these heaths, and the main cause of its failure is the incidence of the needle-cast disease associated with *Lophodermium*. This disease has been variously attributed to an unfavourable climate, or the use of the wrong provenance. Scots pine is no longer native to the areas concerned, although it occurred in prehistoric, and possibly even in historic times. Early imports of seed into both Denmark and Holland are known to have come from inland German sources, but occasional importation from Scandinavia or Scotland gave rise to rather better stands. While further trials are now under way, it seems unlikely that Scots pine will ever play more than a limited role on these heaths, as even in healthy stands the increment is low, equivalent at best to Quality Class III to IV. In many ways the position with regard to the use of this species resembles that on the west coast of Britain, and it seems certain that climatic influences are the pre-disposing cause of failure, an important factor probably being the greater humidity of the western seaboards. Further to the east, Scots pine becomes an important species again, as on the Luneburger Heide of Germany, lying sixty miles from the sea, and thus in a relatively similar position to the pine areas of Britain. Again to the south in Brabant, Holland, Scots pine has been for many years the main species. These inland heaths again appear to have a much greater similarity to the sandy heaths of southern England.

The place occupied by Scots pine in heath afforestation in Britain is filled in Jutland jointly by mountain pine and Norway spruce, the first as a pioneer, the latter as a productive crop, and since the spruce suffers both from exposure to wind and from serious checking in the presence of heather, a most intensive silvicultural regime is required to form this productive crop. Further south, in Schleswig and Drenthe, Japanese larch becomes an important pioneer species.

Technique of Afforestation: (a) Jutland. The movement for the afforestation of heathland in Jutland seems to have originated about 1760 to 1780 in an attempt to improve the miserable conditions of farming communities, who eked out an existence on the fringes of vast wind-swept heaths. At about this time German foresters brought in Scots pine and Norway spruce for use in shelter plantations, but in the extreme conditions most of the planting failed. The planting of heaths for forestry by the State Service dates from about 1800; the resulting plantations of Scots pine showed early promise but were attacked by *Lophodermium* when about fifteen years old. A long period of replanting and beating up with Norway spruce followed, and after years of check and slow growth, satisfactory stands of this species resulted, equivalent at best to about Q.C. IV Norway spruce and in many cases only V to VI, even allowing for the initial check.

In 1866 the Danish Heath Society, a private body, formed under the leadership of an army engineer, E. M. Dalgas, commenced work on the reclamation of the heaths for both agriculture and forestry, using intensive draining, cultivation and manuring techniques, and making great use of shelter belts on potential agricultural land, while allocating the poorer land to plantations. Since this time the two forestry organizations, State Service and Heath Society, have worked side by side on the heaths in a spirit of healthy rivalry. By 1870 mountain pine was shown to be the one species able to grow readily on the poorer heaths, and very extensive plantations were established by sowing or planting, either after hand digging holes or strips, or after simple ploughing. On the better ground Norway spruce was planted in mixture with mountain pine. As early as 1870 deep ploughing to eighteen inches with a horse-drawn plough had commenced, so that pan and leached layers were broken and mixed with the surface peat. This proved very beneficial to the

Norway spruce and from this beginning grew the present system which may be briefly described:—

On the poorer land a double mould-board and subsoiling plough is used before planting pure pine. Where the land is considered capable ultimately of carrying Norway spruce, a many-stemmed form of mountain pine is used. If the land is too poor for Norway spruce, erect mountain pine (var. *rostrata*) may be used, particularly in the more maritime areas, since its production is greater but it is not always healthy inland. Lodgepole pine is also used on a limited scale, but is not favoured because of its rough form, and its liability to windthrow and to attack by *Fomes.*

On the better land much more intensive cultivation is practised, and a typical method is that first the heather is burnt off, and then for one or two years the area is shallow ploughed and harrowed annually so as to break up the litter and raw humus and mix them thoroughly with the leached A horizon. In the following year the whole area is deeply ploughed to about twenty inches, leaving the land ridged at three to four feet, furrow to furrow. Discing or harrowing follows, and often a shallow double mould-board plough is used to prepare the planting positions. At one time field crops or a lupin pre-culture was often employed, but this is not now common. The traditional mixture on ground prepared in this intensive fashion is Norway spruce, set at approximately four and a half feet spacing over the whole area, with a mountain pine nurse set between every other pair of spruce. On the best soils the mountain pine is now omitted and pure Norway spruce is planted; while on average ground large areas have in recent years been planted using Japanese larch instead of mountain pine as the nurse. Today, in addition, small proportions of other species such as Scots pine, silver fir, Douglas fir and hardwoods are often included in intimate mixture, often stem by stem. Little experience is available, however, as to the growth of these mixtures, and Norway spruce is still the main component of the first productive crop. In many areas cultivation to reduce weed competition and conserve moisture is continued after planting, by shallow ploughing or harrowing to two or three inches between the lines of the spruce. Such treatment may be annual until the crop is established.

In comparing this method of repeated cultivations with our own single operation of single-furrow ploughing, it must be emphasised that the sandy soil of Jutland is more easily worked, the use of tracked tractors being exceptional and then only for the deep ploughing, while much of the intercultivation has been with ploughs or harrows drawn by a single horse. As a result of the intensive soil working, weeding is virtually eliminated, the survival of the plants in extreme conditions considerably improved, while better growth ensures early establishment. There may be also long term benefits derived from the intensive cultivation, but there is also a chance that it increases the incidence of *Fomes.*

(b) Schleswig and Dutch Heaths. The intensive methods outlined above have developed against a background of experimentation and mechanisation. In contrast, in the 'Emeis afforestations' dating from 1890 in South Schleswig, Germany, and in the more recent heath afforestations in Drente, Holland, intensive hand work has been used in ground preparation, and in neither case was economy in expenditure on ground preparation a factor of importance. Emeis' system, using convict labour, involved ploughing in eight yard strips, digging ditches between the strips and 'oversanding' the ploughing with subsoil sand from the ditches. The difficulty here is that no clear controls exist to show which features of the system were essential, incorporation of the raw humus, draining or oversanding. In Drente digging by hand, to a depth of two or three spits, in strips, or over the whole area, was used to provide employment in the depressions of 1920-40. Today, ploughing on the Danish system is used.

Afforestation has in both areas been successful, though only after a serious setback through the failure of Scots pine in Drente. Emeis on the Schleswig heaths planted a lavish mixture using four thousand plants to the acre in approximately the following proportions:—mountain pine 16%, Norway spruce 13%, silver fir 13%, Scots pine 10%, hardwoods—alder, birch, oak, beech 35%, other conifers 13%. On much of the better ground a final crop of silver fir and Norway spruce with occasional Scots pine, oak and beech is obtained, indicating that conditions were by no means extreme compared to other heaths. On the worst sites, a small proportion of the whole, a poor crop of mountain and Scots pines with checked spruces, is all that remains after fifty years.

In Drente the species used have altered rapidly over the thirty-five years during which work has proceeded. The failure of Scots pine led to the use of hardwoods to underplant the pine; the hardwoods themselves are however unlikely to form a productive crop, so that conifers, particularly Japanese larch, were later used in mixture with hardwoods, particularly oak and red oak; today an increasing number of conifers, including silver firs, Douglas fir, hemlock and Austrian pine are being used. To raise these crops, pre-culture with lupins and heavy manuring with basic slag and compost from town sewage is found essential. Further south in Brabant, where conditions are in many ways comparable to those on the Surrey heaths, several generations of

Scots pine have been successfully raised on heathland and Scots pine is still the main species used.

Regeneration of Mountain Pine in Jutland. The first regeneration of afforested heath to be undertaken on a large scale was in Jutland, where Norway spruce was introduced into the pioneer mountain pine. Generally the pine reaches 12 to 20 feet after 50 to 60 years; many areas have been successfully underplanted after thinning and the remaining mountain pine removed after the spruce was established. The dangers encountered are that too rapid opening of the canopy enables *Calluna* or *Deschampsia flexuosa* to develop, while the cutting of the mountain pine stems may be followed by severe attacks of *Fomes*. It is thus often difficult to retain the overhead cover for more than ten years, during which time the new crop must be established if it is to develop without a check. In general, however, mountain pine provides an excellent medium for underplanting, in that its demands on soil moisture are not high, its crown is generally not dense, and it does not itself respond rapidly to the opening up, while providing excellent overhead cover against frost. So great indeed is the improvement in the soil conditions under its shade, that at one time the theory was advanced that the roots fixed atmospheric nitrogen.

In order to increase the early growth of the Norway spruce, interploughing of the mountain pine has been introduced in recent years in place of hand digging in preparation for the underplanting. A special double mould-board subsoiling plough, the Tolne, drawn by a small tracked tractor, is employed so that the outfit can pass between the lines of mountain pine after they have been singled or thinned. If it is desired to introduce a proportion of silver fir (*Abies alba*) into the crop at this time, auxiliary nurses (*Prunus serotina*, grey alder, birch, Japanese larch or lodgepole pine) are planted alongside the plants, often within a few inches, so that, should the mountain pine die, the silver fir is not entirely exposed to frosts; in addition these nurses protect the fir from deer damage.

Regeneration of Norway spruce. The earliest regeneration in Norway spruce crops followed storm damage to the oldest State afforestations in 1865 and 1900. The first replanting was with Norway spruce, silver fir and beech, but severe frost and deer damage to the last two species prevented their development. Later, clear cutting of spruce crops was the source of much difficulty, owing to the drying out of the soil, exposure to the wind, and frost, together with damage by *Hylobius*; generally in these areas a new crop of pure spruce was the outcome, even when other species were tried in mixture. The next essays at regeneration were by a uniform shelterwood system with underplanting, but again wind upset the work, as the old crop of Norway spruce proved quite unable to withstand gales when opened up. These difficulties have led to the development, over the past thirty years, of a method of artificial regeneration employing strip cuttings.

The first basic factor taken into consideration is that the main damaging winds are from the west, the strips thus start from the east and as they progress westward their base is widened to offer free passage to gusts entering them from the west. They thus become wedge-shaped, and when the bases widen sufficiently to coalesce, regeneration is completed up to that point from the east side of the area. The crop to be regenerated in this manner is not thinned for several years before cutting the first strip, and, while the strip cutting is in progress, no thinnings are made in the remaining areas. This is found to give reasonable stability. The second important factor is that exposure to full sunlight is found to be very injurious to the 'forest conditions' of the floor, typified by the fact that heat destroys the water-holding capacity of the Norway spruce litter. The east to west strips are thus initially made so narrow that the sun only falls on the floor within them in the morning and afternoon, while at mid-day they are shaded by the crop to the south. They are thus, in practice, rather less in width than the height of the trees, i.e. fifteen to twenty yards wide.

The initial strips, perhaps two hundred yards long, are cut to leave a double width standing between them. The regeneration of the first strip is made with shade-bearers mixed with nurses, thus Norway spruce, silver fir and Douglas fir are mixed with alders, *Prunus serotina* and Japanese larch in various combinations. In the early years, when the better areas were being regenerated, hand preparation was normal, but now on the poorer heaths with narrower strips, root competition from the old crop is found to be severe, and cultivation with the Tolne or disc ploughs is being tried, while manuring experiments are also in progress. It seems possible that natural seedlings of the Norway spruce may be abundant following the cultivation, in which case other species will be planted among them to get the desired mixtures.

The second cutting is made some four years later, when the original strip is extended a similar length to the west, and width to the south; the area cut being double that at the first operation. A similar planting method is followed here, but the removal of the third strip to the south in due course, which completes the operation for the first length, presents more difficulty, since there is no longer side shade. Here it seems probable that a higher proportion of light-demanders must be used, particularly on the southern edge which has been exposed to sun for some eight to ten years. An alternative method under trial is that this third strip shall be underplanted, making use of the side light and without the opening of the top canopy which led to windthrow in the old uniform underplanting. By the methods outlined above, more or less even-aged mixed stands with fairly uniform canopies have been produced within fifteen years over compartments of about twenty-five acres.

Regeneration with Silver Fir. This strip method of regeneration is not found to be necessary where silver fir forms even a small part of the old crop, as on the hill islands of older moraine in both Jutland and South Schleswig. In mixed crops of silver fir and Norway spruce the former will regenerate abundantly and no drastic opening of the canopy is necessary for their survival and growth. The Norway spruce can be removed in the earlier regeneration fellings, leaving the more windfirm silver fir for the final felling. In this manner the disasters which overtook the use of the uniform shelterwood system for pure Norway spruce are avoided.

The present goal in the heath afforestations of both Jutland and Schleswig is mixed even-aged stands in which silver fir is a major component. This species is regarded highly on account of its resistance to exposure and to windthrow and also its freedom from attack by *Fomes*. Its production is moreover much greater than that of Norway spruce over a rotation of from eighty to one hundred and twenty years, although for short rotations the latter species would be superior. How far the use of silver fir can be carried on to the poorer or more difficult heaths is uncertain. The hill islands where it thrives at present are more fertile than the outwash plains, but the deciding factor in the early rotations has been that the former are relatively free from the late spring frosts which have in the past decimated silver fir plantations on the heath flats. The forests on the latter with the longest history, show, however, that, given shelter and intensive silviculture, silver fir can be used far beyond the areas in which it is now common. The severe damage to Norway spruce from *Fomes* makes it undesirable for regenerated Norway spruce stands to contain more than a proportion of this species in the next rotation, hence the great importance attached to the introduction of the relatively resistant silver fir.

Discussion

The silvicultural methods detailed above show how an artificial succession through three forest crops has been obtained, from mountain pine to Norway spruce and then to a mixed forest with silver fir, though probably no single area has passed through all three as yet. In the best areas, as in Schleswig, the mixed forest has been obtained in the first rotation after intensive ground preparation, whereas in the poorest, progress even to the second stage may be impossible and the protection forest of mountain pine must be perpetuated, as on sandy heaths on the west coast of Jutland. It is in the intermediate areas where the forests are marginal for production that the greatest interest to British conditions lie. Silviculture is dominated by fear of windthrow and the incidence of *Fomes*, and by the possibility of soil deterioration under successive crops of pure conifers, particularly spruce. For both the last problems, the safest course in the absence of much greater detailed knowledge is the use of mixtures. There are, however, few heath areas advanced enough for the handling of the mixtures to have itself become a problem, though an example may be quoted from Drente where red oak, planted as a soil improver, is being cut from mixtures, where it threatens to crush all other species by its vigorous crown development. As a protection against wind and fire, permanent hardwood shelter strips are being developed in Jutland. The aim is to grow oak which will outlive two or more rotations of conifers, using intensive cultivation and a succession of conifer and hardwood nurses, together with shrubs to provide low cover. These belts, which break up the forests into small blocks, also provide fire breaks and to some extent aid in soil amelioration, since in the most intensive schemes they may occupy ten per cent of the total forest area. Within the network of belts, which ideally lie about two hundred yards apart in the path of the prevailing wind, there will be greater freedom of management without the fear of extensive blowing. The general practice at the present time is to aim at an even canopy in the mixtures, with moderate low thinnings to strike a balance between the desired rapid diameter increment and the risk of windthrow after heavy thinning.

Summary

The lessons to be learned from the Continental heaths, the general silviculture of which has been briefly described, are mainly in the care and attention devoted to the soil conditions. As far as the initial afforestation is concerned, British practice is very different, but seems well suited to the conditions and unlikely to change radically within the term of the afforestation programme. Ahead lies the problem of regeneration with a challenge to the old British habit of clear felling and replanting. While not suggesting in any way that the systems of regeneration developed on the continent will apply here, it is essential to define the conditions of soil and microclimate under which regeneration, either natural or artificial, will be most readily secured. Silviculturally, a start has been made in a very small way in the various under-or interplanting experiments, and it is obvious that conditions will in certain respects be much easier, and allow a greater range of species to be employed. The reduction in the exposure to which the young crops will be subjected, is an obvious case, and also the elimination of *Calluna* as a competitor, though difficulty may arise with *Deschampsia* if stands are opened to wind and sun. The more uniform climatic conditions to be expected under mature crops increase the relative importance of the soil; hence the calibration of soil factors and particularly of moisture and fertility levels will be valuable. Such aids should lead to the allocation of a greater variety of species to their optimum sites. The conditions in established woods are not all more favourable however, and if continental experience is any guide, considerable damage by wind and fungi must be expected in the next thirty years. Observations and experiments in such areas of damage may be of great assistance in building a regeneration technique for the upland heaths, which can be widely applied when regeneration commences on some scale in about forty years time. Before then it is quite obvious that Continental practice will also have developed and will suggest more useful lines of study, particularly in the handling of mixtures and the effect of various species on the soil conditions.

Chapter 3

THE UPLAND HEATH FORESTS AND EXPERIMENTAL AREAS

The maps reproduced as Figures 1 and 2 show the location of the upland heath forests. From the point of view of this work they may be divided into three groups. First are those forests, or in two cases groups of forests, which were among the first acquired by the Forestry Commission, and in which the formal research work on heath afforestation has been concentrated. Planting in these forests began between 1921 and 1931, so that the oldest crops and experiments are over twenty-five years old. To these forests and experiments have been directed research workers on more fundamental aspects of forestry, and also those workers who wished to make independent researches into various aspects of the heaths. The result of this concentration is that far more is known scientifically about these forests than about others. The six areas concerned are:

(a) Allerston and Langdale Forests, Yorks.
(b) The Black Isle forests of Findon, Millbuie and Kilcoy in Easter Ross
(c) Clashindarroch Forest, Aberdeen
(d) Hamsterley Forest, Durham
(e) Inchnacardoch Forest, Inverness
(f) Teindland Forest, Moray.

Of these, Inchnacardoch and Hamsterley have not been used for experiments for over fifteen years, and the heath in the former forest is only a small western outlier of the formation. These areas and their site conditions are described in the section which follows, together with an outline of the history of their afforestation, and notes on the various experimental areas.

The second group of forests are mainly the large heath forests where little formal experimentation has been carried out, either because they were near forests of the first group, or because planting started so much later that previous experience could be directly applied. Such experiments as are sited in these forests (and most of them contain five to ten trials of various types) are mostly repetitions of those carried out in the main experimental reserves, or experiments relating to particular local problems, and especially to that of the climatic and edaphic limits of afforestation. Brief descriptive notes are also given for the forests in this group.

The remainder of the areas where heath conditions are found are listed below; in many cases heath occupies only a proportion of the total area. Others are young forests and few contain any formal experiments. Many of the lessons learnt in the older forests have been widely applied on these areas and in general it may be taken that preparatory measures and planting prescriptions have tended to follow those in the larger areas.

Finally it should be noted that two areas used for research on marginal peatland and heathland conditions in Caithness, namely Forss and Skiall, are the property of the Department of Agriculture for Scotland. The two blocks, of 30 and 50 acres respectively, were planted on a contract basis by the Research Branch of the Forestry Commission, and incorporate a number of experimental comparisons.

ALLERSTON AND LANGDALE FORESTS, YORKSHIRE

Wykeham, Harwood Dale and Broxa Experimental Areas

These forests are formed of a number of adjacent blocks on the southern fringe of the North York Moors near Scarborough. Heathland afforestation has been continuous since 1921 to give the largest expanse of plantations on the upland heaths at the present time, while the experimental areas contain the biggest concentration of research planting, with a total of well over 200 field experiments, about half the total described in this bulletin. Lastly much of the field work for more fundamental research, sponsored by the Forestry Commission and carried out by workers from Oxford University, was sited in these forests, as indicated by the numerous references to the work of Dimbleby, Leyton, and Rennie. An earlier description of the forest has been given by Sanzen-Baker (1939).

Site

The bulk of the area is flat heathland lying at 500 to 700 feet, and forming sections of a dissected plateau. Each separate 'moor' has an escarpment on two, or even three sides, to the north, east and occasionally to the west also, dropping away rapidly for up to 500 feet into the main 'dales'. To the south

Fig. 1. Location of Upland Heath Forests in Scotland.

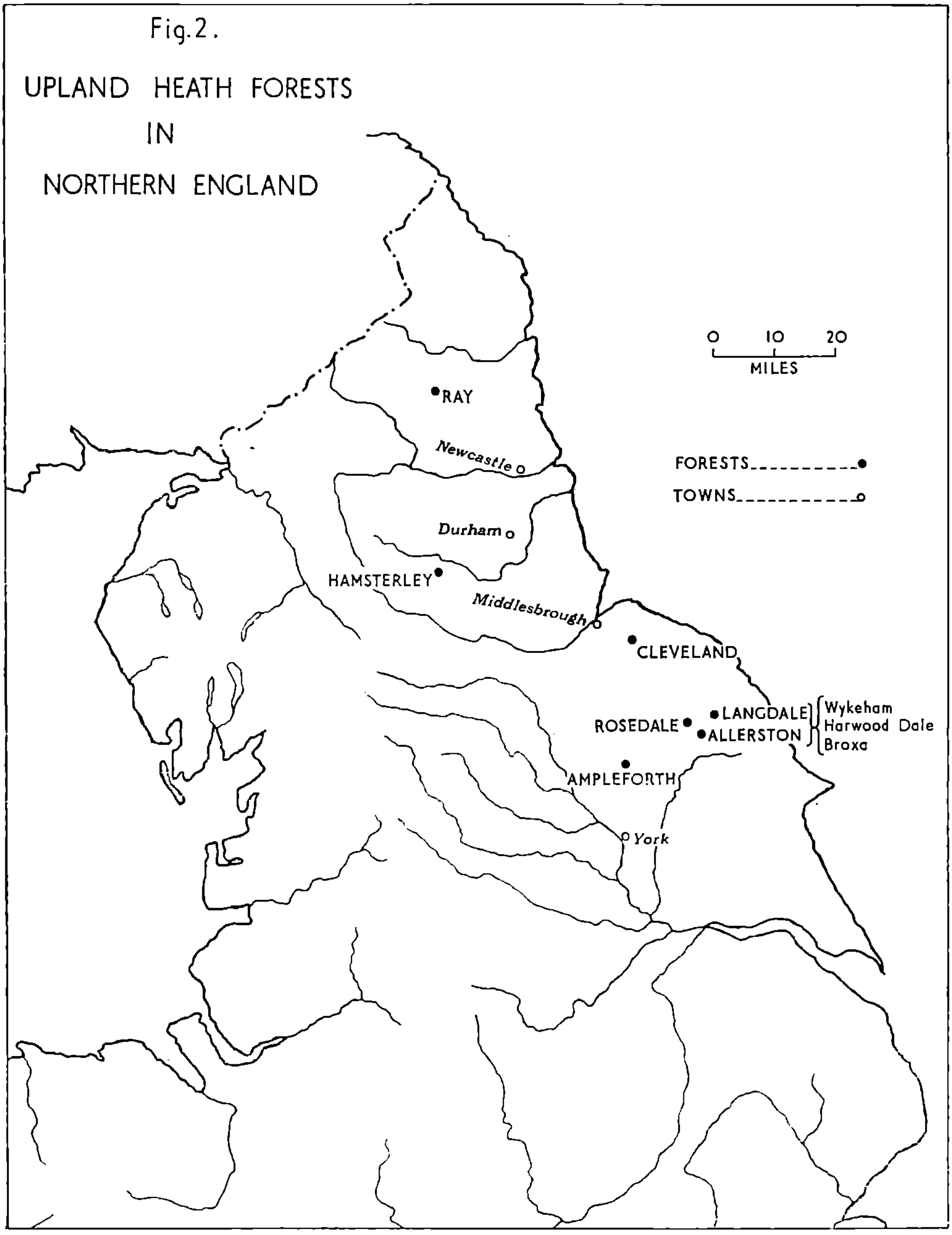

Fig. 2. Location of Upland Heath Forests in Northern England.

the moors slope gently away from the escarpments, and dip gradually into pinnately or palmately branched dale systems, which eventually connect with the next main dale. On the plateau, and in the minor dales, permanent watercourses are absent, while the main dales contain only small streams.

The eastern boundary of the forest mass lies within two to five miles of the sea, and there is fairly severe exposure along the escarpments, but exposure is not a vital factor since the very flatness of the moors leads to the building up of mutual shelter in the plantations. Nevertheless Scots pine generally only retains one year's needles and may be completely browned in spring. The mean annual rainfall on the moors is just over thirty inches, and is unlikely to exceed thirty-four even at the highest point; in the dales it is probably as low as twenty-five inches. The snowfall is slight and damage negligible, while frost damage is slight on the plateau, but may be severe in the dales. The main dales are in fact so different geologically, topographically and climatically, that the major land use is agricultural and they need be considered no further. Many minor dales, dale heads, and large sections of the escarpment come within the forest area.

The geological strata are mainly sandstones of the Calcareous Grits of the Jurassic Middle Oolite, from which all lime has long been leached, so that the soils are strongly acidic. There are outcrops of Oolitic Limestone over 400 acres of Dalby and Staindale, and of Passage Beds on Brompton Moor. Where this sandy formation outcrops on any scale on the plateau, the land has been used for agriculture; small areas give patches of much improved tree growth in the plantations. Oxford Clay runs up many of the dales, particularly on Langdale, while the outlying Harwood Dale block to the north east is on Lower Oolite which is overlain by Estuarine Clays and wash. Over the whole of the Calcareous Grit plateau there is very little drift, and it was shown by Dimbleby (1952) that what little boulder clay remains lies in ice wedges formed in the Pleistocene period.

The soils on various parts of the plateau have been described by Jacks (1932) and Rennie (1951). The peat is two to three inches deep over the leached A horizon; and an almost continuous hard red brown iron pan lies normally at 8 to 11 inches depth, but may vary from 6 to 18 inches. Above the pan there may be a black peat pan; below is reddish and then yellowish subsoil until the parent material is met at 18 inches. The whole soil profile is stony and extremely compact, and the subsoil almost impervious. Small areas with deeper peat do occur, and are even used for cutting fuel at Harwood Dale. Dimbleby (1954) has discussed the origin of these heaths and the development of the podsol, concluding that both have arisen in the last 2,500 years following destruction of broadleaved tree vegetation by Neolithic man. There is no evidence however, that this area was ever covered by high forest.

Dimbleby (1952b) has also shown that where patterns of ice wedges occur, mainly near the escarpments, the pan dips down several inches at each wedge site, and water accumulates in the channel so formed. The peat is often deeper over these channels, hiding what was once a surface depression, and this deeper peat is colonised by *Eriophorum vaginatum* and *Erica tetralix*. From the occurence of the former the polygonal pattern of channels observed in aerial photos may be traced on the ground.

The vegetation of the plateau at the time of acquisition was very simple, with poor *Calluna vulgaris* dominant over the whole area, maintained by burning and grazing. The usual associates are found, but apart from the identification of the occurence of *Eriophorum* with the ice wedge system, no detailed examination of the vegetation was made before the greater part was destroyed on afforestation. Small areas of pine and birch regeneration have been described by Dimbleby (1953), but these lie in almost all cases near seed sources on the fringes of the plateau. On the plateau itself only stunted single trees occurred, though some coniferous plantations had existed in the past. The more fertile larger dales bear on their steep sides the broadleaved woodland that contributes to the beauty of such areas as Hackness and the Forge Valley, which lie just outside the forests. North-facing slopes however carried either poorer open woodland or heather, and with thin soils they form a distinct problem.

History

(General reference, Robinson, Garthwaite et. al. 1950).

At the beginning of the century there were small areas of plantation on the plateau, that were almost all cleared between 1914 and 1926. One notable example at Blackhouse was planted in 1869-70 by Bradley, agent to the Cayley family. It was at 600 ft. on a narrow 'rigg' on the edge of the plateau, where seventy acres were burned and ploughed with a two-horse wrought iron plough to a depth of two inches. Six horses were then used to pull a subsoiler to 10-18 inches, and then finally a wheeled and tined drag was employed to break down and cultivate the plough ridges. The plantation was mainly of European larch with some Scots pine, and the total cost exclusive of fencing was £3 : 1 : 0d. per acre (Bradley, 1872). In 1916 the plantation was sold for £70 per acre when forty-five years old. There are no authentic records of the production, but it appears that certain notes among data collected for felled areas in 1917-20 may refer to the Scots pine of this plantation. They certainly come from the Blackhouse area and show that the Scots pine was about Quality Class IV. In Table 1 are included data from a sample plot on the edge of the plateau near the Wykeham experimental area. Again the Quality Class is low and it must be remembered that neither of these crops were on the poorest sites. It is noteworthy however that the crop of Japanese larch planted in 1922 on the site of Bradley's plantation is considered the best in the area, which bodes well for the second rotation on the area as a whole.

On the acquisition of the first sections of Allerston in 1921, there was thus little evidence as to what species would grow on the plateau, and a survey of the surrounding district showed very poor crops of Scots pine and European larch on the most nearly comparable areas; several examples from the dales showed much better results. The height growth of a shelterbelt of Scots Pine at Sawdon fell off steadily as it ran towards the escarpment. A large planting programme was however started and averaged 440 acres a year from 1921 to 1927. The major part of this was in the dale systems of Staindale and Dalby Warren, but considerable areas were planted on the plateau with very poor results. Over two hundred acres of spruce checked completely, and the areas were finally ploughed and replanted in 1949; Scots pine grew very slowly; Japanese larch died out in patches and survivors were generally poor, while the beech often used in mixture failed completely. In 1928 a halt was called, the annual planting area cut to 150 acres, and a research programme initiated which resulted in the selection for intensive experimentation of the Wykeham area as an example of ploughable ground, and of the Harwood Dale area in 1932 as unploughable. By 1931, adequate ploughing gear had been developed, as described in Chapter 5, and by 1936 results were clear. For these six years Allerston was the only forest where ploughing was the normal method of ground preparation; thereafter outfits were bought for all the major heath forests. The planting programme increased again from 1933 onwards, fell slightly between 1944 and 1946, and then rapidly increased to an average of 600 acres per year for 1949 to 1954. Of a total of 15,000 acres planted to 1956, perhaps 10,000 were heath and of this over 6,000 acres on the plateau had been ploughed.

The choice of species has undergone considerable changes. After the initial setbacks Scots pine was used on ploughed ground, with larch and some beech forming a quarter of the crop, but from 1938 Corsican pine was favoured for a time, while the dying of Scots pine on the Oolite led to a large area being underplanted with beech. When deeper ploughing was achieved, Scots pine and Sitka spruce were increasingly planted in mixture on the plateau, and Japanese larch was used to a greater extent. In recent years Scots pine and Japanese larch have been widely used, sometimes in mixture; while Scots pine/Sitka spruce mixtures are employed only on areas with a thicker peat layer. There will undoubtedly be difficulties in handling many of the mixed crops to obtain full stocking and well balanced crowns, owing to the checking of the spruce and its overtopping by Scots pine. Some of the early ploughed areas on the plateau are now being thinned for the first time, while dale areas of equal age are at the third thinning.

Wykeham Experimental Area. (National Grid reference: SE947885)

This area of 130 acres was used for experiments from 1928 to 1941, and includes certain classic comparisons and species. An early summary of the results was published by Sanzen-Baker (1939). The area runs back from the escarpment for almost a mile, falling from 670 to 570 feet in altitude, the gentle slope being to the south-east. The geology is Calcareous Grit and a typical profile has been described (p. 17). There is undoubtedly some increase in fertility at the lower southern end, but it has not yet proved possible to demonstrate this in terms of crop volumes. Some seventy experiments were planted here, of which half, relating to minor points of technique, have been completed. The remainder covering cultivation, species, mixtures, and manuring, form a most valuable series of demonstrations, though with the passage of time and the development of forest conditions, many of the early contrasts are now masked by treatment interaction.

Harwood Dale Experimental Area (SE967980)

This area of sixty acres was chosen on the most difficult ground type available at the time, and is on the highest point of this section of the forest at about 650 feet, some five miles north of Wykeham and only two miles from the coast. The ground is undulating and exposed; the soil, though leached at the surface under the thin peat, has no hard pan, while the boulders lying in the Estuarine Clay beneath made ploughing impossible until recently. It seems likely that the clay at Harwood Dale is inherently more fertile than the calcareous grit, but the surface conditions are undoubtedly more difficult. The forty experiments sited here were planted 1932-42, and aimed mainly at finding an alternative to ploughing. This group is obsolescent today, and more than half have been "closed", leaving a collection of species and mixtures. In recent years an area of comparable ground at 750 feet a mile to the north (SE967997) has been ploughed and new experiments started.

Broxa Experimental Area (SE952945)

Lies at 650 feet on Hackness Moor midway between Wykeham and Harwood Dale, and was chosen as being almost exactly comparable to Wykeham, when the latter had been planted up. From 1941 until the present time over ninety experiments have been laid out, covering 220 acres. The experiments include almost forty forest extensions from the intensive programme on nursery nutrition planned by E. M. Crowther, and several others planned by members of the staff of the Department of Forestry, Oxford. Other important experiments are those on ploughing and the use of nurse crops.

THE BIN

Aberdeenshire and Banffshire

A number of separate acquisitions have built up this forest to 8,600 acres. Site conditions are very variable and about a quarter can be classed as upland heath. The soils and vegetation were described by Muir and Fraser (1940) along with those of Clashindarroch. The rainfall is thirty-five inches.

Most of the plantable ground in the main block had carried a tree crop previously, although some of the stands are known to have been open and of poor quality. This area was planted mainly with spruce, which in some heather-clad areas experienced a prolonged check. The Balloch and Sillyearn sections had previously carried tree crops on the lower slopes, but the planting of the higher ground has been made possible by ploughing. Scots pine areas on the Bin Hill are of poor quality, and both these areas and those where European larch has died back are being converted to spruce by group felling and inter-planting.

There is an International Norway Spruce provenance trial on grass heath at Dunbennan, while a long term investigation on *Fomes annosus* is being undertaken in the Kinnoir section.

BLACK ISLE FORESTS, ROSS

Findon, Kessock, Millbuie and Kilcoy

The Black Isle district of Ross and Cromarty is a peninsula projecting into the Moray Firth. Much of it was covered in the past with Scots pine, and deteriorated into poor heath after clearance. Between 1927 and 1952, almost all the heathland area has been reafforested; the land type is similar to Teindland Forest forty miles to the east. Comparatively little experimental work has been done in the Black Isle; about twenty experiments are scattered over three of the forests, mainly on the poorer land. (General Reference, Dickson, 1951).

Site

The bulk of the area available for afforestation lies above 400 feet along the main ridge of the peninsula, which at its highest point attains 840 feet, with long gentle slopes to north and south. The rainfall is low, stations on the coast having as little as twenty-five inches, probably rising to thirty inches per annum on the ridge.

The underlying rock throughout the heath area is Old Red Sandstone, which is generally overlain by a stony impermeable drift, which is in turn covered on the lower slopes by sandy glacial wash; both drift and wash are derived from the sandstone. The fibrous surface peat varies from 2 to 12 inches in depth, with an average of 5 to 6 inches, over a podsol with a non-continuous iron pan. The pan is harder and most constantly present in the drift on the upper slopes; in places a broader cemented zone of deposition replaces the iron pan. On certain of the least fertile slopes, both the peat and much of the leached layer have been eroded, possibly after repeated burning, and here the very compact drift comes to the surface. In general on the slopes, it is found that tree growth improves the deeper the peat and the greater the thickness of wash over the drift. No detailed description of the soils or the vegetation has been made, but the description of the poorest ground at Teindland would apply to all the higher ground on the Black Isle.

History

The forest history of the Black Isle is more continuous than that of most of the heath forests. Much of the area was under semi-natural woods or plantations of Scots pine a hundred years ago, but partial clearing for sheep occurred at the end of the last century and the cleared areas in many cases subsequently deteriorated into poor heath. Felling of the forest areas was greatly accelerated from 1914 to 1920 and again from 1939 to 1945, so that only a few hundred acres of the old crop remain, while an extensive fire in the 1920's also destroyed a large area of the poorer pine crops. The most interesting surviving plantation is Bellton Wood, Kilcoy; the difficulties of the site were well appreciated in 1870 at the time of planting when intensive drainage was carried out. Stand data are given in Table 1; though it is only Quality Class IV, it must be remembered that similar areas not drained produced only scrub. It has been observed that the plantations made up to 1870, in a time of agricultural prosperity, were superior to those made after this date. The latter received insufficient ground preparation, many forming only scrub on the high ground, failing in the hollows, and at best forming slow growing stands. An example is given in Table 1 of the growth to be expected in the better parts of the Black Isle, where the Scots pine reached Quality Class III.

Acquisition of the felled and heath areas of the Black Isle started in 1926 with comparatively small areas at Findon and Kessock; much of the latter on an escarpment while the former was heath. The early plantings at Findon were made with very little ground preparation, contrary to the good advice contained in the *Statistical Accounts*, with the result that growth was irregular and generally slow. A good deal of repair work by draining, or in extreme cases by ploughing and replanting, has been required in the earliest-planted areas. The rate of planting was 100 to 150 acres a year from 1927 to 1937, while hand methods were in use. In 1936 the important conclusion was reached, mainly on evidence from Allerston, that much of the poorer ground of the Black Isle would be readily plantable if ploughed. Within three years of this decision a further 8,000 acres was acquired, and ploughing and planting was stepped up to an average of 600 acres per annum from 1938 to 1952. By this time, when the area of bare heath available was almost exhausted, some 8,000 acres had been planted.

Owing to the low rainfall and difficult soil conditions, choice of species has necessarily been conservative; Scots pine forms three-quarters of the total crop. Lodgepole pine was used on the poorer ground during the period of hand preparation, but was little used after ploughing made the use of Scots pine possible over almost the whole area. Sitka spruce was used on some scale in the early years on wetter marginal heath sites, but it was found by experience that these were likely to dry up after planting, and little was used in later years. Japanese larch has been used for fire breaks, which the large continuous areas of pine make very necessary, but only rarely appears as a main crop.

There are interesting examples of interplanting with Douglas fir after ploughing among old scrub Scots pine, and also of underplanting with western hemlock in slow-growing pine plantations.

Experiments

The experiments in the Black Isle fall into two main periods and classes. Important provenance collections of Scots pine were planted at Findon between 1929 and 1942, and of lodgepole pine at Millbuie in 1938, while in the immediate post-war period afforestation experiments, particularly on the use of species other than Scots pine, were planted on the higher ground in Millbuie. A total of twenty-two experiments were set out up to 1955, of which seven are completed and several others badly checked.

CLASHINDARROCH FOREST, ABERDEENSHIRE

Mytice and Drumfergue Experimental Areas

Clashindarroch forest, the major part of which was acquired in 1929, lies on high ground on the western border of Aberdeenshire. The bulk of the area was open heath or moor on acquisition and its altitude in particular has led to problems in afforestation. (General reference: Woolridge *et. al.* 1951).

Some fifty experiments have been carried out there, the most important lying in two enclosures at Drumfergue and Mytice.

Site

Almost the entire forest is above 700 feet and one third of the total area lies over 1,250 feet. The highest land is mainly to the west, but in the south there is the prominent feature of the Tap o' Noth (1,850 feet). Two deep valleys, running generally east to west, divide the areas almost equally, and there are numerous side valleys with side slopes of up to twenty-five degrees. The rainfall is below thirty-five inches in the valleys, rising to over forty inches on the tops. The area is well-known for prolonged wintry weather, and the tops are severely exposed, particularly to the north-east.

The geology, soils, and vegetation have been described in detail by Muir and Fraser (1940), from whom the following brief description is taken. The solid geology is mainly of Highland schists, principally those of the Boyndie Bay group and slates of the Macduff group; there are intrusions of basic igneous rocks in the southern part. A layer of fawn-coloured drift covers the area, even on hill tops of 1,200 to 1,600 feet altitude, but it is not very thick and is mainly derived from the underlying rocks. Impeded drainage is found where the slope is slight: where wash overlies the drift, the impedance occurs at the junction and the soil is often gleyed, especially on the wetter north-facing slopes.

The soils are podsolised over large areas, the two main types being normal podsols with a thin raw humus layer and a soft and discontinuous pan, and peaty podsols where the peat is up to a foot thick and there is a pan generally 4 to 8 inches below the mineral soil level. Brown earths however occur on many of the lower slopes, particularly on those facing south.

A few remnants of natural birchwood have survived at lower levels, but the greater part of the area available for afforestation was occupied by a wide range of heath types, all dominated by *Calluna vulgaris*. These comprise grass heaths of wet or dry types; dry *Calluna* types with which are associated: *Erica cinerea*, *Vaccinium myrtillus*, *Arctostaphylos* or *Deschampsia flexuosa*—*V. myrtillus*; and moist

Calluna types with *Deschampsia*, *V. myrtillus/V. vitis-idaea/E. tetralix* or *Nardus stricta*. Associated with this wetter Callunetum is the 'submoorland' type with *Juncus squarrosus* and *Trichophorum caespitosum*, forming an intermediate to the true hill peat vegetation. Special types of dry heath were recognised as occurring in extreme exposure on the upper slopes, generally above the present afforestation limit. In the western part of the area with a forty inch rainfall, hill peat is found, defined by Muir and Fraser as "peat over a foot deep", with *Eriophorum* and *Trichophorum* in basins and *Calluna* on the ridges and higher slopes.

These authors conclude that the broad distribution of soils and vegetation was more affected by climate than by geological differences. The grass heaths were generally on brown earths on the lower parts of the south-facing slopes, while above lay dry *Calluna* types on podsols with shallow raw humus. On the north-facing slopes were the damp *Calluna* types, and here the raw humus is often deeper, giving peaty podsols. On the tops lie the eroded heaths, or hill peat on the more gentle slopes. These general trends had in the past been obscured and varied by burning, peat cutting, and grazing, while today the enclosure and afforestation have greatly modified the vegetation, deep dense heather filling the rides or any areas not planted.

History

Planting started in 1930, and in the early years much work was on old arable land in the valley bottoms, which was in many places rapidly degenerating to heath. The choice of species gave considerable concern, as it was known that Scots pine suffers severely from exposure, and was therefore to be confined to the lower drier slopes; there, however, the main species planted in the early years was in fact European larch. The higher slopes would be planted with Japanese larch or Sitka spruce according to whether they were dry or wet. All the planting up to 1936 was done by hand methods, mainly notching, except for some ploughing on abandoned arable land, using horse-drawn ploughs. Thereafter all land was tractor ploughed if the slopes permitted. Meanwhile however the Sitka spruce on peaty podsol types had checked, and over 100 acres was ploughed 1936-39 and replanted with pine; a further 400 acres was treated in 1950-52.

In 1937 there was a local occurrence of dieback on European larch in one valley, and by 1942 the crop therein had almost been wiped out. In 1943-45 there was a very widespread occurrence of this disease. This dieback was eventually attributed to two factors working in combination. The first of these was the use of seed of incorrect provenance. The second factor was severe frosting, due to the form of the narrow winding valleys, causing canker which sometimes completely ringed the stems. Further the generally debilitated state of the crop brought on severe attacks of the insect pests *Adelges viridis*, *A. strobilobius* and *Argyresthia atmoriella*. From 1945 however a gradual recovery set in, though some crops had already been destroyed, and others were left rather open. The crops on the old arable land in the valley bottoms, and those on the lower parts of south-facing slopes, fared worst. Though some 200 acres out of over 700 of European larch were replanted or interplanted, a great part of the latter work was found later to have been unnecessary, owing to the unexpected recovery.

As a result of these setbacks the species choice became rather more difficult; Scots pine was in fact used widely to replace checked Sitka spruce, and in mixture with it on new ploughing. The perseverance with Sitka spruce was encouraged by the excellent growth of the first mixtures planted on ploughed ground in 1937. The most difficult decision to be made was on the unploughable slopes above the normal altitude for Scots pine. Here Japanese larch has been used or lodgepole pine, sometimes with Scots pine in mixture.

Over 10,000 acres, most of it heath, have now been afforested, and little remains to plant except for the 7,000 acres originally classified as "unplantable", mainly high land with deeper peat or with the exposed heath vegetation. Recent plantings have included careful extension on to some of the lower ridge tops. This forest shows perhaps a greater variety of crops than any other heath forest; large areas of European and Japanese larch are on the slopes, Scots pine and Sitka spruce mixed on the wetter tops, lodgepole pine replacing the Scots pine in severe exposure; while in the valley bottoms on non-heath soils, other species such as Norway spruce and silver firs add to the variety.

Mytice Experimental Area (NJ493315)

This is an area of some 100 acres lying on a steep hillside facing N.N.W. It runs from just above the Kirkney Burn at 650 feet to the ridge top at almost 1,500 feet, with slopes of one in three in places (25°). The rainfall is about thirty-five inches, and the upper part is severely exposed. Because of its aspect, the whole slope receives relatively low insolation. The parent rocks are slates of the Macduff group; the soil varies from a brown earth by the stream, below the enclosure, to podsols from about 700 to 1,250 feet, and peaty podsols above; there is rarely a pan. The vegetation was mainly *Calluna-Vaccinium* of Muir's wet or dry varieties up to 1,100 feet, with *Calluna*-lichen above. Some twenty-five experiments have been sited here, including extensive larch provenance experiments, collections of provenances, and to a lesser extent of species. Many minor experiments on points of afforestation techniques are now completed.

Drumfergue Experimental Area (NJ470332)

This is a much smaller area but it contains important afforestation experiments. It lies on a shelf at 1,050 feet on the upper slopes, between the Lag Burn at 750 feet and a ridge-top at 1,250 feet. Rainfall is again about thirty-five inches, aspect is north-west, with fairly severe exposure. The soil is a peaty podsol with pan, overlying schists. The vegetation was again *Calluna*-lichen or *Calluna-Vaccinium*. Of five experiments carried out here, two are complete and the remaining three form a valuable series of species and mixture plots.

CULLODEN FOREST, INVERNESS-SHIRE

Of the three blocks of this forest, two, amounting to almost 2,000 acres, were heath and clear felled or open Scots pine woodland. The best of the small areas of the old crop still standing is Quality Class IV, and it seems unlikely that many better stands existed. In many ways the site conditions are similar to those of the Black Isle and Teindland; the altitude varies from 400 to 900 feet and slopes are gentle; rainfall is just over thirty inches, and a strongly developed podsol is found on deep compacted boulder till derived from Old Red Sandstone. The pan in places is harder and more compact than any in the experimental areas; in certain areas rather deeper peat has accumulated due to the waterlogged condition of the ground. East Culloden was acquired in 1925. In some of the early plantings Sitka spruce was used on areas with over six inches of peat; growth has been very slow, and with the inadequate drainage pines did little better. The Dalcross and Dundavie sections, acquired in 1949, present a striking contrast after intensive ground preparation; often the use of disc ploughs was necessitated by the presence of boulders and stumps. (General Reference: Fraser, 1951).

DORNOCH FOREST, SUTHERLAND

This is the most northerly of the heath forests and is interesting in that much of it has been replanted by the Forestry Commission on areas previously afforested by the Duke of Sutherland. In Harriet's Plantation the general conditions of climate, geology, soil and vegetation closely resemble those at Teindland, forty miles to the south-east. In the lower parts of the plantation three sample plots were measured before felling about 1920. Results are given in Table 1 and show that at 350 to 400 feet the Quality Class of the Scots pine was III to V. At the top the crop was open and not worth felling. Most of the area was replanted in 1932-33 but started badly, and the single experiment in this forest was laid out near the highest point at 550 feet. Results (p. 7), and soil investigations carried out by Yeatman (1955) confirm that an improvement on the old crop of scrub can be made with improved technique.

DRUMTOCHTY FOREST, KINCARDINESHIRE

When the present planting programme is complete this area will be a forest of about 8,000 acres, over half of it on former heathland. In the original acquisition, planted 1927-37, the proportion is however far less, the heath occupying only the upper slopes and tops above 800 feet, of which perhaps 1,000 acres were planted. Work on the extensive new areas started in 1953, and is proceeding at 300 acres a year. The original area straddles the Highland fault and the glacial drifts vary rapidly from schistose to material derived from the Old Red Sandstone. The peat depth is usually less than six inches, but it becomes much deeper in places; podsolisation has produced a thin pan on the hill tops, while on the steep upper slopes, erosion has in places produced a truncated podsol. A variety of species were used on these upper slopes and results in many cases have not been satisfactory. Mechanical cultivation is impossible and phosphate was not used at this period. Slow growing crops of mountain and lodgepole pines were produced, and Japanese larch has done fairly well up to 1,000 feet (Japanese larch sample plot S.177 at 940 feet on 4 inch peat over a podsol is Quality Class V). But Scots pine is poor, and spruce put on the apparently wetter slopes has failed. In addition, areas of European larch on the upper slopes have been destroyed by dieback, although below 800 feet this species has recovered well. Roe deer make any small scale rehabilitation of this area difficult. Some of the mountain pine areas have been successfully interplanted with Sitka spruce.

The upper gentler slopes of Strathfinella Hill (1,357 feet) were originally left unplanted as too high and exposed. In 1950-51 two pilot plots were set out here as described in Chapter 11, in order to show whether some 300 acres could in fact be planted by using improved technique. This forest also contains an experiment on the rehabilitation of dieback areas of larch by replanting with other strains. The fertile valleys also contain several of the new seed orchards, from the seed of which many future heath plantations will undoubtedly be formed. (General reference: Maxwell, 1951).

FETTERESSO FOREST, KINCARDINESHIRE

This forest is immediately to the north-east of Drumtochty and will also become a large forest of over 8,000 acres, almost all of it on heath. It lies rather lower, the bulk of the area being between 600 and 1,000 feet; less than 300 acres previously carried woodland, mainly on the lowest ground in the valley of the Cowie Water. Deep drift covers the mica-schist rocks, and while over much of the area there is thin peat and a podsol, often with a pan, there are also extensive areas of deeper peat. This is an unusual feature for a forest so far to the east, with the comparatively low rainfall of 30 to 35 inches. Owing to the repeated burnings, the whole area was heather-clad, the heather tending to minimise the differences in site which in fact exist.

An extensive planting programme was begun in 1946, and an average of 400 acres a year was planted until 1953, there being a reduction to 300 since. Almost all this land has been ploughed. In the early years, Scots pine and Sitka spruce were used almost exclusively, but from 1950 onward increasing use was made of Japanese larch on the less exposed heaths, and lodgepole pine on the more exposed, while the amount of Sitka spruce on the normal heath type was reduced. Sitka spruce has started very well on the deep peat areas, for the peat breaks down after ploughing in a manner unknown on the more typical peatlands of the west. A variety of other species have been tried in this forest.

One problem has been to determine the altitude to which the exposed eastern slopes can be afforested. For the present time the limit has been set at 700 to 900 feet. A pilot plot has been planted on the 1,051 feet Hill of Trusta, the highest point on the eastern side of the forest, in order to assess the plantability of the land so far left on the higher tops. Several smaller plots lie rather lower down, but still above the normal limit. A comprehensive trial on the use of seedlings of five species was made here over five seasons 1951-55. (General reference: Maxwell, 1951).

GLENISLA FOREST, ANGUS

This is a high-lying area on the south-eastern flank of the Grampians, where about 4,500 acres are being afforested. The land lies between 800 and 2,000 feet, forming two steep-sided valleys running south to north. Rainfall is thirty-five inches, with severe exposure and heavy snowfalls on the higher ground. The soils are derived mainly from drift, much of it light in texture and well drained, so that podsolisation is not advanced. The principal vegetation type is *Calluna/Vaccinium*.

Planting began in 1949 and an annual programme of about 300 acres has been maintained. About a third of this, 800 acres to 1957, is ploughable heath types; the remainder is either more fertile or too steep to plough. Scots pine (pure or mixed with European larch), Japanese larch and hybrid larch are the principal species employed, while lodgepole pine replaces Scots pine at high elevations.

GLENLIVET FOREST, BANFFSHIRE

Glenlivet covers an area of 5,500 acres, almost all of it heathland, in Glenrinnes, Glenlivet, and Glenavon in upper Banffshire.

The plantations lie from 650 to 1,500 feet, the bulk being above 1,000 feet, so that exposure is the principal factor limiting growth. The average rainfall is thirty-seven inches, late and early frosts are frequent, while snowfalls are often heavy. The underlying rocks are mainly schists and phyllites producing a fairly fertile soil and a vigorous heath vegetation.

The first acquisition was of 1,150 acres of the lowest land in 1930, and was planted at about 50 acres per annum until after the war. Growth here has been slow, owing to the inadequate ploughing equipment then available and the use of too high a proportion of spruce. The programme was stepped up substantially after the acquisition of large areas from the Commissioners of Crown Lands from 1949 onward. Ploughing and the use of phosphate with all species have given excellent results. After reaching a peak of 900 acres in 1953 the annual programme is now about 500.

Recent acquisitions included 400 acres of mature Scots pine and European larch, much of which was subsequently blown down in the gale of January, 1953. The stands indicate that Q.C. II Scots pine can be expected at the lowest elevations but that at 1,500 the pine/larch are unlikely to be more than Q. C. V.

Experiments at Glenlivet include an early draining experiment, and in recent years a Scots pine provenance trial and a progeny trial from 'plus' Scots pine trees blown in 1953.

HAMSTERLEY FOREST, DURHAM

Hamsterley Forest provides an interesting example of the development of technique in heath planting, and the successful use of the experimental approach to afforestation where evidence from existing plantations was almost completely lacking. (General reference: Forrester, 1951).

Site

The area of 5,500 acres is readily divided into a lowland area of steep-sided valleys, and a heath of over 3,000 acres lying at 750 to 1,000 feet and reaching 1,400 feet at the highest point. The dissecting valleys result in the heath having varied aspects, but the heather-clad upper slopes are gentle compared to those below. The rainfall is higher than on many heaths, reaching forty-five inches.

The geological formation is Millstone Grit and is overlain by gleyed till, giving mainly heavy soils, though sand occurs in places. The soil is generally very compact and contains boulders; the podsol is less well defined than at Allerston, the pan being intermittent. There are sizable areas of deeper peat in hollows, and with the higher rainfall *Sphagnum* was abundant in places.

When used as a grouse moor the area was repeatedly burnt, and as a result the vegetation was initially almost pure *Calluna*. After ploughing, the heather becomes extremely vigorous, two or three feet tall in places, indicating a rather more fertile soil than usual, as does the fact that the valley sides were grass covered with brown earth soils.

History

On acquisition there was on the moor a remarkable plantation at over 1,100 feet, a stand of 120-year-old beech with a few Scots pine. The beech are still vigorous though of poor form, and were apparently planted with pine nurses after ploughing. After acquisition in 1927, the main work for ten years was undertaken in the valleys, but a little planting was carried out on the moor from 1928-32, and three experimental blocks were planted in 1929-30, using a variety of species and methods. These plots were allowed to develop for some years before planting was resumed on a small scale in 1937. An early trial of an agricultural plough in 1930 had been a failure, but ploughing of the heath with heavier equipment started in 1938 following demonstrations of its success at Allerston. The planting programme reached 250 acres by 1940, only to fall again from 1942-47, after which the rate rose steadily until afforestation was completed in 1952.

The early heath plantings were largely of Sitka spruce, which checked as no ploughing was done. Intensive hand preparation in the pilot plots gave more promising results, and much of the later planting from 1937 was of Scots pine and Sitka spruce in mixture. Growth has been slow, but much of the crop is promising.

Experiments

The early pilot plots containing seven experiments, several on minor points, are now completed. Three later experiments planted in 1938-40 on ploughed land continued the main subject of the pilot plots in testing a variety of species and mixtures.

INCHNACARDOCH FOREST, INVERNESS-SHIRE

This forest, one of the earliest acquired by the Forestry Commission, is widely known for the experimental work carried out on peat afforestation. Nevertheless, under the different soil conditions in the valley bottom there was, at the time of purchase, a considerable area of heather moor.

Site

This area lies at only 120 feet above sea level, on the flat floor of the Great Glen, with mountains rising to 2,000 feet on either side, and is in this respect not typical of the 'upland heaths.' Further differences are that the subsoil is of freely-draining glacial sands and gravels, so that wet hollows are commonly drained by digging "sumps", while rainfall at 45 to 50 inches is higher than normal on the heaths.

The surface conditions and soil profiles are however very similar to other heathlands further east, and it is clear that the higher rainfall and freer subsoil drainage to some extent cancel out. Deep peat has not formed, but on the other hand podsolisation has led to impeded surface drainage, and the typical wet surface is found which dries readily once it is ploughed. The soil varies rapidly in the depth of the profile layers, and the pan is intermittent, forming only where the soil is compacted. Where the whole profile is loose, iron staining occurs as in a normal podsol.

History

The area involved is not large, about 300 acres in all; there were no standing crops on acquisition. Experimental work on the moor itself began with small horse ploughings in 1928; two years earlier an important interplanting of pine among checked spruce was carried out on the steep lower slopes of the Glen. Unfortunately only a small number of the experiments were laid out on ploughed ground; the rest of the moor was afforested from 1930 to 1933 with Scots pine, or used for provenance trials of this species, in both cases without ground preparation. Growth has been very variable, reflecting the variations in soil profile, being best on those areas without hard pan, while in the last decade serious outbreaks of pine shoot beetle have retarded growth. Though in some cases Scots pine crops in the provenance trials are, at twenty-five years old, equivalent to Quality Class I-II, many are much poorer, being at present unmeasurable. Lodgepole pine on ploughed ground has formed an excellent crop equivalent to Q. C. I Scots pine.

In all, some twenty experiments were planted on the moor or lower slopes of the Great Glen, the most important being the provenance trials, the interplanting experiment, and a series on the use of the "spaced-group" method of planting. Over half of the experiments are regarded as completed.

MONTREATHMONT FOREST, ANGUS

Montreathmont lies on the plain of Strathmore where about 2,500 acres of low-lying heath have been planted since 1922. With an annual rainfall of thirty inches and elevation of 200 to 300 feet, this is one of the driest and least exposed of the heath forests. The soil and drift, both derived from Old Red Sandstone, impeded drainage, thin peat and podsolisation make it very comparable to the lower ground at Teindland.

Planting by notching, or on turfs, from 1922 to 1946 produced slow growing plantations. Failed acres and checked spruce were subsequently ploughed up and pines, particularly lodgepole pine, used to make them good.

ROSARIE FOREST, MORAY AND BANFFSHIRE

Rosarie Forest lies to the east of the Spey and to the south of Speymouth Forest. Acquisition began in 1942 and reached 6,500 acres by 1957, of which about half was heath land. The plantations extend up to 1,100 feet, and exposure rather than site quality determines the planting limit. Rainfall is about thirty-five inches. The heath sites are of variable quality, lying on schists, quartzite and Old Red Sandstone boulder till, and include old arable land which has reverted to heath. The slopes are mainly steep, so that marked podsolisation occurs only locally, while pan formation is rare.

The early plantings were on old woodland sites felled during 1939/40. For the first few years planting was at a rate of 50 acres per annum, but since 1949 has been maintained at about 300 acres. Prior to this date planting was by notching or mounding according to site, but from 1949 ploughing has been general, the tine replacing the R.L.R. plough in 1952. Scots pine crops acquired at Hillochhead and Parkmore suggest that Quality Class II-IV can be grown; and this species forms the bulk of the new crop. In the mid and late forties Sitka spruce was used in intimate mixture at Auchanacie and Arndilly, where the schistose soil is more fertile, and semi-check has followed the rapid invasion of heather after ploughing. Scots and lodgepole pines have been the principal species used since 1951 and spruce is confined to moister and more fertile areas.

ROSEDALE FOREST, YORKS.

Rosedale lies a few miles to the east of Allerston, and is in many respects comparable to the Harwood Dale Section of that forest. Thus the heathland is not on a plateau but on gently sloping hills, the subsoil is of Estuarine clays over the Lower Oolites, and the soil though podsolised has no hard pan. On the other hand boulders are not so frequent, and exposure is less severe, since this forest is ten miles from the coast.

The earliest planted area, acquired in 1927, contained a relatively small area of moor, but extensive areas were added in 1949. The planting rate then rose to average 500 acres from 1951-56, and the forest will be over 7,000 acres, two-thirds of it on heath. The heath area first acquired was planted from about 1940, and in the early years a good deal of Corsican pine and Sitka spruce were used in mixture; later large areas of Scots pine and Sitka spruce were planted. In recent years the proportion of Sitka spruce has fallen, and it is mainly planted on areas of *Calluna-Molinia* on deeper peat; Scots pine is the main species, with Japanese larch on the *Calluna- Pteridium* slopes.

The ten experiments established in this forest from 1943 onwards are almost all replicas of others in the Broxa experimental area; they mainly concern the use of phosphatic manures and the arrangement of mixtures.

SPEYMOUTH FOREST, MORAYSHIRE

Over half of this 12,000-acre area is poor exposed moorland, varying in altitude from 300 to 850 feet. The general site conditions are very similar to those described below for Teindland, which lies only five miles away on the other side of the River Spey; the rainfall, at twenty-eight inches, is among the lowest of the heath forests. In spite of this low rainfall, run-off has in the past caused serious erosion and the formation of deep gulleys in the Old Red Sandstone boulder till. Parts of the heath areas had been planted about a hundred years ago, but much of this crop was only scrub. An 80-year-old sample plot of Scots pine, now felled, which grew on the heath at 650 feet, was Quality Class V; details are given in Table 1.

The first section of the forest acquired was at Ordiequish, which was planted by hand methods between 1927 and 1937, using a fair proportion of lodgepole pine. The main acquisition was made in 1937 from the Duke of Richmond and Gordon's Estate, and consisted of extensive areas of Scots pine forest and the main block of poor heathland.

The planting programme was 300 to 400 acres a year from 1947 until 1951, when it was stepped up to 700 acres. Since 1950, extensive use has been made of the tine plough, care being taken to plough along the contour. The site gives little scope for variety in the choice of species; Scots pine is the main species, with lodgepole pine on the most exposed areas and Sitka spruce in mixture on flushed areas.

Only a few minor experiments have been sited in this forest.

TEINDLAND FOREST, MORAYSHIRE

Including Findlay's Seat Experimental Area

Teindland Forest, Morayshire, was an early acquisition of the Forestry Commission. Part of the highest ground was chosen in 1925 for experimental work on afforestation as being unplantable by normal methods and typical of the poorer moorland of lower Speyside.

Site

The forest lies on gently sloping hills running from 300 up to 850 feet, with a rainfall of thirty-five inches per annum. The underlying rock is Old Red Sandstone, but this is covered by a great thickness of drift, red boulder till derived from the same rock. Muir (1934) has described the surface geology and soils. The upper slopes, where the drift has not been disturbed by fluvio-glacial action, carry peaty gley podsols with hardpan on boulder till. There is a thin layer of peat and a very hard impervious iron pan at a depth of 8 to 18 inches. The upper layers are compact and stony. Lower on the hill, fluvio-glacial action has given rise to sandy drift with freer drainage and more normal podzol profiles, containing a broad iron and humus-stained layer, and at most a discontinuous iron pan. Only a small proportion of the forest is not podzolised, and there are a few hollows with deep peat. The vegetation types associated with these profiles are as follows:

Peaty gley podzols with hard pan. Semi-natural or century-old plantings of *Pinus sylvestris* forming little more than scrub rarely over fifteen feet high. *Calluna vulgaris* dominant, but poor; ten years after burning the *Calluna* regrowth was barely more than six inches tall; flowering is not heavy. *Erica tetralix* and *Trichophorum caespitosum* are frequent. *Narthecium ossifragum, Juncus squarrosus, Carex binervis* and *Eriophorum vaginatum* occasional. *Cladonia sylvatica* is abundant and *Rhacomitrium lanuginosum* frequent on unburnt moor.

Normal podzols. Almost pure *Calluna* of good growth and healthy appearance, occasional *Erica cinerea, Vaccinium vitis-idaea,* and a rich moss layer of *Hypnum cupressiforme, H. schreberi, Dicranium scoparium, Plagiothecium undulatum.*

History

Most of the original forest area of 1,300 acres was planted with Scots pine about 150 years ago. On the upper slopes remnants of this crop still survive, having rarely attained more than fifteen feet in height. On the lower slopes with normal podzols a marketable crop was raised and cleared during or just after the 1914-18 war. Two plots from the middle slopes and a third from the early Forestry Commission plantings showed a marked fall in production and Quality Class with increasing altitude, which is associated with increasingly poor soils. (Table 1, p. 7.)

On acquisition in 1923, replanting was commenced on the lowest slopes using direct notching. Planting was mainly of Scots pine with a small proportion of European larch. Later the semi-circular spade was used to obtain more soil disturbance, an extracted core being broken up and replaced round the plant; on the poorer areas a system of drains and mounds was employed. It is noteworthy that after soil disturbance nearby, some of the old stunted pine trees developed new leaders. The planting of about 1,200 acres was completed in 1939, leaving as unplantable an area surrounding Findlay's Seat, the highest point. Growth on the upper slopes was not very satisfactory, and there were instances of Scots pine being replaced by lodgepole pine, and applications of slag being made to stimulate growth, while in the early years there was severe damage from black game and pine weevil. In 1942 more than a third of the forest was burnt. Ploughing was employed for the replanting which began in 1945, and was continued in the new acquisition which has brought the total acreage to 2,400. For some years pine/spruce mixtures were widely employed on the ploughed ground, the spruce receiving phosphate, but now pines with a proportion of larch and birch in mixture are generally employed.

An interesting feature of the forest is the spread of broom and gorse on much of the lower ploughed ground; these species may well nurse the Sitka spruce, which without them had checked badly. Early underplantings of old Scots pine scrub with western hemlock have been very successful.

Findlay's Seat Experimental Area (NJ285543)

This was the first site chosen for concentrated silvicultural research on the afforestation of poor heath, being unplantable by normal methods on the evidence of the Scots pine scrub. At an early date three lines of research were initiated.

(1) Assuming that the underlying drift was more fertile than the podsolised surface, trials of pan breaking, subsoiling and spreading of subsoil were laid out.

(2) Assuming that pan breaking was not essential, a second series of experiments tested cultivation of the surface layers by hand and by ploughs. This proved just as successful as (1) but as initial growth was slow, manuring was started at an early date.

(3) An area was set aside for direct sowing trials, which however proved abortive.

Subsequently almost all the lines of current research were represented in this area, but over half the experiments were lost in the 1942 fire. The experimental area has been extended on to adjacent land since 1950; new experiments have been laid out on a large scale, and mainly concern ploughing methods, species, and mixtures.

A number of experiments were established lower down in the forest, but the majority of these also were burnt. In all about one hundred trials have been carried out at Teindland, of which forty-four were burnt and thirty more are considered as completed.

OTHER HEATH FORESTS

The following forests listed from north to south by counties, contain areas of upland heath of from 500 up to 3,000 acres, not all of which has been planted as yet. Old plantations exist in some of these forests and the data from two plots is incorporated in Table 1. Those forests marked with an asterisk contain experiments which are referred to in the main body of this bulletin:—

Scotland

Ross:	Ardross, Clach Liath, Morangie
Inverness-shire:	Strathdearn
Morayshire:	Elchies, Monaughty*, Newtyle*
Aberdeenshire:	Benachie, Pitfichie, Forest of Deer, Tornashean
Angus:	Glenprosen
Perthshire:	Glenerrochty
Kincardine:	Durris*
Fife and Clackmannan:	Devilla*

England

Northumberland:	Ray
Yorkshire:	Ampleforth, Cleveland*

In all it is estimated that the forests described or listed above contain about 90,000 acres of heath, of which between 70,000 and 80,000 had been afforested up to 1957.

THE EXPERIMENTS

Over four hundred and fifty silvicultural experiments were laid out on heathland between 1921 and 1957, individual experiments varying in size from a few square yards to over twenty acres. Almost all of these experiments fulfil the scientific requirement of replication and randomisation. Their design was, at a very early date, based on the technique developed by Fisher at Rothamsted in the twenties, and randomised blocks and Latin squares were commonly used from 1928 onwards. Forest plots have one advantage not enjoyed by agriculture, that small differences can be accumulated over several years growth to produce a striking result; but many disadvantages, notably that the site variation may be much greater in a small area. Plot size is also a continuous problem; the size must increase as increasingly long-term solutions are sought, but with the risk that every increase in plot size decreases the chances of ensuring complete comparability in all other respects.

Many experiments have sought to combine long and short-term objectives by split plots and factorial layouts. It was in such cases that the early experiments often lost efficiency by over-replication and thus the use of unduly small plots, while in other cases the standard of design fell temporarily so that layout became semi-systematic even though replication was adequate. Nevertheless as a whole the results presented are from plot averages and very rarely from single plots. The main lack is at present in long-term comparisons between large plots; the older plots on the whole are small, rarely reaching 0.1 acre (0.04 hectare) and interactions have occurred, often it may be said of great interest. Such interactions in general however will tend to reduce plot differences, and to that extent treatment effects are thus under-estimated. Wherever possible the results have been subjected to statistical analysis.

It should be noted that in general the experimental areas lie on the least fertile and more exposed of the available heath sites.

Note on Numbering of Experiments

Registered experiments. The name of the forest is followed by the experiment number and the Forest Year (Oct. 1st–Sept. 30th) indicated by the symbol "P" in which the experiment was planted, e.g. Teindland 39.P.28 means that the experiment was established between 1st October 1927 and 30th September 1928. The experiment 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., Teindland 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 expressed as percentages of the number planted. 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. All old assessments have been converted to these units.

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 areas 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 basal area and volume measurements, and species and treatments may be compared on this basis. It is also possible to predict future behaviour by the use of yield tables, and an attempt has been made to do this for main species used on the heaths.

Chapter 4

PLANTING WITH PREPARATION OF THE GROUND BY HAND

The traditional method of afforestation on heathland was, until recently, to plant directly with a spade, using a hardy species such as Scots pine and a minimum of ground preparation. All work was carried out by hand and such preparation as was done generally took the form of drains in the wetter parts. A few notable exceptions to this general rule are recorded in the account of the heath forests. In the early years of the Forestry Commission a similar practice was followed, but in the first heath areas acquired results were not promising, and the obvious line of experimental work to be pursued, was that of drainage or cultivation by ploughs. Simultaneously however, a number of experiments were started to find the most effective and economical method of hand planting. These results are still of some value for use where ploughing is not essential to obtain reasonable growth, or where it is considered uneconomic or impractical. There are, moreover, areas of heath where ploughing is impossible on account of rock or boulders, but which are fertile enough to be worth planting without mechanical cultivation.

The history of hand preparation within the Forestry Commission heath areas since 1930 is one of steadily decreasing importance as ploughing gradually became feasible, first on the relatively boulder-free heaths of Allerston, then on the early northern acquisitions, and finally the difficult subjects such as Harwood Dale. Many of the later acquisitions were based on the assumption that ploughing was essential, and in whole forests no extensive areas have been planted by hand methods. Thus it is that today hand preparation on the heaths is a relict method, being practised only on areas inaccessible to ploughs.

Many of the sites where hand methods are still used lie on the fringes of the heaths, where typical conditions are not developed, this particularly applies to steep banks or hills within the heaths and to wet hollows more akin to the peatlands. Today it is almost true to say that any flat heath that cannot be ploughed is not a suitable subject for afforestation, and conversely, that many areas earlier considered as unplantable have in fact been successfully planted, once they have been ploughed. Thus it is that the experimental work on hand preparation ceased in many areas by 1930, and the last experiments were planted in 1940.

Methods of Planting

Some definition and classification of the methods and tools used are necessary as the range was considerable:

Notching. Planting by making one or two cuts with a spade. Methods included the use of the Schlich spade for a simple notch, and of the garden spade for 'L' or 'T' notches; dibbling with conical irons is also included here.

Pitting. Pit planting with a spade. Enough soil to accommodate the roots was turned over, the pit generally being about nine inches square and six to eight inches deep.

Prepared Patches. Generally carried out with a mattock; depending on the time taken, the method may approximate to notching or to pitting. Sometimes the surface peat was worked in, sometimes the turf taken off and replaced after the preparation and the plant put through it; this was known as the "replaced turf" or "lifted turf" method. The placing of the plant in the patches was generally by an 'L' notch made with a spade or mattock.

Pit and Mound. Also known as the Wareham pit method, this is a development of Manteufel's or the Bavarian method. In the most elaborate form a turf two feet by one foot was removed, the soil in the opening broken up with the mattock and piled at one end, and in this mound the plant was set with the broken turf inverted around it.

Mounding. Piles of spoil and surface peat were built either from holes alongside or from drains. This method differs from the *pit and mound* in that the mound here is sited on top of the original surface vegetation. Where the peat becomes thicker this mounding method may approximate to turf planting.

Turfing. Use of squares of peat cut either from holes ('individual turfs') or from drains ('turf and drain').

Hand digging. In certain cases more intensive treatment was used, patches being cultivated by hand digging with a spade to accommodate either individual plants or groups of plants.

Any of these treatments might be accompanied by screefing the vegetation, either to facilitate planting or to allow the turf and "spoil" to lie on the surface without the risk of leaving air pockets. In places where the pan lay within six or eight inches of the surface, any of the more intensive methods, e.g., prepared patches or hand digging, would break the pan over a proportion of the area.

Scots Pine

The majority of the intensive experiments were carried out with Scots pine as the indicator species and results are presented in Table 2. All were early experiments, generally well replicated but for the most part not randomised, so that statistical analysis of the results is not possible. Nevertheless they show quite clearly that on the poorer areas, such as Harwood Dale and the Findlay's Seat area of Teindland (25.P.28), there is a marked benefit both in increased height growth and reduction of losses with the more intensive methods. One exception is that the turf method used in Harwood Dale 9 resulted in heavy losses in the first year 1933, which was a very dry season; it is noteworthy that this was the only treatment which raised the plant above the original soil level. In contrast, on the better site at Teindland (30.P.28), where there was vigorous heather mixed with grass, no substantial difference between treatments occurs, and clearly the most economic treatment would have been notching.

On the poorer ground the use of basic slag was tested with hand planting from an early date and one result from Teindland is included in the table. There was a striking response and the two treatment effects were in this case additive, growth being doubled and losses halved by the combined mounding and manuring. Most of these experiments were small, and it is not possible to follow their history further owing to the interaction of treatments, but later results of Wykeham 6 are given in Figure 5, page 43.

Other Species

There are few intensive experiments comparing hand methods for species other than Scots pine, but further results from Teindland and Wykeham are given in Table 3. Notching was again always the poorest treatment, and generally suffered heavier losses; with other methods of planting, growth increased with the amount of soil working. Once again the effect of phosphate at Teindland requires further consideration. In the four cases shown in Table 3, the overall effect of slag by itself is slightly greater than that of intensive ground preparation. With intensive work and phosphate however, there is in each case a positive interaction in that the effect of the combination is greater than that of the two treatments separately. Four years later this result was true also of the Scots pine in Expt. 25, P.28, though it was not so after ten years (the result given in Table 2). Both these experiments were lost in the 1942 fire at Teindland, while at Allerston phosphate was never used in factorial combination with different hand methods. There is therefore,

TABLE 2: METHODS OF PLANTING

Mean heights after 8-10 years of Scots pine planted by various hand methods.

Early Losses, where appreciable, are shown in brackets.

Heights in feet; losses per cent.

Experiment	*Age Yrs.*	*Methods of planting in approximate order of intensity of ground preparation.*					
		Notch	*Patch*	*Pit*	*Turf*	*Mound*	*Pit and Mound*
Teindland 25.P.28	10	1.8(29)	—	—	—	2.7(20)	—
+2 ozs. basic slag		2.9(12)				3.6(15)	
(*Calluna-Trichophorum-Cladonia*)							
Teindland 30.P.28 .... (*Calluna-Deschampsia*)	9	5.6	—	5.8	—	6.1	—
Wykeham 6.P.28	10	3.0(50)	3.4(46)	—	—	—	—
Harwood Dale 6.P.32 .... +2 ozs. basic slag	8	2.1	—	—	2.5	—	2.6
Harwood Dale 9.P.33 +2 oz. basic slag	10	—	3.8(3)	—	3.7(20)	—	4.4(Nil)

TABLE 3: DIRECT PLANTING

Heights of various species at 9-10 years from planting by hand methods.
Early Losses shown in brackets.

Heights in feet; losses per cent.

Experiment, Age and Species	*Methods of planting in increasing order of intensity*		
	Notching	*Mounds or Patches* †	*Dug Groups*
Teindland 36.P.28 Aged 9 yrs.‡			
Mountain pine	1.3	—	§
+2 ozs. basic slag	1.7	—	3.1
Scots pine	1.1	—	2.4
+2 ozs. basic slag	1.3	—	4.4
Lodgepole pine	1.6	—	2.2
+2 ozs. basic slag	2.4	—	5.3
Teindland 25.P.28 Ages 10 yrs.			
Lodgepole pine	1.3(19)	2.2(20)	—
+2 ozs. basic slag	3.0(23)	4.3(9)	—
Japanese larch	1.9(72)	3.0(50)	—
+2 ozs. basic slag	3.3(67)	5.6(7)	—
Wykeham 6.P.28 Aged 10 yrs.			
Japanese larch	1.7(41)	2.4(42)	—
Corsican pine	2.1(32)	3.1(23)	—
Sitka spruce	1.1(20)	1.4(17)	—

Notes: † Mounds at Teindland, Patches at Wykeham.
‡ Losses are not available in comparable form for this experiment.
§ All the mountain pine were given slag.

little data on which to judge how feasible it would be to raise plantations by the use of phosphate in combination with the best possible hand work.

Notching in Practice

It is necessary at this point to emphasise the failures that took place both in early experiments and general practice with direct notching on the poorer types of heath, which may be taken as those containing *Erica tetralix* and *Trichophorum* (*Scirpus*) with poor *Calluna*, and with water lying for long periods.

The experiments so far quoted are with one exception small, and do not show the full extent of the losses to be expected in extensive work. When these early losses given had been made good by beating up, the deaths continued, so that at Teindland (25.P.28) they again reached figures of the same order, though rather less for Japanese larch and rather more for lodgepole pine (Table 3). This further loss occurred also with the Scots pine (Table 2). At Wykeham, after beating-up in the second year, the immediately subsequent losses were not serious, but over the years both Japanese larch and Sitka spruce were reduced to under 50 per cent stocked, as shown in Table 4. This table includes other larger-scale notch plantings in which the long-term result may be examined, and contrasted in certain cases with adjoining areas which were given more intensive preparation. The figures demonstrate how the point at which serious losses occur may vary with the species or site, and similarly how variable is the point at which the crop becomes established and losses cease, until inter-plant competition commences in the canopy stage. Thus the directly-notched Scots pine at Teindland is not yet established after thirty years, while at Harwood Dale and Wykeham this species is well established despite an early setback at the latter site. At Hamsterley there was disaster with Scots pine, as indeed with all species, except where lodgepole pine was planted on prepared patches with phosphate. This was largely due to blackgame and red grouse, but clearly planting method and phosphate also influenced the results.

Lodgepole pine was also successful at Clashindarroch and Harwood Dale, though only at the latter is Scots pine available for comparison. Results with Japanese larch are variable; after heavy early losses at all sites, it failed where notched at two sites but grew at the third, Clashindarroch. Sitka spruce showed few early losses, but then checked and later died out, over a long period, where notched at Clashindarroch and Wykeham, while with ploughing it survives at both forests.

A further characteristic of these hand-planted areas is the variability of growth. There are areas such as the Findlay's Seat area of Teindland where one can state that over the greater part of the area no crop will be formed from notch planting. At the other extreme is Wykeham where a crop of Quality IV Scots pine could be raised with some certainty. Between lie many areas where the growth varies rapidly from place to place, as for example in the Black Isle at Findon Forest, where a crop may form in one spot but a short distance away the trees check and gradually fail. No systematic work has been done on this point, but clearly on such areas direct planting must be regarded as an unjustifiable risk, even for pine. One may note in passing the remarkable vigour of lodgepole pine in some of these areas at Findon where Scots pine has failed, indicating that this failure is due to some factor being limiting for the latter species, not to a factor prohibiting all tree growth.

Similar variation of growth of pines is to be seen at Harwood Dale in the earliest notched experiments. Once ground preparation is undertaken, even of relatively low intensity, by mounding or simple ploughing, these rapid fluctuations of growth are greatly diminished, so that more even plantations are formed. It is apparent that one is dealing here with sites just limiting for the establishment of Scots pine, where small variations decide between failure and slow growth. By more intensive methods the vigour of the pine is increased and the balance swung in its favour.

Mounds and Prepared Patches

From about 1928 it was accepted that more intensive hand work must be used on areas not being ploughed. The actual method adopted varied from place to place. At Teindland a number of experi-

TABLE 4: DEATHS AFTER PLANTING BY VARIOUS METHODS

Cumulative losses in notch-planted experiments shown where possible in comparison with those in areas planted by more intensive methods.

Legend — Increased losses over previous figure.
+ Additional losses after replacement of previous figure.
C Canopy closed; figures no longer comparable.

Percentages.

Experiment / *Years of assessment* / *Treatment*	*Scots pine*	*Lodgepole or Corsican pine*	*Japanese larch*	*Sitka spruce*
Teindland 13.P.26				
2nd, 6th, 22nd, 30th years				
(a) Notched	2–18–25–37	—	—	—
(b) On drainside spoil	2—3—3—C	—	—	—
Clashindarroch 7.P.33		Lodgepole pine		
1st, 5th, 15th years				
(a) Notched	—	0—2—6	0–29–29	0—1–36
(b) Shallow complete ploughed....	—	0——3	1——10	1——7
Hamsterley 1.P.29				
1st and 10th years				
(a) Notched	43+42	9+42	38+89	—
(b) Prepared patches	27+40	5+21	28+83	—
(c) Patches+1 oz. slag	26+38	7+16	13+52	—
Harwood Dale 1.P.32				
1st, 9th and 24th years				
Notched+2 ozs. slag	6—10—17	2—11—14	—	—
Wykeham 6.P.28		Corsican pine		
2nd, 7th and 20th years				
(a) Notched	50+13—C	32+15—C	41+41—89	20+11—45
(b) Patch preparation	46+ 5—C	23+ 8—C	42+39—63	17+12—48
(c) Shallow complete ploughed....	54+ 6—C	23+ 7—C	27+23—C	8+ 7—9

Notes: All losses are given as percentages of the initial number planted.
At Hamsterley extensive repair work was carried out after the 10th year with addition of phosphate.
At Wykeham losses shown for the second year are totals for replacement in the first and second years. The Scots pine first used here was of poor quality.

TABLE 5: GROUND PREPARATION METHODS

Dominant heights 15 years after planting in Harwood Dale 24.P.39 with costs of the preparation by hand given as a measure of intensity.

Treatment	*Ground Preparation Cost per acre 1939*	*Dominant heights in feet*	
		Scots pine	*Japanese larch*
Patches (lifted turf)	£4	12.2	7.5
Pit and Mound	£5½	13.6	11.6
Mock double furrow ploughing	£18	15.4	15.8
6 ft. x 6 ft. dug patches at 8 ft. centres	£29	15.7	16.9
Standard Error		±0.6*	±1.4*
Difference for significance at 5% level		2.1	4.8

Notes: Spacing was 4 ft. x 4 ft.=2,722 per acre.
Basic slag applied at 2 oz. per plant.
* Significant.

ments were planted on mounds cut from holes or later from drains; while at Harwood Dale the replaced turf method was used for a few years, and then from 1936 the pit and mound method was normal, until hand work ceased in 1943. In almost all cases basic slag was employed in addition to more intensive preparation. With these methods pines grew satisfactorily, and while larch and spruce often checked badly, they did not die out as with notching, and may even yet in some cases form a crop, although after twenty years few areas are yet in canopy.

As an alternative to the above methods the spaced group method of planting was also employed in the period before ploughing became normal practice, since this system allowed the use of intensive hand methods at a more economic cost. The method is more fully discussed in Chapter 12, page 134.

There is at Harwood Dale a further intensive experiment giving useful information on the relative growth with different hand methods. Owing to the presence of boulders, this forest proved a far less tractable subject for ploughing than either Teindland or Allerston, so that, as late as 1939, efforts were being made to assess the relative merits of different hand systems, and also to estimate what the effect of ploughing would be if it were possible. Table 5 shows the results for this experiment, and since it was on a larger scale, costs can be given. Though the costs of the intensive treatments are quite fantastic from the practical point of view, they are useful indications of the relative intensity of the treatments and the amount of soil disturbance achieved. It is apparent that patch preparation is quite adequate for Scots pine, but rather more intensive treatment is required for Japanese larch if equal growth of the two species is to be maintained in a mixture. The species were in fact in equal proportions in groups of four at a spacing of 4×4 feet, but it may be calculated that had a plantation been made to the following prescription:—

(1) Spacing increased to 4½ feet
(2) Proportion of pine to larch raised to 3:1
(3) Larch planted on pit and mound, pine on patches;

an approximately equal growth of eleven to twelve feet in 15 years for the two species could have been obtained at a preparation cost (in 1939) of seventy shillings per acre. It may be noted here however, that in an earlier costing trial close by, planted by these two methods but without phosphate, the Japanese larch failed while the Scots pine is still semi-checked and only two to eight feet high after twenty years (14.P.35).

Points of Technique

Besides the work on tools and methods of planting, there have been various tests on details of technique; on the season of planting; on the effect of care in handling or maltreatment of the plants at planting; and on the need for weathering or prepared ground before planting.

The first experiment on any heath type was a "season of planting" experiment for Sitka spruce at Inchnacardoch, on a grass-heather slope on leached loams and gravels with small areas of peat in the wetter hollows. Plantings were made monthly from March 1923 to February 1924 and in the relatively high rainfall of over fifty inches losses were low throughout the year, but later on the plants checked on all the heather ground (Inchnacardoch 4.P.23).

Care in Planting. Many steep slopes have been successfully planted by hand on relatively fertile ground at Clashindarroch. Two experiments there attempted to gauge the effect of care in notch planting, and the second also included various degrees of root pruning prior to planting. These experiments were laid out before ploughing became general, and at a time when the losses and rate of beating-up in heath plantations were causing concern. In the first experiment, careful vertical notching was compared with bending of the roots into a 'U'; making the roots 'L' shaped in a shallow notch, as often occurred with mattock planting; and as an extreme treatment, twisting the main roots into a knot. Of the four species planted, Sitka spruce checked, while the remaining three, Scots pine, lodgepole pine and Japanese larch, suffered no losses and show no significant differences in height (Clashindarroch 16.P.34).

The next year a more extensive trial was laid out, in which seedlings and transplants of five species were used. This experiment was rather more successful, in that although there were significant differences in height in only two cases, there was a general tendency for growth to be slightly reduced by maltreatment, accompanied by an increase in losses, which one might expect after such handling. The separate experiments for each species, being of a replicated small plot design, show individually rather erratic results, but the overall picture is clear as presented in Table 6. It is apparent that transplant losses were doubled by bending or light pruning of the roots, and trebled by the most severe pruning. The losses of the seedlings were not so high proportionally to the control, but were more than double those of the transplants; culminating in a loss of fifty per cent with severe pruning. The separate table of losses by species indicates the relative resistance of the pines, and the very heavy losses of Japanese larch and Douglas fir seedlings, and also suggests that, with the exception of this last species, growth of the survivors has been remarkably good.

The outcome of these experiments supports the conclusion that bad lifting, breaking the roots, or their poor placement may be among the causes of death after planting, but the general level of losses in the experiments suggests they do not inevitably cause severe losses, at least of transplants. Other factors such as firming of the plants are likely to be of greater importance; the plants in these experiments were carefully planted as regards setting and firming. There is in addition the seasonal factor which probably over-rides all others and is illustrated by very severe losses in certain years. The problem of finding the cause of losses in planting is, however, not suited to experimental approach, and a form of operational research might be more productive.

At Harwood Dale a single trial, planted by the pit-and-mound method, tested a machine to roll the roots of one-year-old Corsican pine in soil prior to planting; but no reduction of early losses was secured by this system (Harwood Dale 21.P.38). The method was more widely tested on ploughed ground as described in Chapter 5 (p. 69).

Advanced Ground Preparation. At Harwood Dale also two experiments tested the value of advance

TABLE 6: EFFECTS OF BAD PLANTING AND ROOT PRUNING

Heights and losses ten years after planting, for seedlings and transplants of five species, Clashindarroch PT.35/1.

	Seedlings		*Transplants*	
	Feet	%	*Feet*	%
Treatment means for all species:				
Control Roots vertical in notch	5.1	24	6.0	7
Roots bent to L in notch....	4.8	33	5.7	15
Roots bent to U in notch	4.7	32	5.8	12
Main roots pruned to 5″	4.8	38	5.6	12
Main roots pruned to 2″	5.2	40	5.6	14
Main roots to 5″, side roots to ½″	4.9	48	5.2	21
Species means for all treatments:				
Scots pine	5.2	11	4.3	9
Lodgepole pine	6.3	15	7.2	6
European larch	4.5	33	5.8	17
Japanese larch	6.0	55	7.0	18
Douglas fir	3.2	68	3.9	16

TABLE 7: EFFECT OF DRAINING

Results from Teindland Expt. 13, P.26, showing the effect of draining on losses and height growth of Scots pine, and also the water levels in test wells in the 25-year-old crop. See also Fig. 3 and Plate 15.

Drains	*Plants Notched*	*Mean Heights 11 yrs.* *Feet*	*Mean Heights and Losses 22 yrs. Feet (and Percent)*	*Dominant Heights 30 yrs.* *Feet*	*Mean depth of Water Table in Test Wells*† *in inches* 1951	1952
Nil	Direct	1.3	3.5(25)	6.5	10	11
16 feet apart‡ 6 in. deep	Direct	2.2	5.8(11)	15.8	12	12
	On spoil	2.9	7.5(6)			
12 in. deep	Direct	2.8	9.3(12)	23.0 (=Q.C.IV)	21	21
	On spoil	4.4	13.0(3)			

Notes: ‡ Plants are at 4 x 4 feet and between each pair of drains are two lines of plants notched into unbroken heath, and two lines notched on the drainside spoil.

† Five wells were opened in each plot to a depth of two feet. The level of the water below the ground surface was measured every two weeks and a mean taken for the year.

preparation of the hand-prepared patches, lifted turf, or pit-and-mound methods of planting, the object being to allow time for weathering and aeration of the exposed soil. In the first experiment, planting was spread over two years, thus "confounding" season and plants with advance preparation; the second year's planting, in the dry year of 1940, suffered more losses and still lagged in height after four years (Harwood Dale 24.P.39-40). In the second, where planting was simultaneous after (a) preparation a year in advance and (b) preparation immediately before planting, Japanese larch suffered rather more losses and grew more slowly, though not significantly so, where the mounds had been formed in advance (Harwood Dale 25.P.40).

In this experiment also, prepared patches were formed in advance by throwing out the soil and leaving it for a year to weather, refilling the hole just before planting. Here growth was significantly faster, 15 feet after fifteen years as compared to 11½ in controls dug over at the time of planting, but losses were doubled with the advance preparation. This treatment, though successful, savours more of repeated cultivation than normal preparation in advance of planting, and unless mechanised would be far too expensive for use on any scale.

None of the investigations described above have been pursued further in relation to hand methods, but with the great increase in ploughing dating from about 1930-35, several parallel experiments exist on ploughed ground and are described in Chapter 5 following.

Draining

From the start of experimental work at Teindland, drainage was considered necessary in the Findlay's Seat area, but not on the better lower parts of the forest. All but one of the drainage experiments described below are on heavy boulder clays in north-east Scotland; in contrast, in other heath areas the construction of drains to run surface water off the area has hardly been considered. In the event it has been found that, once ploughing became general, only a very small number of drains is necessary even on these heavy soils, and then mainly to take surplus water after heavy rain from focal points in the ploughing to the natural drainage channels. At the time of the initiation of the experiments it appeared, however, that drainage might be a critical factor, since one of the most obvious features of the heaths was the water which lay on the ground surface for many months of the year.

In the first year's work at Teindland an experiment on depth and cost of draining was laid out (13.P.26, Table 7). The soil conditions and root development in this experiment have been described by Yeatman (1955, pp. 32-35 and 62). The drains were in some cases hand-made, and in others opened by a horse-drawn plough and subsoiler prior to bottoming by hand; the drain spacing was sixteen feet throughout, with two effective depths. Scots pine was the indicator species chosen and, while all the plants in the control plots were notched, half the plants in the drained plots were set on the spoil which had been piled on both sides of the drains. A most interesting feature of this experiment has always been the different rates of development between these drainside plants and those remote from the drains. Figure 3 shows clearly the effect of more intensive treatment, as the drainside trees improve enormously with the increased depth which is accompanied by the provision of an increasing volume of spoil for rooting. The trees directly notched in the drained plots are, moreover, superior to those notched in the controls, presumably due to the effects of the drains and of the shelter provided by the taller drainside trees, though again the relative importance of the two cannot be judged. The long-term result of such a system is however clear; a crop of Quality Class III–IV has been produced in place of worthless scrub. One drawback to this method of drainage is that the vast majority of the dominants and thus of the final crop come from the drainside trees, and not, as is desirable, from those midway between drains.

A much older example of this effect is to be seen in parts of Bellton Wood, an eighty-year-old plantation now included in Kilcoy Forest, which must have been planted by the same system as used in this Teindland experiment. Drains at various spacing were used according to the nature of the ground, and in the better parts of the wood a very high proportion of the final crop trees are on the drainsides, while in the poorer and wetter parts of the wood only drainside trees survive. This markedly better development of drainside trees cannot be considered a desirable result in two respects: first, that the development and spacing of the final crop is largely determined from the time of planting, leaving little freedom of action in the handling of the crop; and secondly, one-sided root development is encouraged, leading to instability. It was in fact among the drainside trees of the best plots of the Teindland experiment that the only wind-throws in the Findlay's Seat area occurred in the gale of January 1953; and this was in spite of the fact that trees in other experiments are considerably taller and that the crop in which the windblow took place was well under the critical height of thirty-five feet, below which height crops as a general rule escaped damage in this gale.

A second experiment laid out in the same year was concerned with the distance between drains; spacings of six and twelve feet being used for drains

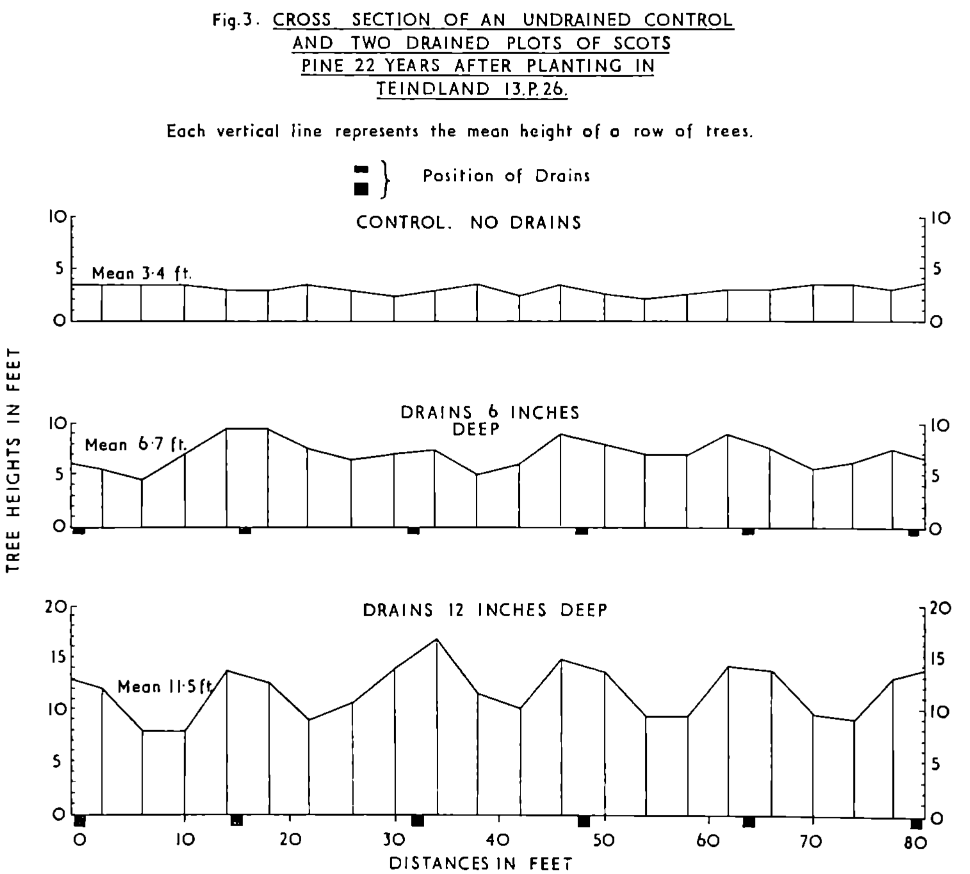

Fig. 3. Drained and Undrained Plots at Teindland. (13.P.26.)

TABLE 8: SOIL WORKING

Dominant heights of four species, 18 years from planting, Teindland 60.P.36 and Glenlivet 1.P.36, using different systems of drainage which involved different intensities of soil disturbance.

Drain spacing:	*Relative Intensity of Working‡*		*Dominant heights in feet*								*Mean level of Water Table at Teindland 1951-52. Inches*	
			Lodgepole pine		*Japanese larch*		*Sitka spruce*		*Oregon alder*			
Wide 30′ *or Close* 9′	30′	9′	30′	9′	30′	9′	30′	9′	30′	9′	30′	9′
Drain depth: Shallow, 6 inch	—	1½	—	12.6	—	10.9	—	6.1	—	5.5	—	10.4
Normal, 1 foot	1	3	14.1	17.7	13.8	18.6	7.2	10.3	5.3	7.6	11.8	13.6
Deep, 3 feet	3	9	16.6	17.1	18.2	19.1	7.9	11.2	7.6	9.9	21.2	†
S.E.			±1.0*		±1.0**		±1.2		±1.0*		—	—
Diff. for sign. 5%			3.2′		3.1′		3.8′		4.1′		—	—

Notes: All plants received one ounce of phosphatic manure.
The results were combined for the two sites, there being two replications at Glenlivet and one at Teindland. Results are so comparable that in only one case, Sitka spruce, was there a significant difference between blocks on the two sites.
‡ The relative intensity has been calculated as an approximation of the quantity of soil shifted per unit area, using normal drains at wide spacing as the standard.
† It was not practicable to site pits in this treatment owing to the quantity of spoil heaped between drains.
* Significant. ** Highly significant.

cut by the horse-drawn plough (Teindland 12.P.26). When the experiment was burnt in 1942, growth of the Scots pine in the more intensively drained plots was double that in those less intensively drained; these latter were superior to the notched control.

In the years that followed these early experiments, "hand draining and mounding" was employed in certain of the more difficult heath forests. McEwan (1930) reports the use of this system as suitable on peat and the poorer heaths, and himself used it on some scale at Teindland, laying out the drains at twenty to thirty chains per acre (a spacing of thirty to twenty feet). But conditions were not so favourable to the system as on the peatlands, where it grew into the well-known "turf planting" system. The special peat draining tools were not all suitable, and the surface peat and soil of the heaths tended to break apart while being spread out from the drains. Thus to produce 'mounds' on a heath was more expensive than to produce 'turfs' on an area with deeper peat. Moreover, ploughing was easier mechanically on the heath with its firmer surface, and consequently the hand work era was shorter, and intensive work was confined to a few forests of north-east Scotland, principally Teindland where however, most of the plantations so formed were burnt in 1942. Thus it is that areas planted by draining and mounding are comparatively rare on the heaths; and although these striking experimental results had been obtained and were apparent from an early date, they were quickly outmoded by later developments.

For some years after the early draining experiments at Teindland, interest centred on ploughing for cultivation rather than for draining. One small draining experiment of similar type to those described at Teindland, was laid out in the Dalby beat of Allerston Forest with the plants notched between drains at two spacings and in an undrained control (Dalby 24.P.33). The soil was very variable, and on sections with rather deeper peat Sitka spruce responded well to closely spaced drains, but on the more typical heath it checked in all treatments. The Scots pine showed considerably better growth in the more intensive plots, but the whole area grew very slowly, as might be expected of notched plants.

In 1936, a set of three experiments was planted in Scotland to re-examine the question of drain depth versus spacing. Two of these experiments, at Teindland and the More Inch section of Glenlivet Forest, Banffshire, the results of which are set out in Table 8, were identical in layout, while the third was a pocket edition sited in a ride in Harriet's Wood, Dornoch Forest, Sutherland, where the crop of pine planted in 1931 had checked badly. These experiments used as indicators, lodgepole pine, Japanese larch, Sitka spruce and Oregon alder, considered at the time to be the most promising of their respective genera under extreme conditions. The treatments employed in the two identical trials were a minimal preparation as a control, using turf mounds from shallow furrows at a spacing of nine feet, and four draining treatments with "normal" (one foot deep) drains and three feet "deep" drains at spacings of nine and thirty feet. In all cases enough spoil was spread to make planting mounds, the rest being piled at the drainsides as convenient. With the deep drains at close spacing this resulted in a continuous layer of spoil almost a foot deep being spread between the drains. The normal drains were cut through the peat well into the leached layer for most of their length, often running just above the pan, which has in time become weathered; the deep drains were cut well into the subsoil throughout their length. At Glenlivet there are occasional patches of deeper peat where the normal drains were confined to the peat.

At Dornoch the draining treatments were reduced to one spacing for each depth, but there was in addition an absolute "control" of notched plants. The application of phosphate was omitted through an oversight, and (probably as a result) many deaths occurred. The number of trees remaining is so small that it cannot provide reliable figures comparable to those from the other trials. It has however been assessed in an exactly similar manner, and since this experiment and the surrounding plantations were investigated in some detail by Yeatman (1955, pp. 40-44 and 67-71), the growth results are given in Table 9. This is the only experiment at Dornoch and is sited on the poorest part of the forest; Yeatman found conditions very similar to those at Findlay's Seat, and the experiment has given comparable results to the draining experiments there. The figures show an interesting range of response to the treatments, lodgepole pine being the least sensitive species, followed by the Japanese larch, Oregon alder and Sitka spruce. The fact that individual alders are now the tallest trees in the area is remarkable. As a result of the growth observed in this experiment, the surrounding blank areas have been replanted.

In Table 8 the treatments have been calibrated for approximate intensity of working, assuming that if the depth of drains is doubled or their spacing is halved, the effect is the same. One-foot-deep drains at thirty feet spacing are used as the standard; this was about the intensity of draining used in practice in Teindland at this time. Records of the level of the water table, measured in open pits midway between the drains, were maintained in the Teindland experiment in 1951-52 in order to obtain some idea of the effect of the treatments. Consideration of the figures for relative intensity of working, water table level, and height growth, raises the problem of whether the operative factor was in fact drainage, or the cultivation effect of disrupting peat and pan and providing aerated spoil for rooting.

The growth figures show a significant difference between the two least intensive treatments and the three most intensive for three of the species, the exception being Sitka spruce. It would appear that for lodgepole pine and Japanese larch, normal drains at close spacing provided optimum conditions, there being no further increase in growth with greater intensity; but that for Sitka spruce and Oregon alder the optimum has not been reached in the range covered. It is evident however, that the great decrease in water level obtained with deep draining brings no corresponding increase in growth. On the other hand, taking the two systems which give equal 'intensity of working', namely normal drains at nine feet and deep drains at thirty feet, one finds growth even, again with the exception of Sitka spruce. These correlations strongly suggest that it is the amount of soil disturbance rather than the actual removal of water by draining which is operating here. This statement may be qualified by observing that this may not be true at relatively low intensities of working, since the normal drains at wide spacing

TABLE 9: DRAINAGE EXPERIMENT AT DORNOCH

Results from Dornoch 1.P.36. Dominant heights twenty years after planting. Feet

Draining Treatment	*Relative Intensity*	*Lodgepole pine*	*Japanese larch*	*Oregon alder*	*Sitka spruce (Mixed with the other species)*
Notched (control)	0	13	Failed	(10)	Failed or checked
Shallow at 8 ft.	1½	15	(9)	(7)	
Normal at 16 ft.	1½	18	16	13	
Deep at 16 ft.	6	22	23	25	20

Notes: No phosphate applied.
The plots are so small that the above figures represent the means of only 3—6 trees, (9 for Sitka spruce).
Figures bracketed above show treatments in which a crop will not be formed, owing to heavy losses.

are better, though not significantly so, than the shallow close drains which are at about the same intensity. This may be because the shallow drains did not reach the mineral soil over much of their length, being largely confined to the peat. This result is confirmed from Dornoch, where again normal drains at a wider spacing are superior to shallow drains at close spacing.

At Glenlivet and Teindland it appears that Sitka spruce has responded to closeness of draining more than depth, though none of the differences are significant. This difference in behaviour is probably due to the inability of this species to compete with heather. A further point is that these experiments are of inadequate size to show the long-term effects of deep draining. It is possible that the effect of this treatment would not be apparent at the heights which the trees have so far attained, while at a later stage the depth of rooting might control growth. This factor might be expected to operate on heaths with a gleyed podsol, such as Dornoch and Teindland, or those borderline heaths where the rainfall is unusually heavy.

One other experiment gives some evidence on this question of drainage on the gley podsols. An area at Findlay's Seat was prepared for the planting of spaced groups by digging over patches seven feet square with a spade (Teindland 36.P.29). Four years later three-quarters of the area was drained by a ramifying system of drains, perhaps a foot deep and twenty to thirty feet apart; these drains running between the groups, gave little extra spoil to the trees. Nevertheless, when the experiment was accidentally burnt ten years later the pines in the drained sections averaged 9 feet, compared with 7½ in the control. Neither the hand-dug patches nor the drains are likely to have broken the pan here, and it is possible that it is where the pan is not broken that lateral drainage is necessary. In general, however, once ploughing to alleviate the surface conditions and cause a certain amount of soil disturbance became general practice, it has not been found necessary to lay out drainage systems as in the days of hand work. In the series of draining experiments described, now that the tree cover is closed, the drain bottoms are covered with needle litter and run water only in exceptional circumstances, and this is also true of much of the extensive drainage system put in at Harwood Dale during the period when it was impossible to plough.

Chapter 5

PLOUGHING

The history of the development of ploughing practice in the Forestry Commission is a complicated story, and almost amounts to a history of the afforestation of the upland heaths, so great has been the influence of ground preparation on silvicultural technique. Progress was inevitably irregular, owing to the period of time which must elapse before results from a given trial become available, and because planting was being steadily extended on the heaths all the time, so that promising methods were adopted in practice while the results from intensive trials were awaited. Decisive steps forward were taken either when results became apparent in earlier experiments, when improved machinery was developed, or when more effective tractors appeared on the market.

The trials may be divided into two types, the mechanical, in which the capabilities of tractors or machines were investigated, and the silvicultural, which followed up the success of any given machine in achieving cultivation, by planting up the areas with a variety of species, often with the addition of fertilizer. Stages may be distinguished in ploughing practice corresponding to increases in the depths of cultivation. These stages are relative, in that they are not all present in all areas and that as each outfit—tractor and plough—moved on to more difficult ground the depth of cultivation achieved tended to fall. Over the whole range of the heath forests, planting has gradually extended on to ever more difficult ground so that the equipment required has of necessity become more powerful and increasingly heavy.

The first of four main phases may be defined as that of shallow ploughing using wheeled tractors or horses, and strengthened agricultural ploughs; the depth achieved rarely exceeded six inches. These equipments were used only for experiments in each of the main heath areas, and on a limited field scale in Allerston Forest.

In the second stage early crawler tractors were employed to pull strengthened or re-designed ploughs based on the strongest agricultural models available. With these outfits ploughing became the rule in the heathland forests, using a system of ploughing single furrows spaced at the desired planting distance, and working to depths of rather less than one foot; this is termed moderately deep ploughing.

Breakages with these equipments were at times serious, and the trend towards ploughing ever more difficult ground led to the design of forest ploughs which would on the worst ground maintain the desired depth of one foot, while on easier ground they would achieve considerably more.

This third phase of deep ploughing with single furrow ploughs lasted some ten years, during which large acreages were ploughed, but in recent years this form of ploughing has to an increasing extent been replaced by tine ploughing. This method involves a return to a shallower-going plough body but this is built on to a very robust subsoiler or tine to give as great a depth of cultivation as with the deep ploughs. Subsoiling had earlier been pioneered in experiments, and was used on a field scale at Allerston for some years before the phase of deep ploughing.

The sections which follow trace these stages, and record the experimental results which have accrued to date from the trials laid out on various types of ploughing. The terms used need some definition. Ploughing of one furrow for each line of trees is referred to as "single-furrow ploughing," ploughing of two or three furrows per line of trees, as "double-furrow" or "triple-furrow" ploughing, while continuous ploughing, as of a field, is termed "complete ploughing".

The early strengthened agricultural ploughs, built for complete ploughing with the land wheel and furrow wheel working at different levels, had considerable difficulty in carrying out single-furrow ploughing, as it is only when cutting the second or even the third furrow that they attain their normal working depth. The later forest ploughs were designed for single-furrow work with wheels of equal size, both running on the unbroken surface between furrows; these types have in certain cases been modified for complete ploughing where this method was used in experiments. Figure 4 sets out the range of ploughing methods used and the nomenclature employed in this work.

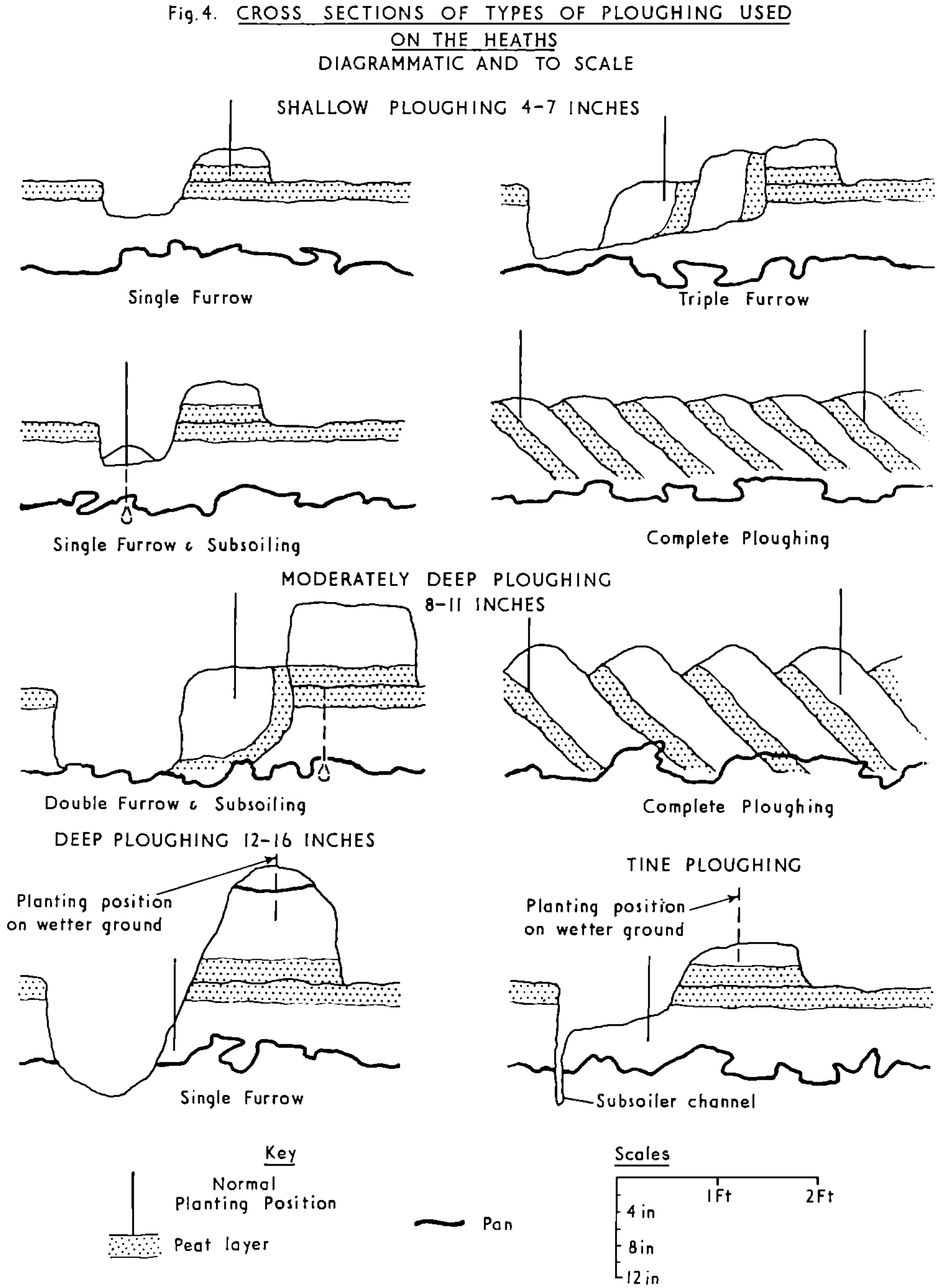

Fig. 4. Types of Ploughing used on the Heaths.

PLOUGHING TRIALS

The Early Trials: Shallow ploughing (4-7 inches)

Once afforestation of the heathlands commenced, ploughing was an obvious line of approach, since the successful breaking-in of better quality heather moors had been a feature of agriculture in the eighteenth and early nineteenth centuries. During that period there was occasionally an excursion into ploughing as in the case recorded on Dalby Moor, on a site now included in Allerston Forest (see p. 14). Within a few miles of the site of this pioneer work by Joseph Bradley, the first Forestry Commission ploughing on heaths took place in 1922, when a considerable area of moor was ploughed and planted with Sitka spruce. The equipment used was very light, a Fordson wheeled tractor and agricultural type plough with a small subsoiling attachment. All the spruce checked within a few years and the area had ultimately to be replanted.

In 1924 the same or similar equipment was used to prepare the ground for the first experiment on typical heathland, a trial of species on ploughed ground (Staindale 1.P.24). The area had been burnt over, but even so the plough did no more than skim off the three-inch layer of wet peat, while the subsoiler stirred the top few inches of the leached sandy A horizon, rarely if ever touching the pan. A number of species were planted, but the experiment as a whole was unsuccessful, so that some years later the greater part was abandoned and reploughed using stronger tackle. This replanting was successful.

In Scotland the first experiment on ploughing for the purpose of cultivation, rather than as a means of cutting drains, was carried out in 1927-28 at Findlay's Seat, using three horses drawing an agricultural plough, which penetrated four to six inches, turning over the surface peat and part of the leached layer (Teindland 23.P.28). This experiment would possibly have suffered a similar fate to that at Staindale but for the fact that a heavy dressing of basic slag was applied. Three intensities of shallow ploughing were compared, and in the early years there was an overall slight improvement on the more intensive complete ploughing, as compared with double-furrow ploughing. Three-quarters of the experiment was burnt in 1942 and the single block remaining is regarded as a species and manuring trial and results are given in Figure 9 (p. 88).

Once it had been shown that, given suitable tackle, the heaths could be ploughed, the next phase was to lay out experiments to compare growth after ploughing at different intensities with that following planting by hand methods. The most comprehensive experiment on these lines was laid out at Wykeham in 1928, to compare notching, hand preparation of patches, shattering of the pan by explosives, and three intensities of shallow ploughing (Wykeham 6.P.28). The ploughing was carried out by a twenty-five horsepower International tractor drawing a double-furrow plough from which one share and all the wheels had been removed! With a disc coulter and the remaining share in operation, single-furrows reached a depth of four to five inches, but with triple-furrows penetration improved in the second and third furrows, so that a maximum of six to eight inches was achieved. Complete ploughing attained this depth over much of the area, and the iron pan was broken over considerable patches, where it chanced to be within this distance from the surface; the pan here was rather shallower than is usual at Allerston. The results of this experiment have been striking and the position after twenty years is presented in Figure 5. The result of almost every combination of the treatments is of value in considering the effect of intensity of preparation on the growth of the different species. It is worth noting that the plot size is small, and thus where the trees survived the early years, the preparation treatments have undoubtedly interacted and in all probability reduced the height range between the extremes. In addition, in the so-called pure spruce plots there is clear evidence that the species have also interacted, and this is also likely to be true of other species, though it is impossible to estimate to what extent.

The diagram shows that the pines were least sensitive to ground preparation, but even so there is a thirty to forty percent improvement between the extreme treatments, with the probability that this is a conservative estimate owing to interaction. Corsican pine, in common with Japanese larch but not with Scots pine, indicates that the patch preparation by hand was a superior method to the single-furrow ploughing. While the pines survived after the initial beating-up and ultimately grew in all treatments, Japanese larch died out within a few years where water-logging took place on the unploughed ground and on the single-furrow ploughing, though the small number which survived on the prepared patches have grown well. In contrast the larch has outgrown the pines in the two most intensive treatments, the complete ploughing and that part of the three-furrow ploughing where slag was applied. Sitka spruce checked and died out slowly on the unploughed ground, but on the three-furrow and complete ploughing it survived to be nursed into growth later by the adjacent pines and larch. The diagram also indicates the mean heights at ten years, and the results show close correlation with those obtained at twice that age, suggesting that while interaction may have reduced the scale of the treatment differences, the relative positions have not been unduly affected.

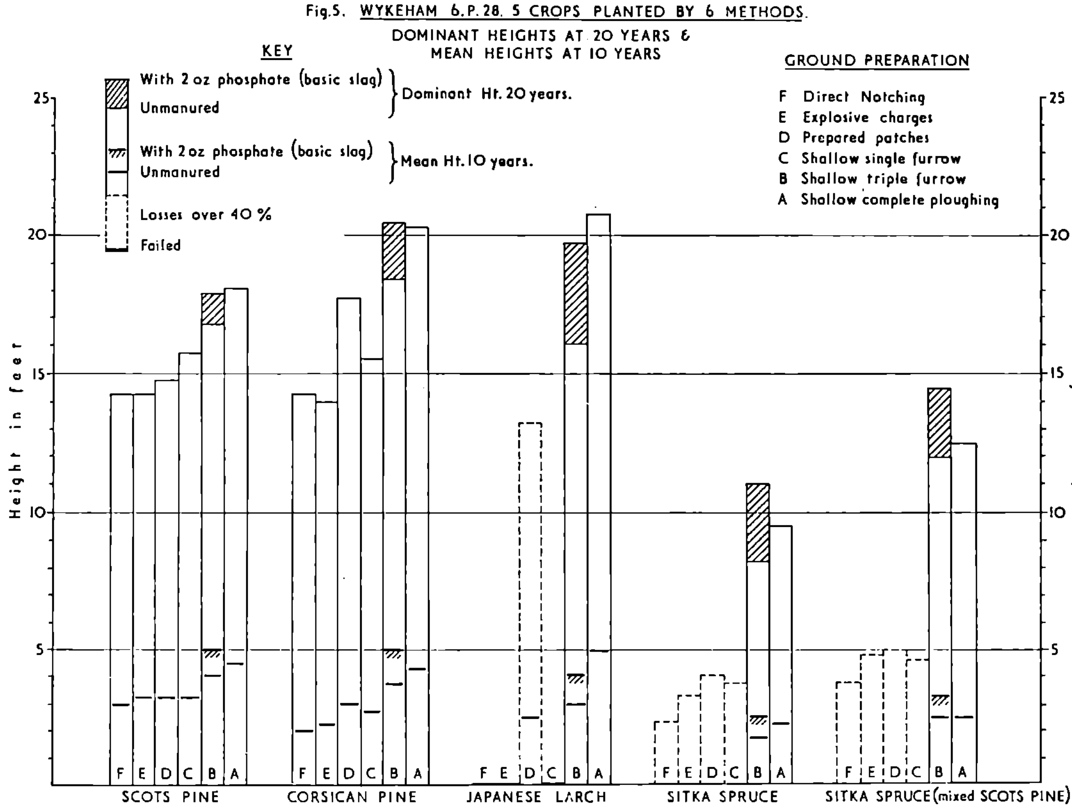

Fig. 5. Five Crops Planted by Six Methods at Wykeham. (6.P.28.)

Rooting conditions in this experiment were investigated in some detail by Yeatman (1955, p. 21-31 and 51-61), who found that rooting is largely confined to areas of soil disturbance, particularly in the case of Japanese larch. On the prepared patches the main roots of this species are superficial, running in the surface peat, even the fine roots being confined to the top two or three inches of the A horizon. After complete ploughing, the roots penetrated freely to the pan, here lying about six to eight inches deep. In contrast Scots pine exploited the soil down to the pan, even where planted on prepared patches. The results in terms of growth are thus directly correlated with the observed differences in rooting.

The immediate result of the successful completion of the ploughing in this experiment was that, from 1930, planting on the main stretch of the plateau moorland at Allerston (Staindale, Dalby and Wykeham) was confined to ploughed ground, and a considerable area was ploughed at Wykeham for planting in 1929-30, using this shallow ploughing equipment. It was decided to use the three-furrow method as a compromise between the maximum possible disturbance and economy, and the experiment just described has since proved the wisdom of this choice. It was recorded at the time that this ploughing was not as satisfactory as in the small-scale experiment. A species trial planted on part of this triple-furrow ploughed area provides an interesting comparison with a similar trial planted the previous year on mattock-prepared patches (Wykeham 2 P.28 and 9 P.29). The long term results, given in Table 37 (p. 86), have been combined since there is now no appreciable benefit from this mechanical preparation method. The relatively low intensity of ground preparation achieved is emphasised by the failure of Japanese larch on both the shallow ploughing and on the hand-prepared patches. At about this period a certain amount of ploughing was let out on contract, and a considerable area was ploughed by steam tackle in Staindale. On the whole however contract ploughing was unsatisfactory, since the ground was too difficult to be an acceptable proposition to the firms concerned, nor was their equipment sufficiently robust.

In Scotland meanwhile two successively stronger horse-drawn ploughs were developed and employed in experiments from 1929-31 on a number of heathland areas with considerable success, though they failed on areas with more than three or four inches of peat. In several places comparisons were made between hand methods and ploughing, the most extensive trials being at Clashindarroch (6 and 7, P.31-33). The results of three such experiments are presented in Table 10. Growth was very slow at first in all these experiments. At Inchnacardoch and Clashindarroch this was probably due to the absence of phosphate, while at Teindland very small transplants were used and establishment was particularly slow. Nevertheless the growth in the ploughed plots was, at an early date, clearly better than any obtained previously, and average shoot lengths were generally double those in the controls.

Shallow ploughing is the only system of ground preparation for which examples are available from the majority of the experimental areas, bearing crops of a sufficient age to reflect the influence of the site factors. Top heights from plots of a minimum area of one-tenth acre have been presented in Tables 36 and 37 (pages 85 and 86) and discussed in Chapter 6 (p. 63). At Wykeham stronger tackle was, within a year or two, used for ploughing to greater depths; but at Teindland three-furrow or complete shallow ploughing was undertaken from time to time for experiments until 1936. The peaty hollows and the compactness of the soil made the work too slow and expensive for the use of this gear on a field scale, and the initial planting of the forest, as opposed to the experimental area, was completed in 1939 using hand methods of preparation. There was in fact no large-scale use of ploughs on the Scottish heaths until 1937, when the results from the next series of experiments at Allerston were becoming clear.

Moderately Deep Ploughing (8-11 inches)

In 1930 an important field trial had been carried out in Staindale in the Allerston district; a Caterpillar 'Twenty' tractor was used to draw a series of Ransome tools, a double-furrow ("Deeptrac") a single-furrow ("Unitrac") and a disc plough, and also a subsoiler ("Killifer"). Very full records of vegetation, soil conditions and performance were maintained, and from them the subsequent experiments were designed (Guillebaud and Steven, 1930). Satisfactory operation was obtained with the subsoiler set at about fifteen inches deep, and its passage through the soil was found to make the subsequent ploughing much easier. The disc plough was found unsuitable, but with the single and double-furrow ploughs depths were obtained of nine to ten inches and twelve inches respectively. Observation showed that only the subsoiler broke the pan, and that it caused considerable shattering, leaving behind a continuous channel up to four inches in diameter. Shortly after this trial, observation on the 1928 experiment, then "three seasons planted", showed clearly that single-furrow shallow ploughing was not enough, and that more intensive work was essential for quick establishment.

On this basis the next ploughing experiment at Wykeham was designed to use deeper double-furrow ploughing as the control, and this was achieved with an Oliver two-furrow plough (Wykeham 11.P.31). The depth of ploughing achieved, some eight to eleven inches, is subsequently referred to as 'moderately deep' to distinguish it from the later phase

TABLE 10: GROUND PREPARATION

Early results from experiments comparing hand-planted plots and those shallow ploughed by the three-horse experimental ploughs in 1929-31.

Initial losses shown where they exceed 5%.

Mean Heights in feet; losses per cent.

	Age Yrs.	*Species*	*Handwork*	*Ploughed*
Teindland 41.P.29			Mounds	3 furrow or 10 ft. wide strips
Control	5	P.C.	0.9	0.8
+2 ozs. basic slag		P.C.	1.4	1.8
Inchnacardoch 81 & 82.P.31			Notched	10 ft. wide ploughed strips
Planted (without phosphate) two years	7	S.P.	1.6 (20%)	1.9 (13%)
after ploughing		P.C.	1.0	1.5
		J.L.	2.6 (10%)	3.1 (29%)
Clashindarroch 6.P.33			Notched	Complete ploughing
Planted (without phosphate) two years	5	P.C.	1.5	2.4
after ploughing		J.L.	1.2 (16%)	2.8
		S.S.	0.5	0.9

Note: P.C. = Lodgepole pine. S.P. = Scots pine. J.L. = Japanese larch. S.S. = Sitka spruce.

TABLE 11: INTENSITY OF PLOUGHING

Mean Heights at 10 years from planting in the three major ploughing experiments at Allerston.

Feet

Experiment and Ploughing Type	*Scots pine*	*Corsican pine*	*Lodgepole pine*	*Japanese larch*	*Sitka spruce*
Shallow. Wykeham 6.P.28					
Triple furrow	3.9	3.8	—	2.9	1.8
+2 oz. phosphate	4.9	5.1	—	4.0	2.6
Complete	4.6	4.2	—	4.9	2.2
—	—	—	—	—	—
Moderately Deep. Wykeham 11.P.31					
Double furrow	(6.0)	(8.7)	6.9	5.2	2.1
+2 oz. phosphate	—	—	8.4	8.8	3.0
2 furrow+subsoiling	—	—	7.2	6.9	1.9
+2 oz. phosphate	—	—	8.6	11.3	3.7
Complete	—	—	9.2	9.5	3.9
+2 oz. phosphate	—	—	9.6	13.2	4.6
Deep. Broxa 8 and 9.P.43					
Single Furrow	—	—	—	—	—
with 1 oz. phosphate	8.9	6.3	—	7.2	4.3
Complete	—	—	—	—	—
with 1 oz. phosphate	8.6	8.1	—	10.7	5.5

Notes: Figures in brackets are from experiments 12.P.31 and 16.P.31 on the same ploughing type immediately adjoining the ploughing experiment. Figures for all the deep ploughing experiments are by interpolation between successive assessments.

The difference in the phosphate dose, 2 oz. at Wykeham and 1 oz. at Broxa, is confounded with the other differences which may exist between the sites.

of deep ploughing. Two treatments giving more intensive cultivation were included in the experiment, double-furrow ploughing after subsoiling with the Killifer subsoiler, and complete ploughing; the subsoiler worked here at a depth of from twelve to sixteen inches. The rooting conditions obtained are described by Yeatman (1955), this being one of the main types of ground preparation which he investigated. The ploughing was very successful, early growth in the double furrows, the least intensive method, being better than on the complete shallow ploughing. Since the double-furrow ploughing required one run of the tractor per line of trees whereas the shallow complete required four or five, it is apparent that the method represented a great advance in technique. The results of the two Wykeham ploughing experiments ten years after planting are compared in Table 11. Only two species were common to both experiments, Japanese larch and Sitka spruce, the species showing fastest and slowest growth respectively. The progression from shallow triple-furrows to moderately deep complete ploughing led to a trebling of the height of the larch after ten years, while the addition of phosphate added a further thirty percent regardless of ploughing treatment. The response of Sitka spruce, though much less, was still striking. There is a suggestion from the results of nearby experiments, and from the behaviour of the lodgepole within the second experiment, that Scots and Corsican pines would continue to respond to the increased intensity of working. It should be noted however that the overall increase in height was fifty percent for the lodgepole pine compared to one-hundred-and-fifty percent for Japanese larch, so that the response of the latter species has been three times as great.

The results of this experiment are shown in greater detail in Figure 6, which brings out a number of points of interest. Heights are given for three ages, each the mean of the results from the two years of planting. In the first two cases mean heights are given, in the third dominant height was used, as by then some plots had been thinned. As regards ploughing it is clear that at first the complete ploughing led, and the double-furrow was poorest, for all five species, whether phosphate was applied or not. A major change took place however between the twelfth and eighteenth years and the double-furrow ploughing with subsoiling took the lead for four species out of five, the exception being Sitka spruce. It had long been known that subsoiling was the only treatment whereby the pan was broken over the major part of the plots, and it had also been observed from soil pits that the subsoiler channels were still in existence; Yeatman has shown convincingly that the roots were in fact exploiting the opening up of the subsoil by these channels. These results provide the only evidence, as yet, of the effectiveness of subsoiling, a matter of great importance in recent years with the development of the tine ploughs described below.

The behaviour of the different species on the various methods is also of interest. Lodgepole pine and Japanese larch have grown faster than in almost any other experiment on the heaths. The European larch is of a poor provenance but some individuals are now growing well, a fact brought out by the change to dominant heights in the third assessment. The birch is also of poor type though it grew rapidly at first. Sitka spruce checked after the first few years but recovered rapidly when nursing by the adjacent species started; in contrast to all other species it is still tallest on the complete ploughing. This is probably due to the more complete suppression of the heather achieved in this treatment, and to the greater opportunity given by complete ploughing for root exploitation under the canopy of other species. This experiment is an outstanding example of species interaction and nursing as is discussed in Chapter 9 (p. 118).

Figure 6 also makes clear the very great effect of phosphate, even with intensive ploughing, but the apparent lessening of the difference in the latest assessment, particularly with lodgepole pine and Japanese larch, is probably mainly due to interaction, since the control and manured plots are only eight plants square. While the ploughed strips are twice this width, about twenty-five yards across, it is doubtful even here if later assessments, which have shown very even results for all treatments, truly reflect the results which would have been obtained with larger units.

The success of this deeper ploughing was in no doubt from an early date. As little as three years

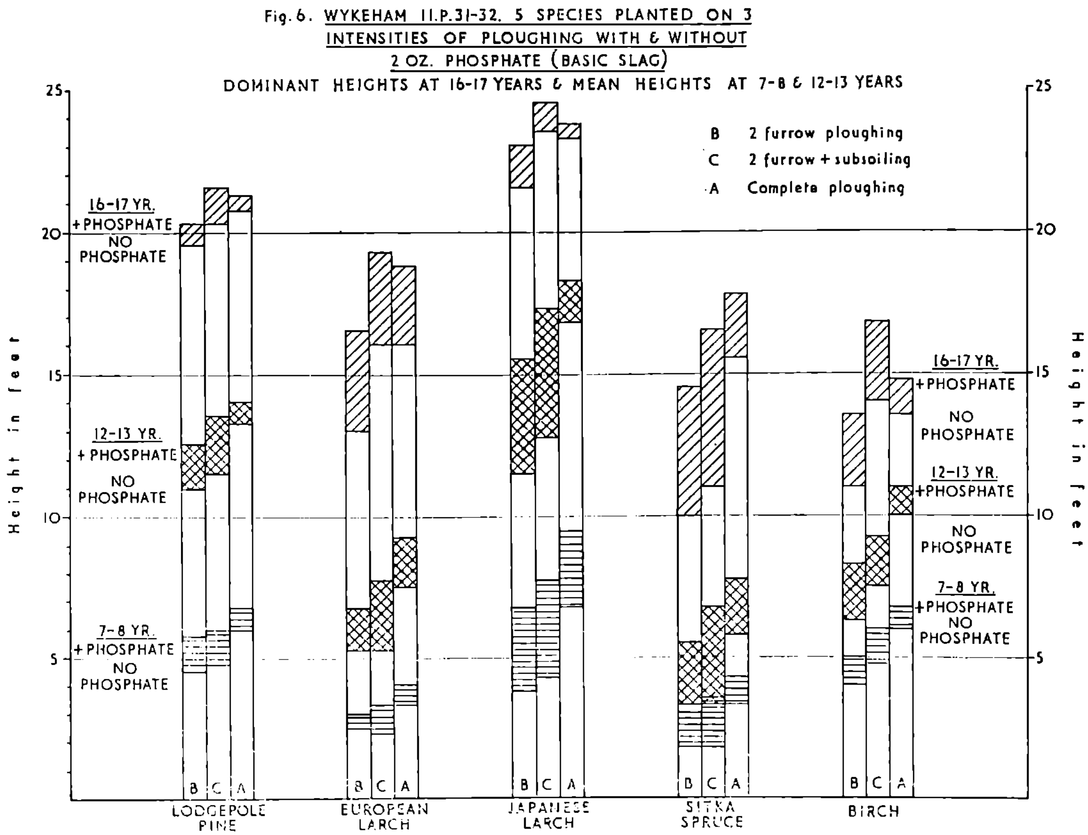

Fig. 6. Five Species. Three intensities of ploughing, with and without Basic Slag at Wykeham. (11.P.31-32).

from planting the progress of this experiment compared favourably with that of the earlier shallow-ploughed areas. Virtually all the subsequent experiments at Wykeham were planted on double-furrow or complete-ploughed land worked with the Oliver plough. A double-share tool was however found to be unsuitable for the majority of the heath areas, where there is more stone, and particularly boulders, of larger size than are found generally at Wykeham. For this reason the ploughs ordered in 1937 for use in the north were modified for single-furrow working, the furrows being spaced at about five feet. The effects of the introduction of large-scale ploughing in north-east Scotland were considerable, as may be illustrated from the Black Isle.

Planting had been proceeding slowly in Findon Forest, where 1,200 acres were planted from 1927-37, at about 100 acres per annum, using hand methods of ground preparation. Establishment and early growth were very slow indeed, many areas of Scots pine not having formed canopy after twenty years. Millbuie Forest nearby was acquired in 1937, when it became apparent at Wykeham that ploughing would radically increase the early growth rate of many species of conifers. A brief trial of a double-furrow plough was unsuccessful, and a Ransome Unitrac Major was then tested. After a good deal of strengthening and some modification, it did satisfactory work, and improved models, the Solotrac and Haddington, followed within a few years. For ten years extensive programmes were carried out with these ploughs, Millbuie averaging 440 acres per annum from 1938-1950, with a peak programme of over 700 acres in 1941. With the Haddington, a form specially designed for single-furrow work, depths of about a foot were achieved, but it could not attain this depth regularly on the harder heaths, and from about 1946 onwards it was gradually replaced by the stronger ploughs, the development of which is considered below. Ploughing of upland heath had by 1940 become the rule, and areas of the poorest types of ground which could not be ploughed were omitted as "unplantable".

Meanwhile at Allerston affairs had taken a rather different turn. Though the Oliver double-furrow plough had done good work in the 1931 experiments, and on a considerable acreage of moor in the surrounding forests, not all the ploughing was so successful, particularly in certain areas at Staindale which were much more stony, and where owing to poor ploughing, establishment was slow. A method of ploughing was therefore developed using the Killifer subsoiler and a single-furrow plough in tandem, to produce shallow single-furrow ploughing with subsoiling; the power of the tractor not being sufficient to pull the subsoiler and a deep-going plough at one time. This method proved fairly successful; the subsoiler reached a depth of over a foot and the pan was regularly broken. Between 1938 and 1942 this outfit was used at Hamsterley and Allerston forests, including experiments at the former, and also in the Wykeham and Broxa experiments. At Hamsterley this type of ploughing was compared with hand-work in an experiment with a demonstration type layout. Ground variation has made interpretations of results rather difficult and the experiment, now fifteen years old, adds no additional information (Hamsterley 9.P.39). The method was not critically compared with other ploughing methods until 1943, when it was tried at Broxa alongside the deep-going R.L.R. plough which superseded it at about this time.

Deep Ploughing (12 to 16 inches)

In 1942 a Massey-Harris Grub-breaker plough was tested at Langdale Forest, Yorks.; though not adapted for single-furrow ploughing, it was stronger than any previous plough, and when used for double-furrow ploughing, the second furrow cut was eighteen inches wide and up to sixteen inches deep. This trial led directly to the designing of the first R.L.R. plough built by Messrs. Russell's of Kirbymoorside, Yorks., to carry out single-furrow ploughing to a depth of fourteen to sixteen inches, with the object of breaking the pan and forming a large pile of spoil for planting. The plough was named after Sir Roy Lister Robinson, later Lord Robinson, then Chairman of the Forestry Commission, and its introduction made necessary the use of forty-horse-power tracked tractors. The prototype plough was tested in an extensive ploughing trial at Broxa; Langdale Forest, on a site closely comparable to the experimental reserve at Wykeham, which was by this time fully planted. This was the first occasion on which different ploughs were used to produce the various ploughing treatments in an experiment (Broxa 8 and 9.P.43). The full range of methods used was as follows:—

(F.) Notch planting as a demonstration control.

(A.) Shallow single-furrow ploughing with subsoiling, carried out by drawing the Killifer subsoiler in front of the Oliver plough with one share in position.

(D.) Shallow double-furrow ploughing and subsoiling carried out in two operations with the Oliver plough carrying two shares followed by the subsoiler. The lesser depth attained with this method as compared to that in the Wykeham experiments was due to the reduced efficiency of the equipment, which was by then ten years old and almost worn out.

(B.) Deep single-furrow ploughing, carried out with the prototype R.L.R.

(E.) Subsoiling with the Killifer subsoiler followed by single-furrow ploughing with the R.L.R., so arranged that the subsoiler channel lay beneath the plough ridge.

(C.) Deep complete ploughing, carried out with the R.L.R. plough after adjustment.

These six treatments have been arranged in estimated order of increasing soil disturbance and the results to date are summarised in Figure 7, which shows to a certain extent increases in growth with the estimated intensity, though this trend is obscured in parts of the experiment by the levelling effects of other treatments such as the inter-sowing with broom. There are obvious differences in the results from the ploughings at the north and south ends of the experiments, as demonstrated by the two sets of plots of pure Sitka spruce, and also anomalous results such as the relatively poor growth of the larch on the deep single-furrow ploughing. Owing to the systematic layout used the results cannot be analysed, but since the plots are large the long-term results will be of great value as compared to all previous experiments where the strips of ploughing were narrow. These experiments are considered further in connection with the nursing of Sitka spruce, for the growth of this species over the many acres of these experiments far exceeds that obtained in earlier trials.

In a third experiment laid out in the same year, an intensive comparison of the R.L.R. single-furrow ploughing, and the shallow single-furrow plus subsoiling, was made, using five alternating strips of the two ploughings; in general the difference is surprisingly little. On account of its robust construction however the R.L.R. plough rapidly superseded all other ploughs in the Allerston district, though the Solotrac was also used in Scotland.

A trial of somewhat similar design to those at Broxa was undertaken in 1947 at Teindland, but broom was not used and the species employed were mountain, Scots and lodgepole pines, and hybrid larch, as nurses for Sitka spruce. For all species,

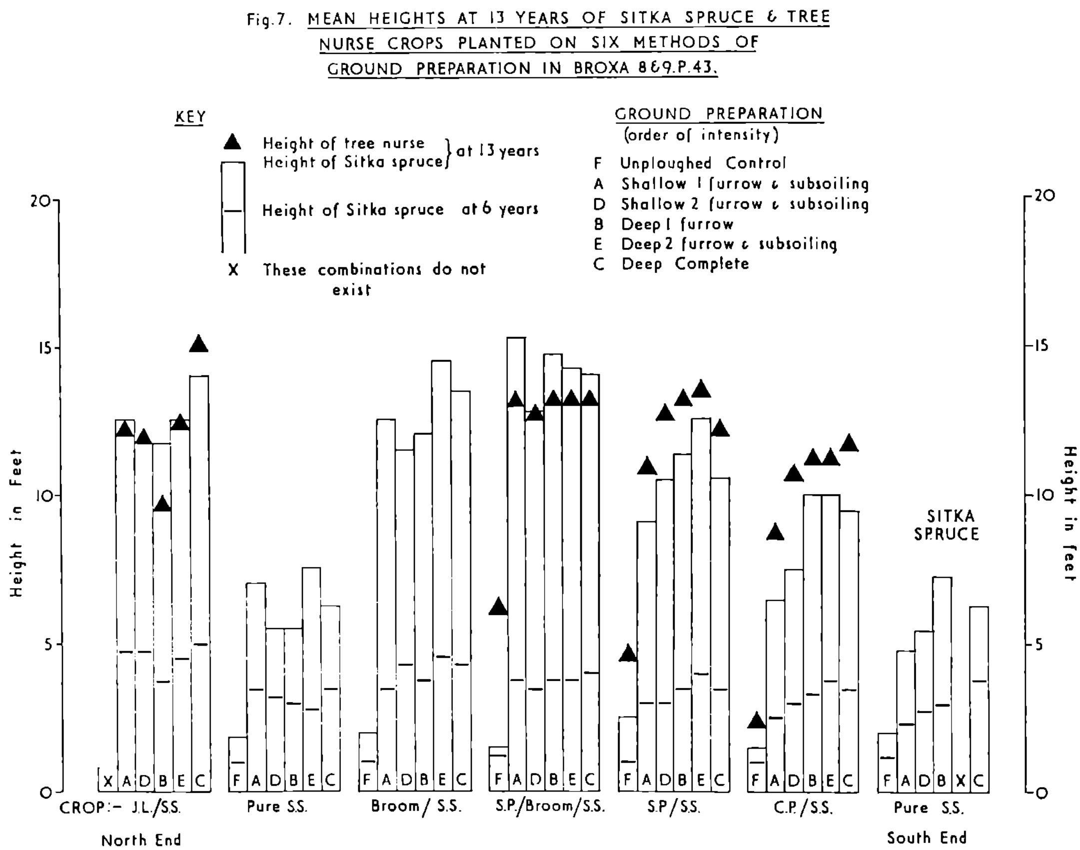

Fig. 7. Sitka spruce and Nurse Crops on Six Methods of Ground Preparation at Broxa. (8 and 9.P.43.)

TABLE 12: INTENSITY OF PLOUGHING

Mean heights of Scots pine and Sitka spruce 10 years after planting in the 1946-47 series of experiments, as compared with those from Broxa 8.P.43.

Feet

Ploughing treatments and species	*Millbuie* 11.*P*.46	*Clashindarroch* 36.*P* 47	*Fetteresso* 1 *P*.46	*Mean of* 3 *sites*†	*Broxa* 8.*P*.43
Deep 1-furrow (control)					
Scots pine	4.5	3.8	5.0	4.56	(8.9)
Sitka spruce	1.3	4.3	3.2 (3.7)	2.8	(4.3)
Deep Complete Scots pine	5.5	4.1	6.0	5.42	(8.6)
Deep Complete Sitka spruce	2.4	5.1	5.5 (5.4)	4.1	(5.5)
Shallow complete Scots pine	5.3	4.1	5.2	5.05	—
Shallow complete Sitka spruce	2.3	4.8	4.2 (4.6)	3.6	—
Standard error				±0.19* ±0.21**	
Difference for significance at 5%				0.61 0.69	

Notes: † There were two replications at Millbuie and Fetteresso and one at Clashindarroch.
() Figures in brackets indicate where phosphate was applied at 1–1½ ozs. per plant. A top dressing applied to the major part of the Millbuie trial in 1951 has had a negligible effect.

early results reflect the intensity of ploughing, but the nurses have not so far influenced the growth of Sitka spruce. Growth here is slower than at Broxa, so that it will be some years before results of interest accrue (Teindland 69.P.48).

These experiments are related to a series of extensive trials carried out by Conservancies in Scotland in 1946-47, using methods of ploughing which were feasible on a field scale, viz. single and complete deep-ploughing, compared with complete shallow-ploughing, the areas being planted with a mixture of Scots pine and Sitka spruce. Results are given in Table 12 and show quite clearly that, of the three methods used, deep single-furrow is always the least effective and deep complete the most effective, with shallow complete ploughing intermediate. This last treatment was carried out in two of these experiments with a Massey-Harris Prairiebuster, which cut a furrow six to eight inches deep and up to two feet wide; and in the third experiment with an R.L.R. set to work at a depth of six inches. Economically however, the deep single-furrow, cut with the R.L.R. or Solotrac, remained the most satisfactory; except that this method was found to be inadequate on many sites for raising Sitka spruce in mixture with pine, since the spruce checked and was outgrown by the pine in the early years. The experiment at Fetteresso shows that on relatively good sites the spruce will hold its own when given more intensive ground preparation. Phosphate was given only at this site, and it is noteworthy that the beneficial effect on the spruce, small in the control, is lost in the most intensive treatment, namely deep complete ploughing. In exposure and at a higher altitude at Clashindarroch the spruce is growing better than the pine in all treatments. As a long-term object the proportion of Sitka spruce in the final crop, arising from the different intensities, will be observed.

Deep single-furrow ploughs remain in use in some areas, but have in recent years been replaced to a great extent by tine ploughs as described below. A special type of plough was developed for use in felled woodlands in 1947, and was also employed on some of the difficult heath areas of north-east Scotland. This outfit consisted of a single large disc mounted on the bulldozing yoke of a tracked tractor so that the driver could steer the disc between stumps or boulders. While it did useful work, the strain on the tractor was excessive and this equipment also has been replaced by the tine ploughs.

Tine Ploughing and Other Recent Developments

About 1950 it was becoming apparent that the deep single-furrow ploughs, the R.L.R. and Solotrac, were of limited use on areas with boulders, since breakages and the forcing out of the plough, often for several yards at a time, greatly reduced their efficiency. There had also arisen the question as to what deep single-furrow ploughing was achieving besides pan-breaking and why this could not be achieved more easily by subsoiling. In addition, by this time it has been demonstrated that furrow planting was satisfactory, thus raising a further doubt as to the need to throw out a high ridge of soil from the deep single-furrows. Trials commenced with a Blaw-Knox Ripper tine originally used by contractors on airfield construction. After its ability to penetrate deeper than the R.L.R. plough had been proved, tests began on the provision of a suitable mouldboard and carriage. Manoeuvrability was becoming an important feature in heath ploughing, as the long straight runs found at Allerston and the Black Isle, for which the R.L.R. was well suited, were no longer found in the newer and more difficult areas. Thus in 1950 a tine was mounted on a forty horse-power tracked tractor to give greater manoeuvrability, and this has proved an excellent outfit for irregular, boulder-strewn or stump-strewn ground. For more normal working, the tine was first carried on a Cuthbertson draining plough transport, and subsequently on a specially designed carriage. Single and double mouldboards were tested, and in general the single one was found more versatile; use of a single mouldboard involved the use of a long landside, and so the present design of tine plough took shape. This form of plough has proved most versatile, and has replaced a variety of earlier tools, while at the same time breakages and maintenance costs have been reduced. The tine has been compared with other methods in the latest series of ploughing experiments which have been laid out on a long-term basis, in order to try to observe the effects of ploughing over the whole rotation, and if desired in succeeding rotations. In these experiments great care was taken to record what was achieved by the ploughs in the various plots, and details are presented in Table 13, which shows both the measured depths and cross-sectional area of disturbance, and the volumes and proportions calculated from them. The method of ploughing, rather than the tools, were under test here, and the results throw considerable light on past experiments, if one can assume that the treatments as defined have remained roughly similar over the years. Thus, for instance, the figures confirm that shallow complete ploughing is slightly more intensive in terms of soil disturbance than deep single-furrow or tine ploughing, whereas deep complete ploughing is more than three times as effective. (The greater overall efficiency

TABLE 13: EFFECTS ACHIEVED BY VARIOUS TYPES OF PLOUGHING IN TEINDLAND EXPERIMENT 81.P.52 AND HARWOOD DALE EXPERIMENT 41.P.54

Profile features:
Teindland: Peat depth 3.1 inches±0.25 inches; pan at 14.5±2.8 inches.
Harwood Dale: Peat depth 5.0 inches±0.7 inches; subsoil at approximately 12 inches.
(These standard errors are for means of plots, not for the individual profiles).

Method of Ploughing	*Depth of ploughing, ins.*		*Breakage of pan, Teind.*	*Subsoil brought up, H'wd. D.*	*Volume of disturbed soil per plant, cubic feet*		*Approx. proportions from previous col.*	
	Teind.	*H'wd. D.*	%	%	*Teind.*	*H'wd D.*	*Teind.*	*H'wd. D.*
(A) Deep single furrow (control)	12.0	10.5	27	37	6.8	6.0	1	1 (control=unity)
(B) Single furrow+subsoil .... (single mouldboard tine)	16.4*	14.8*	67	20	7.8	6.2	1¼	1
(C) Shallow complete	6.7	6.2	Nil	7	10.8	8.2	1½	1¼
(D) Shallow complete .... +subsoil	7.4 16.8‡	6.3 22.7‡	73	Nil	15.2	7.5†	2¼	1¼†
(E) Deep complete	12.9	13.4	53	87	24.7	23.0	3¾	3¾
(F) Deep complete .... +cultivation	12.2	—	40	—	23.9	—	3½	—
Standard error	±0.55**	±0.50**						
Difference necessary for significance 5% 1%	1.7 2.5	2.8 2.4						

Notes: Method of recording was to note depth of peat, pan, ploughing and subsoiling at ten fixed sampling spots per plot. Cross-sections of 4½ feet were made after ploughing to estimate the cross-sectional area of disturbance, which multiplied by 4½ gives the average volume of disturbed soil per plant at 4½ x 4½ feet. See also Plates 32 and 33.

‡ Depths reached by subsoiler.

† In the clayey soil of Harwood Dale it was not found possible to chart the area of soil disturbed by the subsoiler, as was done at Teindland.

** Highly significant.

of complete ploughing may be noted, for while the tractor passes 2½ times for one line of trees on completely ploughed land, as compared with once in single-furrow ploughing, the disturbance effect may be over 3½ times as great). See Plate 33.

The main purpose of these experiments is long-term comparison, and they are not expected to alter current practice. The tine plough has proved itself so effective and robust a tool, that within two or three years of the first trials it virtually replaced all other ploughs on the Scottish heaths, though in England the R.L.R. plough is still used. The earlier of these two experiments, that at Teindland, has confirmed after six years growth that results from the two methods are almost exactly equal, and the final choice of tool has in fact been made from a mechanical rather than a silvicultural angle.

Yeatman (1955), from his work on the rooting systems, advocated complete surface cultivation to a minimum of eight inches, with subsoiling where the pan lay within eighteen inches of the surface. These experiments were designed before he arrived at this conclusion, but it can be seen that "Treatment D", shallow complete-ploughing plus subsoiling, approximates to this prescription, though it is not quite so deep nor so intensively subsoiled as he advocated. No tools were available however to carry out this treatment on an economic basis, and it was in fact achieved by subsoiling with a tine plough from which the mouldboard had been removed, followed by shallow ploughing with an agricultural plough (the Fisher Humphrey "Bracre").

In an attempt to make this method economic, trials were made from 1953 to 1955 with stump-jump disc ploughs of Australian design. Preliminary trials of a light machine proved hopeful, and were incorporated into an experimental comparison with the tine plough (Devilla 2.P.53). A heavy Australian plough (the Shearer "Majestic") was imported as it was hoped this eight-disc machine would cultivate to eight inches over a width of five feet; but trials have proved unsatisfactory owing to its inability to obtain good penetration on the compacted heathland soils.

In the meanwhile, development of the tine plough has been rapid, and several types are now in use; besides the differences in mounting, direct on the tractor with hydraulic lift, or on a carriage, there are local variations in the design of the plough body according as to whether deeper or shallower furrows are required. Thus in wetter areas a body is used designed to give a definite furrow, and planting is on the furrow-side, while on the drier heaths only a screef is cut with the share, and the tine is set to run at a greater depth, the plants being set in the tine channel. It appears at the present time that the tine ploughs may suffice for some period, and no early developments are foreseen.

TECHNIQUE OF PLOUGHING AND OF PLANTING ON PLOUGHED GROUND

As ploughing was developed as the main method of ground preparation, it became necessary to investigate various points of technique, both as to the manner of carrying out the ploughing, and of planting on the ploughed ground. Some of the earliest ploughing trials indicated that the losses in the first years after planting might be higher than with hand methods, and instances of this occurred in experiments at Inchnacardoch (81.P.31, Table 10, p. 44) and Wykeham (6.P.28). In certain cases the losses after ploughing amounted to almost complete failure, and replanting was necessary, as in the first ploughing trial on Inchnacardoch Moor using the horse-drawn experimental plough. On single-furrow, triple-furrow, and complete ploughing, losses in the first year of Scots and lodgepole pines and Japanese larch increased with the intensity of ploughing, averaging sixteen percent in notched controls and fifty-one percent on the complete ploughing. Japanese larch, the most sensitive species, lost ninety-four percent in the completely ploughed area as opposed to only fourteen percent in the controls (Inchnacardoch 69.P.28).

Examination of such cases suggested that planting on unconsolidated plough ridges was the main cause; the sod turned by these early ploughs being thin, and thus too light to weigh down the stiff branches of the heather, allowed the soil and the plant to dry out in a dry season. It was also noted that the plants used as replacements one year after ploughing in these experiments generally grew very well and suffered little further loss.

Two methods were tested to reduce the chances of drying out, first burning-off the heather in order to get the plough ridge to lie better, and secondly allowing a period for consolidation between ploughing and planting. On non-continuous ploughing, as opposed to complete ploughing, there was also the possibility of varying the position of planting relative to the ridge and furrow.

Heather Burning and Delay in Planting

In 1931 a comprehensive trial was made at Clashindarroch of both the effect of burning before ploughing, and of allowing time for consolidation after ploughing (6 & 7.P.31-33). Here the difficulties of burning small areas led to the use of two parallel strips of ground for the burning trial, one strip being burnt in March before *both* were ploughed in October 1930. Planting was then carried out over three years, and in the third year controls of notched plants were added alongside each strip; both these controls, however, fell on unburnt ground. The exact arrangement is of some importance, for in the absence of replication of the burning treatment it is obvious that any possible effect will be confounded with site difference.

The results of early growth and losses are presented in Table 14, which provides evidence of the possible importance of both the factors investigated. Losses of over five percent occurred only on the unburnt area, and there only with Japanese larch, except for the first year's planting of lodgepole pine. 1933 was a drought year, and that year Japanese larch which had been directly notched lost heavily, while losses were negligible on the ploughed ground which had by then had over two years to consolidate. Burning was beneficial to the growth of all species, the height being increased one-third overall for lodgepole pine and Japanese larch, and being doubled for Sitka spruce. Examination of the results from the planting of the individual years shows that the effect of burning was much greater in the 1931 plots than in the 1932 plots, while in the 1933 plots it was small, and in the case of the larch, negligible. These facts strongly suggest that the burning rather than any site variation was in fact responsible for the differences in growth observed.

The three years' plantings, when compared, show no striking difference in losses, though overall they were rather heavier in the early years; the result might have been different had the first year's planting fallen in the drought year of 1933, when on fresh ploughing very heavy losses might have been expected. The figures must in this comparison be considered in broad terms, since differences in planting year are confounded with differences in origin, age, and size of the plants at planting. There is no evidence of any substantial benefit to growth from delay in planting for the pine and larch, though in each of these species there are examples in the table of a later year's planting overtaking an earlier. For Sitka spruce on the other hand, there is evidence that delay is harmful; after twenty years the spruce of the 1932 and 1933 plantings lag behind those of 1931, probably due to the operation of the heather/spruce interaction which is considered in Chapter 10 (p. 127).

This result is fully confirmed by results elsewhere; thus at Wykeham one compartment was ploughed in 1933 and planted up with experiments during the next five years. In this area there are several examples of spruces having checked more severely than those on freshly ploughed ground, while pines were relatively unaffected. The records show clearly that heather had re-invaded the ploughed ground in the interval between ploughing and planting, being in fact far more vigorous than before the ploughing.

TABLE 14: EXPERIMENTS ON HEATHER BURNING AND DELAY BETWEEN PLOUGHING AND PLANTING

Clashindarroch 6 and 7.P.31. Heights in 1937/8, five to seven years after planting in successive years on ploughed ground, part of which had been burnt over prior to ploughing. Losses noted where over 5%.

Heights in feet; losses per cent.

Age when measured	*Treatment*	*Lodgepole pine*	*Japanese larch*	*Sitka spruce*	*Mean losses all species*
7	Ploughed				
	1931 Control	3.1(6%)	4.4(10%)	1.3	1931: 4.2%
	Burnt	4.6	6.1	2.8	
6	1932 Control	3.1	2.7(10%)	1.2	1932: 2.6%
	Burnt	4.2	3.8	2.4	
5	1933 Control	2.4	2.8	0.9	1933: 0.6%
	Burnt	3.0	2.9	1.9	
5	Notched				
	1933 Control	1.5	1.2(24%)	0.5	—
	Main effects of treatment in feet: (omitting notched plots)				
	Planting: 1931	3.8	5.2	2.0	—
	1932	—0.2	—2.0	—0.2	—
	1933	—1.1	—2.4	—0.7	—
	Burning: Unburnt	2.9	3.3	1.1	—
	Burnt	+1.1	+1.0	+1.2	—

TABLE 15: EFFECTS OF HEATHER BURNING

Mean heights five to six years after planting in Wykeham 33.P.34 and 38.P.34 on completely ploughed ground, on part of which the heather had been burnt prior to ploughing.

Feet

Treatment	38.P.34	33.P.34	
	Scots pine	*Japanese larch*	*Sitka spruce*
	6 *years*	5 *years*	5 *years*
Not burnt, ploughed 1931	2.4	3.2	1.6
Burnt 1931, ploughed 1932	3.6	4.4	2.8
Standard error	(Systematic	±0.29*	±0.23*
Difference for significance at 5% level	layout)	1.0	0.8

Notes: Losses were negligible throughout.
* Significant.

This rapid re-growth of heather was a quite unexpected feature of the advent of ploughing, for in a comprehensive report on the position with regard to experiments at Allerston in 1930 it was noted that there was 'no vegetation capable of making rapid growth on the newly broken-up ground'.

In the early years of ploughing at Allerston there was a tendency to push ahead with ground preparation regardless of the planting programme, but these results led to a change of policy and a reduction in the balance of ploughed land held in hand. In more extreme conditions at Millbuie, growth of pines has been very much worse on "old" ploughing than on fresh, so it is apparent that, though only the growth of Sitka spruce was affected at Clashindarroch and Wykeham, the differences between species are of degree rather than of kind. (Millbuie 2.P.42).

There is one further example of the effects of burning prior to ploughing, which arose from two experiments at Wykeham having been planted on moderately deep completely ploughed ground, where half of the area had been burnt before ploughing. Results are given in Table 15 which shows that there is some confounding with differences in date of ploughing, but that the evidence supports a beneficial result from burning and two-year-old ploughing as opposed to three-year-old ploughing alone, lodgepole pine, Japanese larch and Sitka spruce all being affected.

The long-term results of the various experiments considered in this section do not show any permanent effect from heather burning or year of planting, and the small absolute differences in height are lost as the plantations grow taller. The general conclusion on the question of burning before planting is that it should be undertaken if it will assist the consolidation of the plough ridges, that is to say mainly on old woody heather. The practical value of burning is very great on rocky ground, as it enables the tractor driver to pick his way and minimise wear and tear to tractor and plough. The main drawback to burning is that as the forests grow in size and value, so there is less inclination to undertake even controlled burning, and one of the main points in favour of the deep single-furrow ploughs is that they can operate in deep heather better than any other type owing to the weight of ridge turned. As regards allowing time for consolidation after ploughing, the conclusion reached is that while there is no advantage in delaying planting on ground where the spoil is lying well, no harm is done if heather land is ploughed up to two years in advance, provided pines or larch are the species to be employed. Practical experience suggests that the weathering of one winter is advantageous, and two may elapse between ploughing and planting, but that not more than one growing season should intervene. Both these points of technique are of considerable importance in the planning and execution of the large programmes of ploughing and planting which are undertaken on the heaths.

Position of Planting

The earliest experiments on ploughed ground were all planted by notching the plants into the upturned ridges. This position certainly set the plants above the water, which often lay in the furrows after shallow ploughing, and also ensured immediate access for the roots to the plough soil and the decaying vegetation under the plough ridge; but at the same time the plant was fully exposed and ran the risk of lack of water in a dry year. The heavy losses already recorded in certain of the early ploughing trials, and the poor appearance of the plants in the first year or two, led to reconsideration of the method.

As a result, in a number of the earlier experiments on the double-furrow ploughing at Wykeham, the plants were set on the unbroken strip between ridge and furrow, where it was hoped that the losses would be low, as in notch planting, but that the subsequent growth would be superior to notched plants once the roots reached the broken ground.

An experiment was made to test this point, but unfortunately on three-year-old ploughing, where the conditions are not so critical, and with a relatively insensitive species, Scots pine. Losses were negligible in all positions, but after the first four years, plants in the highest position, here the first ridge, averaged three or four inches *less* than those on the unbroken strip or on the second ridge (Wykeham 30.P.33).

Losses in other experiments, planted on the second ridge of the moderately deep ploughing, were far less than on the earlier shallow ploughing, and this position was adopted, giving drainage, access to spoil, together with some shelter provided by the first ridge.

In the same period an experiment was made to test the effect of bad planting on ploughing, a point already discussed in relation to hand planting. Scots pine was planted with its roots vertical and with roots bent in a U so that the tips were pointing up (Wykeham 38.P.34). Losses were negligible, and after nine years those deeply notched averaged 5.0 feet compared to 4.7 feet for those 'badly planted'

With the development of other plough types, the necessity to reconsider the planting position arose. For the shallow ploughing and subsoiling used in general practice from 1936 to 1942 at Allerston and Hamsterley, the method adopted was to notch pines and larch in the subsoiler channel, while spruce was planted with the semicircular spade on the plough ridge. In the small number of experiments planted on this type, however, spruce and other more tender species, such as western hemlock, were also notched, but into mounds of mineral soil in the furrow bottom instead of direct into the subsoiler channel.

An experiment with Sitka spruce at Broxa to test various positions ended in all the spruce checking badly, but the early losses on the ridge were much heavier than with notching or mounding in the furrow (Broxa 5.P.41). On the same ploughing type at Hamsterley, a large-scale experiment on mixtures tested out the current method in practice against the furrow-bottom mounding for seven species. Results showed a consistent small benefit from the mounding, generally under six inches or about ten per cent of the height growth in the first seven years. But the cost of this method would be much higher, and on this site all species have grown well regardless of method. (Hamsterley 10.P.40).

In 1943, with the commencement of deep ploughing with the R.L.R. plough, the problem again

TABLE 16: POSITION OF PLANTING

First-year losses, height growth, and rate of planting for Scots pine and Sitka spruce planted in various positions on deep single-furrow ploughing in Broxa 17.P.45.

Position of planting	*Scots pine (without manure)* 1st yr. losses	Scots pine Height in feet after 4 yrs.	6 yrs.	10 yrs.	*Sitka spruce (planted with 1 oz. basic slag)* 1st yr. losses	Sitka spruce Height in feet after 4 yrs.	6 yrs.	10 yrs.	Number planted per man-hour
Control on the unbroken strip	8%	2.15	3.4	8.3	Nil	2.3	3.0	5.8	121
Planted on:									
Top of ridge	16%	1.65	3.2	7.7	Nil	1.9	2.6	4.8	144
Step in ridge	3%	2.4	4.2	9.3	Nil	2.45	3.4	5.9	92
Bottom of furrow	3%	2.75	4.4	9.0	Nil	3.1	3.8	6.5	168
Standard error ±		0.08**	0.08**	0.26*		0.07**	0.11**	0.39	
Difference for significance 5%	—	0.27	0.27	0.88	—	0.25	0.39	1.16	—
Difference for significance 1%	—	0.41	0.40	—	—	0.38	0.60	—	—

Notes: The loss of significance in the Sitka spruce and its reduction in level for Scots pine at the last assessment is presumably due to variation in the ground beginning to influence growth, thus increasing the variability and standard error. In the case of Sitka spruce certain plots have checked.
** Highly significant. * Significant.

TABLE 17: POSITION OF PLANTING

Losses and mean heights of Sitka spruce six years after planting in various positions on deep single-furrow ploughing.

Position of planting	*Broxa Experiments Over 2–3 years*			*Kilcoy 2.P.49*				*Details of losses after 6 years of 1st year seedlings in Broxa 54*†	
	1st year seedlings		1+1	*1st year seedlings*		1+1 *transplants*			
	Losses %	*Hts. ft.*	*Hts. ft.*	*Losses* %	*Hts. ft.*	*Losses* %	*Hts. ft.*	*Planted normally* %	*Planted deeply* %
Top of ridge	13	2.9	3.8	29	2.3	8	2.1	32	30
Ridge side	19	3.4	4.2	26	2.5	14	2.5	32	23
Step in ridge	10	4.3	4.9	24	2.3	9	2.2	13	17
Furrow side	8	4.5	5.3	3	3.1	—	2.7	12	27
Bottom of furrow	13	4.6	5.6	4	3.2	—	2.5	13	23
Standard Error	±0.16**		±0.18**	0.23*		0.29		—	—
Difference for significance 5%	0.48		0.58	0.7		—		—	—
1%	0.67		0.77	—		—		—	—

Notes: Broxa figures for 1st year seedlings are means from experiments 32.P.48, 54.P.49 and 75.P.50. Figures for 1+1 transplants are from the first two years only. Results from the different years' planting after 6 years may be summarised:—

	1st year seedlings		1+1 *transplants*	
1948	4.1 ft.	17%	5.6 ft.	Nil
1949	3.7 ft.	19%	3.9 ft.	2%
1950	4.0 ft.	1%	—	—

† This is one of the few examples showing wide variation in losses between normal and deep planting, with apparent interaction with position.

** Highly significant. * Significant.

arose as to where to plant, especially since, with a ridge over a foot high and a furrow a foot deep, the range of 'microsite' and microclimate were now much greater than previously. As a general rule, pending the outcome of experiments, the plants were set in a step cut in the ridge side, which proved effective, but rather more expensive than previous methods, owing to the time spent preparing the position before the actual planting. A comprehensive experiment was laid out at Broxa using two species, to investigate growth, losses and the relative cost of four positions. Results, given in Table 16, confirmed that the ridge top was the worst place to plant, while the prepared step and the furrow bottom positions were better than planting in the unbroken strip.

When cost was considered it was clear that the furrow bottom was the optimum, as planting was almost twice as fast as with stepping. When first observed this result represented too great a break with the current practice of using the step or ridge top, for its immediate adoption; but further trials were put in hand using Sitka spruce as the species most sensitive to planting conditions. As furrows may often "run water" in heavy storms in the early years after planting, an additional position on the furrow side was used, and a second new position was on the ridge side without a cut step.

Within a year or so, the indications in the new experiments consistently confirmed the Broxa result that furrow planting was superior. A recommendation was made that the furrow side should be adopted on the grounds that this position provided a compromise, allowing the passage of water along the furrows, ready access to spoil, and low risk of drying out, together with minimum planting cost. As a result, furrow planting has been widely adopted on the drier heaths; where the rainfall is heavier, the peat deeper, and the furrows act more frequently as drains, the ridge position is still used.

Later results from this series of experiments are given in Table 17 and fully confirm earlier indications, there being ample evidence that both survival and height growth are best in the furrow.

Further experiments repeated the test with Scots pine and Japanese larch and obtained the same results (Table 18). The evidence is in fact now overwhelming. One of these trials, however, included a small section of deeper peat where a small hollow led to conditions much wetter than the normal heaths with a grass-rush vegetation. Here furrow planting led to almost complete failure, and the experiment shows quite clearly that the conclusions only apply to the true heath, and that ridge planting is necessary when conditions approach that of the peatlands (Clashindarroch 39.P.50).

There was in addition in these experiments a test of the depth of planting, as it was felt that this might interact with position, i.e. plants on the ridge might benefit from being set deeper than normal, while those in the furrow might suffer, since during the first few years after deep single-furrow ploughing there is continual washing of spoil off the sides into the furrows. This expectation was not fulfilled, however, and in none of the experiments was there a significant difference in growth due to planting depth, nor any indication of an interaction with position of planting. In one or two cases, however, losses did suggest a relationship of the type expected, and an example is given in Table 17. The assumption seems reasonable that, having accepted furrow planting, care should be taken to set the plants only to the same depth as they were in the nursery, while if ridge planting is necessary then rather deeper planting is a worthwhile precaution if the soil is friable.

With the advent of the tine ploughs, the question was whether to plant in the tine channel or in the furrow side. Trials were again set out and early results show that the furrow side is satisfactory but in some cases the subsoiler channel is even better. This position has already been used on some scale in practice, but cases have occurred in which plants have been heaved out of the subsoiler channel by frost, and also where waterlogging of the tine channel has increased losses. It would appear wise to use this position only on the drier and more permeable sites, changing to the furrow side on heavier soils, and reverting to the ridge in the wettest areas. It appears that this must be a matter on which the ganger and even the individual planter to some extent make the final decision, but the importance of the choice should clearly be emphasised to all concerned.

MEASURES OF GROUND PREPARATION OTHER THAN SIMPLE PLOUGHING

Apart from the main stream of planting, draining, and ploughing trials already described, there were a number of experiments concerned with the preparation of the ground for planting, which are not easily described in relation to the majority. Most of them were laid out in an attempt to elucidate the relative importance of the various adverse factors of the planting site, which may be listed as the heather, the surface peat, the anaerobic and compacted topsoil, and the hard pan. Certain of the more fundamental experiments designed by workers at the Imperial Forestry Institute are briefly described as an indication of how they fit in with the '*ad hoc*' or more directly practical experiments carried out by the Forestry Commission Research staff. Methods of ground preparation more intensive than complete ploughing are also included.

Modification of the Vegetation Cover and of Individual Features of the Profile

Heather Burning. A single early trial at Clashindarroch attempted to find the effect of burning of the heather on the survival and growth of trees notch-planted on the burnt-over ground. This trial followed observation of the improved growth of Scots pine where slash had been burned before planting at Teindland. Burning, however, is not an operation susceptible to investigation by the small plot technique, as it is difficult to get a good "burn" on small areas, and when well alight, to limit its extent as precisely as desired. At high altitude and

TABLE 18: POSITION OF PLANTING

Mean heights and losses after three years for Scots pine and Japanese larch planted on various positions on deep single furrow ploughing in Broxa 89.P.53.

Heights in feet; losses per cent.

Position of planting	*Scots pine* *1st year seedlings*		*Scots pine* *1+1 transplants*		*Japanese larch* *1st year seedlings*		*Japanese larch* *1+1 transplants*	
Top of ridge	0.4	(71)	0.8	(37)	1.2	(5)	1.3	(22)
Ridgeside	0.6	(23)	0.8	(17)	1.0	(22)	1.1	(23)
Step	1.1	(3)	1.2	(2)	2.0	—	2.1	(7)
Furrowside	1.2	—	1.4	—	1.9	—	2.3	(8)
Bottom of furrow	1.1	(10)	1.3	—	2.2	—	1.8	(2)
Standard error	±0.06**		±0.08**		±0.10**		±0.14**	
Difference for 5%	0.19		0.26		0.29		0.44	
Significance 1%	0.27		0.36		0.41		0.61	

Note: ** = Highly significant.

TABLE 19: PLANTING ON VARIOUS HORIZONS OF A PODSOL

Mean heights after twelve years of four species planted at different levels in Inchnacardoch 106.P.34.

Feet

Profile layer in which planted	*Depth in inches*	*Scots pine*	*Lodgepole pine*	*Japanese larch*	*Mean*	*Sitka spruce*
Surface peat	0—3	11.2	12.8	10.0	11.4	1.1
Leached layer	3—7	11.1	13.4	12.7	12.5	1.1
Pan and deposition layer	7—9	10.8	12.7	9.1	10.9	1.6
Subsoil	Below 18	9.0	13.2	10.1	10.8	2.3
Standard error ±	—	0.43*	0.79	0.99	0.73†	0.22*
Difference necessary for significance at 5%	—	1.5	2.7	3.4	1.4	0.76

Notes: † This figure is significant at the 10% level.
* Significant at 5% level.

in severe exposure, the only difference seen between burnt and control plots was that, in the first years, plants in the controls were of much better colour, and appeared to have benefitted from the shelter of the heather, rather than suffered through competition with it. (Clashindarroch 2.P.31).

Planting in the Podsol Horizons. Two small experiments investigated the effects of planting into each layer of the podsol. To do this, small plots were stripped of the various horizons, and the plants carefully set into the layer below. Differences in microclimatic conditions and soil drainage at the various levels were eliminated as far as possible by erecting artificial shelter around the experiment, and by draining the subsoil plantings to an even lower level. Even so the conditions did not represent those to be found in the particular layer in the untouched moor, in that the lower plots also drained the upper, but by draining all levels it was hoped that the relative suitability of each as a medium for tree growth would be demonstrated. In one of the trials, results were not significantly different after eight years, at which time the experiment was accidentally burnt (Teindland 50.P.34), but in the second, significant differences in growth occurred in two cases as shown in Table 19.

Though there were insufficient plants and replications to give more than an indication, the results suggest that while lodgepole pine was most tolerant of planting conditions, Scots pine and Japanese larch grew better in the peat and leached horizons than in the lower zones, while Sitka spruce grew best in the subsoil, checking badly in the surface layers. The better growth of the Sitka spruce was associated with the fact that the subsoil layers were not recolonised by heather. These results fall into line with those from the position-of-planting experiments already described, in that planting in the furrow side, the optimum position, also entails planting below the original ground level and generally in the leached horizon.

Explosive Charges. Rupture of the iron pan without extensive cultivation in order to reduce waterlogging was another early line of work. The use of explosives to this end was tested in field trials in 1926, and after the approximate weight of charge, depth of setting, and spacing, had been worked out for maximum disturbance at a comparable cost to ploughing, the results were incorporated into two experiments at Wykeham. In the first trial, different charges of two to four ounces were exploded at a depth of three feet and at a spacing of fifteen feet apart. The ground was observed to heave and small craters were formed; digging showed that the pan had definitely been fractured within a radius of one to two feet; possibly the effect extended further, but this was not obvious to the eye. The notched Scots pine grew very slowly at first, but have now formed a satisfactory crop. In the absence of replicated controls it is impossible to be certain, but the crop appears to be better than that in an adjacent experiment where plants from the same lot were planted with mattocks, the pan rarely being reached. It seems that the breaking of the pan by the explosives may have had some long-term effect, probably by allowing water to drain away through the pan (Wykeham 3 & 4.P.28).

A minimum treatment with explosives was incorporated into the ground preparation trial shown in Figure 5 (Wykeham 6.P.28). Here two-ounce charges were exploded at a depth of eighteen inches, but only three charges were used in each of the small species units. Growth has been identical with that in notched plots for all four species, and it seems possible that with this shallow setting, the force of the explosions was expended upwards, and the treatment was thus less effective than in the first trial described.

Cultivation of the Surface Peat. The compact and blanket-like structure of the surface peat layer has long been recognised as one of the unfavourable features of the podsol profile. When waterlogged, as it is for the greater part of the year, it forms an effective seal, leading to the prolongation of anaerobic conditions for much greater periods than the parent material and rainfall would suggest probable. It was found that in many cases shallow ploughing immediately reduced the amount of surface water and the general wetness of the heaths, even though it did not break the pan. Rennie (1950) had described an experiment using rotavators, undertaken to elucidate how far surface cultivation to break this peat layer would improve tree growth; results are given in Table 61 (p. 130) and show that for Sitka spruce the improvement is negligible.

In a further *ad hoc* trial, the larger tractor-mounted rotovator was run over an area at Broxa three times, mixing heather, peat, and top soil to a depth of about six inches; in addition an old Killifer subsoiler was used, thus combining pan breaking with mixing of the surface peat into the upper soil-layers. (Broxa 77.P.50). The results are extremely poor, and may be contrasted with those from another experiment planted that year with the same species on deep single-furrow ploughing (Broxa 76.P.50). After six years, heights for Scots pine are: 1.8 feet and 4.5 feet, and for Douglas fir: 0.6 feet and 2.3 feet respectively; in addition losses were heavy with the Douglas fir in the rotary-hoed plot, although the site was at planting considered as above average in quality for the Broxa area. Abundant heather regrowth has occurred on the rotovated ground, which appears to have provided an ideal medium for its regeneration.

The inescapable conclusion is that no single treatment has yet been found which can in any way replace ploughing, the effects of which are undoubtedly complex. Further implications of these trials are considered in the discussion below on the functions of ground preparation on the heaths.

Intensive Cultivation

A small number of experiments have investigated the possibility that cultivation more intensive than complete ploughing would bring further growth responses. They have been inspired particularly by the Danish system of repeated ploughings before planting the first crop of spruce on heathland. Unfortunately none of the experiments are entirely satisfactory in design, and the results need to be examined in detail. In the first experiment a single plot of complete ploughing and a second adjacent plot, ploughed three times within a year, were planted up with five species. As shown in Table 20 growth and survival of Japanese larch and Oregon alder have been considerably improved by the intensive cultivation where phosphate was applied, but only survival of the larch was improved by the

TABLE 20: CULTIVATION

Mean heights and losses after fifteen years of five species planted with and without phosphate, on ploughed and intensively cultivated ground, in Teindland 49.P.33.

Heights in feet; losses per cent.

Ground preparation *Jan.* 1932 *Nov.* 1932 *April* 1933	*Ploughed Plot* *Nil* *Complete shallow ploughed* *Nil*		*Intensively cultivated plot* *Complete shallow ploughed* *Grubbed and harrowed* *Reploughed and harrowed*	
Species	*Control*	*2 oz. slag*	*Control*	*2 oz. slag*
Japanese larch	4.2 (60)	8.3 (29)	3.3 (31)	11.7 (5)
Norway spruce	1.5 (39)	1.7 (11)	1.0 (42)	1.9 (4)
Sitka spruce	1.2 (32)	4.1 (11)	0.8 (42)	2.4 (2)
Birch	1.8 (36)	3.2 (29)	1.9 (25)	3.4 (19)
Oregon Alder	Failed	5.9† (52)	Failed	12.7† (38)
Means for all species:—				
Control	1.7 (53)	—	1.4 (48)	—
+slag	—	4.6 (26)	—	6.4 (14)

Notes: † Considerable dieback had occurred before these measurements were made and further deterioration has now taken place.
Early results of this experiment have been given by Guillebaud (1938).

TABLE 21: INTENSITY OF CULTIVATION

Mean heights in Inchnacardoch P.T. 34/6 and Teindland 34/1.

Feet

Treatment and number of cultivations	*Planted, 2 oz. slag per plant:-*	1943 *Heights Teindland*		*Teindland & Inchnacardoch Means for Sitka spruce* ‡	
		Scots pine	*Japanese larch*	*No inter-cultivation*	*Inter-cultivated two years after planting*
Control. No cultivation .... (0)	1934	1.8 3.3†	2.8 4.3†	0.8	1.1
Dug over to 7 in., March 1934 .... (1)	1934	5.7	10.0	2.3	2.7
Dug and redug September 1934 .... (2)	1935	5.5	9.0	2.6	3.1
Dug, redug 1934. Tilth made February 1935 (3)	1935	5.2	9.5	2.7	3.1
As last, but potatoes raised with slag, potash and sulphate of ammonia in 1935 (4+)	1936	4.7	9.6	3.4	3.4

Notes: (1) Stocks of the original transplants were relined in the nursery for the later plantings, so that the age from seed of each species is the same throughout the experiments.

(2) The Scots pine and Japanese larch sections at Inchnacardoch were seriously damaged by blackgame and the results are therefore omitted.

† The effects of intercultivation are only shown for the controls of pine and larch, for other treatments the effect was negligible, and results are averaged.

‡ Results were very comparable and have been averaged in view of the very small numbers of plants involved.

cultivation without phosphate. In contrast the other three species, birch and the two spruces, show an improvement in growth with phosphate but none with intensive cultivation, though there is a suggestion of better survival with the combination of intensive cultivation and phosphate.

The second set of two experiments tackled the problem in an intensive manner, using replicated small plots, in which the first cultivation was by hand to simulate complete ploughing. The cultivations continued over two years, each plot being planted up with plants drawn from a common stock in the nursery as its quota of cultivations was completed. Looking back it is quite clear that the operations should have been started in different years and have been worked towards a common planting date using stock, not only of a common origin, but also of uniform age and size. These experiments, however, have produced some of the best Sitka spruce both on Inchnacardoch Moor and in the Findlay's Seat area, and the early data is therefore presented in Table 21. For Japanese larch and Scots pine there is little benefit beyond the first cultivation, whereas for Sitka spruce there is a steady improvement as the number of cultivations is increased; with a further improvement, except in the most intensively worked plots, where intercultivation was carried out two years after planting.

It will be observed that these results are diametrically opposite to those in the first experiment, where Japanese larch responded but Sitka spruce did not, and the suggestion is made that the difference in the method of cultivation is responsible. In the first experiment the three cultivations were carried out mechanically, much of the heather remaining at or near the surface, and within two years the great vigour of the heather regrowth was reported in both intensively cultivated and manured plots. In contrast, in the hand-cultivated experiments the heather was carefully dug in, and at the second digging instructions were given that it was not to be brought to the surface. In addition, it is certain that hand digging to seven inches would be a more effective method of cultivation than the shallow ploughing of that period, which probably never exceeded six inches in depth, with many broken furrows and shallow lengths owing to the irregularity of the ground. Hence it would appear that, in the first trial, the general level of intensity was low, so that larch responded to increased cultivation, while spruces even then never emerged from "check". In contrast, in the second set, the single digging achieved near-optimum conditions for Japanese larch, and the subsequent cultivations resulted in steady improvement of the Sitka spruce, the severity of the initial check being progressively reduced. The present state of this species is that, in these intimate mixtures with pine and larch, dominants have achieved about twenty feet after twenty years, and will come to form part of the final crop, though the other species are as yet rather taller. The intensive methods used in this experiment have thus been very successful for Sitka spruce, though quite unnecessary for pine and larch.

THE FUNCTION OF PLOUGHING ON THE UPLAND HEATHS

Having described the development of the present practice of ploughing on the upland heaths, and the alternatives tried out and rejected, together with the details of the technique evolved, it is now possible to discuss the functions of ploughing in the preparation of the ground for planting.

The basic requirement is to alter the site so as to make it more suitable for tree growth, this being achieved by regulating the water regime, improving the aeration, reducing compaction, and mobilising nutrients, particularly nitrogen.

Considering each of these points in turn, the single-furrow type of ploughing, which is used almost exclusively in practice, provides a furrow which will in emergency run water; but the original belief that actual drains were required to remove water from the heath has been shown to be unfounded, since once the pan is broken, or the soil disturbed to a sufficient depth, waterlogging is no longer a problem. Rainfall of thirty-five inches or less would, in fact, suggest that in the long run conservation of water, rather than its removal, may be required in order to support the transpiration of a heavy tree crop.

The reduction of compaction is necessary in order to increase the penetration of roots, which has been found to be extremely slow on the untouched moor. It has been demonstrated in every investigation made into the soil conditions, that free rooting is associated with soil disturbance, or with regions of less compacted material, and this point is discussed at length by Yeatman (1955).

The breaking of the surface peat which accompanies any form of ploughing also plays a large part in increasing the possibility of aeration, since the peat in its natural state has been found to act as an impermeable seal when saturated with water.

The mobilisation of nutrients is effected by the decay of the buried vegetation, and also over a longer period by the exposure and aeration of the peat and pan. The first of these processes was for long considered to be largely responsible for the excellent early growth on ploughed ground, but in view of the success of furrow planting, well removed from the decaying vegetation, this conclusion is open to question.

The second function of ploughing is the provision of a suitable planting spot. It is desirable that the soil shall be loose for ease in planting, but be capable of firming with the heel. The absence of vegetation from the planting spot is an important factor both in the actual planting and in ensuring that the plant shall be free from competition for as long as possible. This means that in any intermittent ploughing method, such as the single-furrow, the plant should be placed more or less mid-way between the remaining bands of vegetation. It has proved beneficial if the plant is placed low or high on the ridge system, according to whether the site is drier or wetter. A further point is that the heaths are as a rule exposed, and good early growth is achieved where some shelter can be provided by the plough ridge, suggesting that furrow planting is preferable wherever possible.

The above considerations are all taken into account in the present system of ploughing, which uses either deep single furrows or shallower furrows with subsoiling, followed by planting on the furrow side or in the subsoiler channel wherever soil conditions allow.

The benefits which have followed from ploughing may also be summarised. The rapid early growth on ploughed ground ensures rapid establishment, which in turn reduces the risk of damage from causes which operate mainly before closure of the canopy, particularly browsing, frost and fire, since the number of years spent in the susceptible phase is substantially reduced. There is also reason to believe that losses through late spring frosts are less severe on ploughed than on unploughed ground. The reduction of losses following ploughing are striking, and better growth and reduced losses have led to an increase in the range of species which it is possible to use in afforestation, the extensive use made of Japanese larch being the outstanding example.

Ploughing to a large extent eliminates the differences in microsite between one planting spot and another which are found on the open heath, thus leading to the formation of very much more regular plantations in which almost every individual plant enters the canopy. This in turn allows the use of wider spacing and to a large extent eliminates the enormous early wastage of plants found in the old close-spaced hand-planted plantations. It is possible that this uniformity of growth makes early thinning more essential, because the individuals do not so readily become dominant or suppressed as in the more irregular hand-planted areas.

The raising of the Quality Class of the crop is an undoubted fact on all the poorer heaths. At the present stage of development, it is not possible to specify exactly the extent of this improvement, but it is clear that it may be of the order of one to two Quality Classes, since crops, though of low Quality Class, have been produced with early ploughing, and often without phosphate, where previous attempts at afforestation had produced only worthless scrub. An example of this is the Scots pine on Findlay's Seat area, which after twenty-five years, are double the height of their hundred-year-old predecessors. For the majority of the heaths, however, no such long-term comparison is yet possible; timber crops were grown previously without ploughing, and though early growth after ploughing has been much faster, it will be necessary to compare production over a given rotation before the final benefit derived from ploughing can be accurately assessed.

There are further practical advantages arising from the use of ploughing which do not, however, affect the long-term development of the crop. First, rapid planting allows the completion of large planting programmes within a limited planting season, without the employment to any great extent of seasonal labour. Whereas in the early years of the Forestry Commission large squads were taken on for the planting season, it is now possible for a small squad to carry out a large programme in a matter of weeks and to be employed for the rest of the year on fencing, draining and the raising of the plants; clearly a much more satisfactory arrangement. Secondly, the use of small, relatively cheap, planting stock is now general, 1+1 transplants being normal and seedlings sometimes employed, as compared with the 2+1, 2+2 or older transplants of earlier decades. Finally, the elimination of the vegetation and rapid establishment have been achieved to such an extent that weeding is reduced to negligible proportions on the majority of the heaths, and many large areas of plantation have not been weeded at all.

In spite of the adoption of ploughing, the use of a fairly uniform technique, and the general acknowledgment of the benefits resulting from ploughing, there remain a number of questions on which opinion is divided, or the final outcome uncertain.

The major objection to ploughing is made on the grounds that it represents an attempt to "cash-in" on the accumulated fertility of the ground, and that the spectacular results achieved in the early years will not be continued into the later stages or succeeding crops. So far, however, there is no evidence that on the poorer heaths the growth rate will ever fall on ploughed land to the level found in earlier hand-planted areas.

It may also be claimed that in breaking up the podsol, ploughing is at least partially reversing the deterioration of the past millenium and that it is impossible to return to an optimum soil condition in one step. This school of thought argues that if ploughing produces one economic crop that is sufficient justification, and that it is the subsequent silvicultural regime that must be adjusted to the maintenance or improvement of the level of fertility in subsequent generations. Even if there is no long-term benefit from the relatively low intensity of cultivation practised, the short-term benefit is such that the prospects of afforestation on many sites have been enormously increased, while any increased intensity of cultivation at the start would render the first rotation uneconomic. Ploughing as practised today is the minimum required to give establishment within a reasonable period. This matter can be decided only over a long period, and a small number of the existing ploughing experiments where the plots are large, are suitable for the determination of production over several rotations.

More immediate practical objections to ploughing are concerned mainly with the ridge and furrow system consequent on single-furrow ploughing. Yeatman (1955) has shown that the main roots of all species are generally orientated in the direction of the ploughing, but that this is not the case in completely ploughed areas. Any such orientation of the root system must be regarded as undesirable, as producing a crop more susceptible to wind-throw.

The question of extraction over ridge ploughing has also caused some concern, though it has not yet caused difficulty in practice. It may be found necessary to use machinery to re-grade extraction racks, particularly in the deep single-furrow ploughing on heavy heath soils. In this respect the tine ploughing with its shallower furrow is to be preferred.

Taking a wider view of the ploughing method in vogue, it is interesting to note that in the most comparable areas abroad complete ploughing is the rule, and that often cultivation is carried out at intervals over several years before planting. It has often excited interest that the Forestry Commission alone should follow this distinct method of single-furrow ploughing. It may be relevant to point out that in areas such as the Danish heaths there is no native pioneer tree, and the repeated cultivation has been found essential to rear a timber crop of Norway spruce in the first rotation, the alternative being less cultivation to produce a firewood crop of mountain pine. In contrast British conditions are such that a productive pioneer crop of pine may be produced by the single-furrow method. At the same time British heaths are far wetter, more irregular in terrain, strongly compacted, and with stones and boulders forming a very serious obstacle to ploughing. As a result it is often found impossible to re-traverse an area once broken by the plough, even using powerful crawler tractors, whereas on the easier conditions of the continental heaths wheeled tractors can re-traverse ploughed ground freely. The cost of more intensive cultivation on our heaths would be out of all proportion to the limited benefit to growth demonstrated in the experiments.

A further subject on which long term investigation will become necessary is that in countries such as Denmark and Germany, where ploughing has been extensively practised for a much longer period than in Britain, it appears, though it is not yet proven, that the incidence of root rot may be proportional to the amount of cultivation. If this is so it may raise great problems in our heathland forests.

Chapter 6

THE MAIN SPECIES USED ON THE HEATHS

SCOTS PINE

Pinus sylvestris L.

Scots pine is native to the northern portions of the upland heaths, while in Yorkshire it certainly formed forests at one time, though the species appears to have become virtually extinct before being re-introduced by man. The denudation of the hills of Britain by man, his grazing animals, and his uncontrolled burning, is a story that has been told elsewhere. It is possible that soil deterioration started under Scots pine and heather, while its rate probably increased when heather became dominant after the destruction of tree cover. Scots pine has been the natural choice for all subsequent attempts to re-forest the upland heaths, and even today, after the introduction of several promising exotics, it still forms the greater proportion of the crop in the majority of the forests. Thus in the Black Isle forests of Ross-shire almost ninety per cent of the crops planted by the Forestry Commission are of Scots pine, while in the Allerston district of Yorkshire it forms over half, though here it has been used to a considerable extent as a nurse for other species. There is, however, a break in the artificial distribution of this species in that it is used much less in the highest and more exposed forests of Clashindarroch and Drumtochty, where its liability to blasting and to snowbreak make it unsuitable for large-scale use.

Comparative Growth

As the only native species, Scots pine acts as a control to all the trials of exotics. It is exceeded in early height growth by lodgepole pine under almost all circumstances and, once intensive soil preparation is undertaken, by Japanese and European larches also, while on the wetter heaths it is exceeded in many cases by Sitka spruce. On the English heaths it may well be partly replaced by Corsican pine, as it has been in the south of England for the production of Corsican pine on comparable sites is considerably greater.

Tables 36, 37 and 38, which are discussed on page 85, give the evidence available from experiments on the relative productivity of four main species on heath sites, and it is thus apparent that if the predominance of Scots pine is to continue it may depend on the superiority of its timber, and so ultimately on price differentials. On many sites of low productivity it seems likely that it will be replaced by "bulk-producing" species, lodgepole pine on the drier sites and Sitka spruce on the wetter ones.

Provenance

There have been a small number of planned experiments comparing Scots pine of different seed origins, both from Britain and abroad, but the main work has been the collection of seed from good stands, and the planting out of the progeny, in order to preserve the strain of the best stands available. The collections were made from 1929-39, and fortunately anticipated the felling of many of the parent stands during the 1939-45 war. The resulting plantations comprise some hundreds of plots at Inchnacardoch (92.P.31-36) and Findon (3.P.34-42), of almost 150 seed origins, mainly from the Scots pine areas of northern and eastern Scotland, but with a few English and Continental origins. Both these areas were taken in hand before ploughing was general, and the plants were notch-planted without any phosphate manuring. This has provided rigorous testing conditions, for both sites were poor heath with a well-developed pan, while the Findon site is in addition very exposed; as a result establishment and growth have been extremely slow and very variable. This last phenomenon, though associated with all notch plantings, can in this case be referred to obvious variations in micro-topography, associated with changes in ground flora and variation in the vigour of the *Calluna*. At Inchnacardoch, trenches have shown good growth to be associated with local occurrence of thin peat over coarse sand, and the formation of a thick iron-stained B horizon; while poor growth occurs where the peat is thicker and where hard pan occurs over compact gravel, the fluctuation being rapid in places. As a result of this great local variation, it is not yet possible to draw detailed conclusions from these plantings; until now the micro-site has had more influence on growth than the provenance. It is clear that after their slow establishment the plots are now entering a period of more rapid growth and should provide information on variation in form, and also a valuable source of genetical material for the production of improved strains of Scots pine by tree breeding.

Besides these two large collections, there were three older experiments on the heath, results from which have been given by Edwards (1953). The first, planted on the lower ground at Teindland in 1928, compared Finnish, Latvian and French provenances with two Scottish lots from the estates of Pitgaveny, Morayshire and Beaufort, Inverness-shire. From the evidence available after twenty years, these last appear likely to give the best crops, being equalled in height and basal area, though not in form, by those from Latvia (Teindland 32.P.28). The northern Finnish provenances failed completely, as did one such provenance in a comparable trial at Inchnacardoch (58.P.28). Here the growth of the other foreign lots was better than at Teindland, the most vigorous again being those of Latvian origin.

The most comprehensive experiment was planted at Findon in 1929, and final results for the intensive section have been given by Edwards (1953) and have been condensed in Table 22; once again the superiority of home-collected seed is seen, and also interesting differences in needle length under these conditions. It is not suggested that the needle differences are diagnostic, since the nutrition of some provenances appears to be upset, the home lots being dark green, while the foreign are yellow-green. That early growth and volume production of Scots pine may be high on the heaths is shown by stand data indicating growth equivalent to Quality Class II at twenty-three years in the adjacent extensive trials of the home provenances, an example of which has been given in Table 1 (p. 7). Figures given by Edwards suggest important differences in stem form in these extensive plots, 'East England' and 'Strath Conon' having twice as many Class I stems as 'Darnaway' and 'Loch Fyne', with 'Innes' very poor indeed.

The outcome of this work, and the realisation over the past twenty years of the importance of provenance, is that seed collection has been arranged on a regional basis in East Scotland, the stands being classified as to their suitability to supply each locality, including many of the heathland forests. As a check on this classification, progeny from selected seed stands is being compared in a series of experiments covering a range of climatic conditions; on good heath (*Calluna-Vaccinium*) at high elevation (1,250 ft.) at Glenisla Forest, Angus (3.P.54); on rather poorer heath and more severe climate (1,350 ft.) at Glenlivet Forest, Aberdeenshire (5.P.54); with a control on good Scots pine land (Bracken/grass or *Calluna-Erica tetralix*) in a milder area at

TABLE 22: PROVENANCE OF SCOTS PINE

Selected results to show the range of height growth and needle length 22 years after planting in Findon 1 P.29. (After Edwards, 1953).

Country and range of provenances	*No. of lots*	*(Means and range of values)*	
		Heights in feet	*Needle length, mm.*
Scottish, Argyll-Moray	4	20.6 (20.1–22)	34½ (34–35)
East England, believed originally Scottish	1	22.5	36
Finnish 60° 15′—62° 30′ N.	4‡	11.5 (8.8–14.5)	27 (26–28)
Latvia, var. *rigensis*	1	10.0	32
Ural Mts. var. *uralensis*	1†	7.4	37
Georgia var. *hamata*	1	9.6	35
Spain var. *nevadensis*	1†	4.8	34
Standard Error		±1.2**	±1.3**
Difference for significance: 5%		3.5	3.6
1%		4.7	4.8

Notes: ‡ A fifth provenance from 67° 15′ N. failed.
† These suffered heavy losses.
** Highly significant.

TABLE 23: AGE AND TYPE OF SCOTS PINE

Percentage losses and mean heights in a number of experiments.

Experiment, site and treatments	*Age, yrs.*	*Seedlings* 1+0 %	*Seedlings* 1+0 *Ft.*	*Seedlings* 2+0 %	*Seedlings* 2+0 *Ft.*	*Transplants* 1+1 %	*Transplants* 1+1 *Ft.*	*Transplants* 2+1 %	*Transplants* 2+1 *Ft.*
Hand preparation: Teindland. Poor site, Findlay's seat 17.P.27	6	23	1.1	18	1.1	—	—	6	1.8
22.P.28	6	28	0.6	—	—	10	1.2	13	1.1
Calluna—grass .... 31.P.28§‡	4	27	0.9	56	0.8	15	1.2	18	1.2
Good site rich Calluna .... 30.P.28‡	6	—	—	—	—	4	2.2	3	2.3
Wykeham. 3.P.28	7	94†	0.8	—	—	23	1.9	44	2.0
Ploughed ground: Wykeham 7.P.29	7	48	1.1	56	1.8	28	1.8	33	2.5
26.P.33 Control	8	47	2.3	—	—	18	4.2	—	—
Slag	—	41	4.0	—	—	31	5.3	—	—
Fetteresso 3.P.51	3	44	—	—	—	23	—	—	—
(Samples of P.52	3	46	—	—	—	18	—	—	—
seedlings P.53	3	38	—	—	—	14	—	—	—
planted over P.54	3	36	—	—	—	22	—	—	—
large areas) P.55	1	53	—	—	—	22	—	—	—
Mean of 5 seasons	—	42	—	—	—	18	—	—	—

Notes: ‡ Planted from same seed lot throughout the experiment.
† The total losses, including replacements, amounted to 200% over five years.
§ The best lot in this experiment was ½+1½ raised by lining out plants by hand in August. Losses 6% Height 1.4.

lower elevation (300 ft.) at Laiken Forest, Nairnshire. These trials have been planted in replicated plots of rather over one-tenth acre, and should provide information of the greatest aid to the selection of Scots pine for use on the heaths, as well as generally in the region, for the emphasis has been placed on finding strains suitable for the more exacting sites.

Type of Planting Stock

As might be expected with the species which holds such a dominant position in the afforestation of the heaths, a great deal of work has been done on the best type of stock for planting, and on its production in the nursery. The first experiment on planting stock was notch-planted at Findlay's Seat, Teindland in 1926, using four "ages" of plant which had come from various sources (6.P.26). The growth was very poor and the plants had not reached one foot after four years, but transplants were rather better than seedlings, so the experiment was replaced by others using mound planting, and the results of these and a similar trial at Wykeham are given in Table 23, which shows that on the whole the one-plus-one transplants made better growth or suffered fewer losses than seedlings or older transplants. These early trials suffered from the disadvantages that the origins and nursery histories of the various lots of plants were often different. The problem is almost insoluble, since using the same seed lot one must plant in different years, which is not equitable as regards season nor in planting on old ploughing, while to hold over seed under artificial conditions might itself introduce the risk of bias.

Compromise is essential and the former alternative was adapted in two experiments at Teindland, where ten "ages" of Scots pine were set out over four years, all having been raised from one seed lot (14.P.26-29 and 15.P.27-30). The site here was not typical heath, but old Scots pine woodland on river gravels; but the results were of interest in that 1+1 or 1+1+1 transplants were the most successful, while the types which remained two years *in situ* in the nursery immediately before planting (2+0, 1+2, 1+1+2, 2+2) suffered double the losses (thirty per cent), of those transplanted for one year before planting (1+1, 1+1+1, 1+2+1, 2+1, 2+1+1).

The second alternative of sowing the same seed in different years was used to produce the plants for Teindland 31, and here the 1+1, and particularly the ½+1½, were the most satisfactory. These results were confirmed by the later experiments on ploughed ground, and 1+1 transplants have for many years been in general use, while 2+1 are used when the first year's growth is too small to permit the plants being handled.

With the adoption of ploughing as normal practice, considerable attention was paid to the use of one-year-old seedlings, in the hope that the economy so made would to some extent offset the increased cost of ground preparation. Half an acre had already been established by notch-planting seedlings without ploughing on grass-heath at Teindland, at a cost of under £4 per acre, and this gave some promise of success (Teindland 38.P.29). The handling of these small seedlings between nursery and forest was known to be important, and experiments at Wykeham compared plants which had been lifted at Kennington Nursery, Oxford, and stored for various periods before dispatch. Puddling was tested as a possible aid before transport, and great care was taken in packing. The results showed a considerable increase in losses with storage, in three cases out of four, and this was only alleviated by puddling in one. Losses of one-year seedlings after rapid transport were negligible, while those of two-year-old seedlings were much heavier (Wykeham 12 and 13.P.31 and 18.P.32). With large nursery and planting programmes it is inevitable that some plants remain in the sheugh or in transit for some time; these experiments show that one-year seedlings will survive if reasonably treated.

The main difficulty at this time however was to produce one-year plants fit for handling, and the next phase in plant production was the development of the heathland nursery. A single trial was made using the root-roll machine (p. 69) for planting one-year Scots pine, but losses were higher with this method than with normally planted controls which had received phosphate (Glenlivet 3.P.37).

From 1937 onward, the plants raised in early trials of Dr. Rayner's composts were compared with produce from the agricultural type or 'established' nurseries. These trials in several instances showed the early superiority of the heathland stock, but this result was transitory, as deaths were negligible throughout the series, and height differences less than six inches after six to ten years (Wykeham 48.P.37, Harwood Dale 16 and 18.P.37-38, Broxa 16 and 19.P.45-46). This was undoubtedly due to the care taken in handling the relatively small numbers of plants from the time of lifting in the nursery until planting, which was generally carried out within twenty-four hours. Similarly in the extension experiments carried out for the late Dr. Crowther of Rothamsted at Broxa, first year seedling stock has done very well as reported by Crowther & Benzian (1953) and Benzian (1955). It is apparent that this method of testing is insufficiently near normal practice, nor is it always possible in large-scale planting to attain such perfection of technique; the same argument could be applied to many of the "age and type" comparisons already described.

Accordingly, from 1951 to 1955, an extensive trial was arranged at Fetteresso Forest, by which the whole planting area of the season was scattered with 100-plant plots of one-year seedlings, with an adjoining control of one-plus-one transplants. Species, and planting method, varied according to the ground type, which contains all variations from typical heath to deep peat bogs and grass-heath. All seedlings received phosphate, but transplants received it only where the adjacent planting was to receive it also. Over the five years, some 150 such plots were laid out, and once planted these plots were given routine attention as regards weeding and protection. The results given for Scots pine in Table 23, together with the almost exactly comparable losses with lodgepole pine (Table 30 p. 74) and Japanese larch (Table 32 p. 79) show just how wide is the gap between experimental planting at Allerston and general experience under more difficult conditions at Fetteresso, where besides the variable site, roe deer, hares, and blackgame all play their part in reducing survival.

It is clear that this extensive trial suggests great caution in the use of any planting stock less robust than one-plus-one transplants until experience on some scale, over several years, preferably on some such basis as that used at Fetteresso, has proved that losses can be kept down to reasonable levels. Recent trials on this subject are the testing of plants which have been undercut in their second year in place of transplanting. Early results under experimental conditions are promising, but the need for caution in wide-scale application is appreciated. (Broxa 90.P.53, Teindland 84.P.53, Harwood Dale 42 and 45.P.54-55 and Speymouth 3.P.55.)

Use in Mixture

Scots pine has been used widely in experiments and general practice as a nurse crop, mainly for Sitka spruce, and young crops have also been used experimentally as shelter for the introduction of other species; these subjects are dealt with in Chapters 9 and 7 respectively. The only mixed crops where Scots pine is itself considered as the more important species, are the long-term mixtures with lodgepole pine or with European larch; in the former case Scots pine is used to "enrich" the lodgepole pine in difficult sites; in the latter, on better sites, the larch may be regarded as an "enrichment" species, since the bulk of the crop will probably be Scots pine.

Experiments on manuring at Teindland, planted with alternating single or double lines of Scots and lodgepole pines, have given rise to three mixed blocks. The main stocking is of lodgepole pine, but in two cases enough Scots pine dominants remain to form a substantial portion of the final crop (Teindland 39 and 42.P.29-30). The lodgepole pine used here was the slow-growing 'Alberta' provenance, and the proportion of Scots pine surviving might have been greatly reduced had a faster form been used. It is also noticeable, in these blocks, that the Scots pine has been completely suppressed where neither species received phosphate, since the lodgepole is more tolerant of phosphate deficiency. At Inchnacardoch a more typical provenance of lodgepole pine, from 'Hat Creek', was used in two mixtures with Scots pine; in spaced groups the Scots pine is two feet behind, and in single line mixtures the Scots is now being suppressed (82.P.31). The need for spatial separation in bands or groups of these species when in mixture is thus emphasised.

Thinning

While no results from experiments on the heaths are available at the present time, owing to the general slow growth, it is apparent that with the wide spacings used now as compared to earlier times—$4\frac{1}{2}$ ft. $\times$ $4\frac{1}{2}$ ft. is now the closest spacing used,—the importance of the early cleaning to remove broken-topped dominants is enhanced. A replicated experiment at Findon Forest, comprising plots with spacings from 3×3 to 8×8 feet, is being used to compare different grades of thinning, and also tests pruning of selected dominants in spacings from $4\frac{1}{2}\times4\frac{1}{2}$ feet upwards (Findon 7.P.35).

Summary

Overall it is estimated that Scots pine has been employed on rather more than half the area of upland heath so far planted by the Forestry Commission, and that the main reason is its ability to compete with heather and to grow under conditions which, until recent years, no other timber-producing species was known to tolerate. Although the timber produced by this species on the heaths is of high quality, the early growth of Scots pine is generally very slow, and its production is also relatively low, so that there have been constant efforts to find species which could replace it on certain heath sites, particularly the poorest and the best, and it is largely these trials that are described in this chapter. The introduction of further species also serves to diversify the forests, to give greater freedom in management and in the range of produce, than if one species was to be employed almost exclusively.

CORSICAN PINE

Pinus nigra var. *calabrica* (Loudon) Schneider

Corsican pine has been used on some scale in both experimental and general planting at Allerston and other heath forests in north-east England, but on the Scottish heaths it has been planted in only a small number of experiments. The position of this species is at present in the balance, as it has on some sites suffered severe dieback in the pole stage after satisfactory early growth. Thus it is that even at Allerston it has been little used recently, although during the decade from 1938 it was used extensively and in preference to Scots pine.

Comparative Growth

Corsican pine checked or failed in early notch-planted species trials at Clashindarroch (9.P.31) and Findon, Ross-shire (4.P.38), under conditions where only lodgepole pine started well. There are good plantations on sand at Culbin and Lossie forests in the Moray Firth region of Scotland, and therefore this pine was retried on coastal heaths in Caithness in 1950 and 1951. It has started better than Scots pine, but not as well as lodgepole pine, where other species apart from Sitka spruce are poor (Skiall 1 & 2.P.50-51, and Forss 1.P.51).

On the higher inland moor forests of Slaley, Northumberland, and Hamsterley, Durham, both of which run to 1,000 feet, Corsican pine plantations have suffered from dieback; details of its incidence at the former forest have been given by Day (1945). It is thus only at Allerston, among the upland heath forests, that Corsican pine can be considered a major species; and even there, though fairly near the sea, and generally at altitudes of below 750 feet, the pine must be considered as at its limit, and is in fact dying back in some areas. On these heaths it is at present a potentially valuable component likely to produce large volumes and to provide trees of some girth as compared to other species. Figures given in Table 24 show that Corsican pine generally draws level in height with Scots pine by the twenty-fifth year, though in most of these experiments it lagged somewhat in the early years. The oldest of the plantations have been thinned twice, and stand data are given in Table 37, showing the very much greater early production of Corsican as compared to Scots pine. The yield table figures in Table 38 show that the advantage of Corsican pine is largely lost after fifty years, when production might be expected to be only twenty-five per cent greater if the quality classes are maintained. It is apparent that these results pose a problem as to whether its use should be extended on account of the superior production, or restricted for fear of dieback. At the present time it is little used, but several thousand acres are approaching the critical pole stage, and the outcome in ten to fifteen years time will decide the future role of this species at Allerston.

Reaction to Treatment

The figures given in the summary of results from various ploughing methods at Allerston (Table 11,

p. 44) and of the manuring experiments (Table 49, p. 111) show that Corsican pine responds in a comparable manner to Scots pine. A major difference however is the difficulty encountered in planting and in its initial establishment; the methods used to overcome them are detailed below.

Provenance

There are no experiments comparing different origins of Corsican pine on equal terms. The majority of the plants used have been raised from seed from Valdoniello Forest, Corsica. One particular importation of seed from Calabria, Italy, gave rise to trees of particularly bad form. They are slower growing, with closer-set branches, and stiffer, more pointed needles, than the Corsican race; their botanical position is uncertain. Odd trees of this form are well known in Corsican pine plantations from other sources, and clearly they should be removed in early thinnings. Many of the later plantings of Corsican pine are from home-collected seed from stands of known good form in the south of England.

Type of Planting Stock; Method of Planting

Corsican pine is notoriously difficult to transplant and to plant, on account of the long tap root and sparse laterals, so that the loss of the former jeopardises its chance of survival more than with other pines. On this account a number of experiments have been devoted to methods of overcoming the heavy death rates which often occur in the first years after planting. It was thought that the tap root should be preserved intact if possible. One method of doing this was to plant one-year seedlings, but the first problem was to grow plants large enough to handle in the first year, all the earlier experiments had been planted with two-plus-one transplants, and losses over the first two seasons ranged from thirty to fifty per cent, being considerably greater than the losses of Scots and lodgepole pines, but about the same as those of Japanese larch (Wykeham 2 & 6.P.28 and 9.P.29).

The earliest trial of seedlings was made at Wykeham in 1931 as one of a series of experiments designed to find how far their use could compensate for the cost of ploughing, which had then just been accepted as essential. Large one-year plants raised with conifer humus at Kennington (Experiment 29) were compared with controls grown in normal soil (Wykeham 16.P.31). Losses after two years were twenty-four per cent in the controls as compared to ten for the special plants, which was a very good "take" for seedlings, for in the next trial on rather rough fresh ploughing at Wykeham losses rose to seventy per cent (26.P.33). In the same experiment,

TABLE 24: CORSICAN PINE

Comparison of growth rates in the Allerston district and at Hamsterley with those of Scots and lodgepole pines, illustrated by mean heights at about 15 years and top heights at 25 years.

Heights in feet

Experiment Ground preparation	*Age yrs.*	*Scots pine*	*Corsican pine*	*Lodgepole pine*
Staindale 1A.P.31 Ploughed Mod. deep	25	24½	27	26
Wykeham 2.P.28† Prepared patches	14	5.4	5.3	7.9
	25	27	27½	33
Wykeham 9.P.29† Shallow ploughed	14	6.5	7.3	9.6
	25	29	29	36
Harwood Dale 2.P.32 Hand dug groups	17	12	13	—
	25	21½	23½	—
Broxa 8 & 10.P.43 Deep ploughed	13	13½	11½	—
Hamsterley 10.P.40 Mod. deep ploughed	15	17½	17½	25

Notes: The last three experiments received phosphate, the first three did not.
† Stand data for these experiments is given in Table 37.

TABLE 25: SURVIVAL OF CORSICAN PINE

Losses in the first two years of stock raised under different nursery regimes and planted out under various conditions in experiments at Allerton 1937-39. The results from trials of a root roll machine are included.

Losses per cent.

Experiment *Ground preparation* *Manuring*	*Age of plant*	*Established Nursery*		*Heathland Nursery*	
		Normal	*Rolled*	*Normal*	*Rolled*
Wykeham 47.P.37 8 yr. old ploughing No manure	1+0 2+0	— —	— —	1 8	1½ ½
Harwood Dale 20.P.38 Pit and mound 2 ozs. basic slag	2+1	6	—	Nil	—
Harwood Dale 21.P.38 Pit and mound †phosphate	1+0	29	33	70	77
Langdale 1.P.38 Ploughed †phosphate	1+0	—	—	37	56
Langdale 2.P.39 Ploughed †±phosphate (mean)	1+0	28	29	43	31

Notes: Plants for the Wykeham experiment were stored in water from lifting to rolling and were then immediately planted.
All the 1938 plantings were made during a prolonged spring drought, and the planting of Harwood Dale 21 was delayed until early May.
† Phosphate was applied as 1 oz. dose after planting by normal methods or as ¾ oz. in the roll.

losses of 1+1+1 transplants were thirty per cent, but on the other hand losses of 1+1 and 1+1+1 transplants were low in well consolidated ground, hand-dug at Harwood Dale (2.P.32), or on old ploughing at Wykeham (45.P.36).

In 1937-39 a series of experiments was made using a 'root-roll machine' of French manufacture, by which the roots were enclosed in a paper roll seven inches long and an inch across, filled with soil or humus, and mixed with phosphate in certain cases; the dimensions made this roll suitable for use with seedlings of Corsican pine, as a high proportion of the tap root could be accommodated. The first seedlings raised with one of Dr. Rayner's composts in an experimental nursery on the heath were employed in the trials of this machine, together with controls from the local nurseries of the 'established' agricultural type. The results given in Table 25 show that the benefit from "rolling" the roots was negligible, but that wide fluctuation of losses occurred due to other causes; the type of plant and the particular season were clearly both important.

In the following years transplants from the experimental heathland nurseries became available and they were planted out for comparison with stock from the 'established' nurseries. The results given in Table 26, taken in conjunction with Table 25, suggest that one-plus-ones are the best stock to use. It is relevant to suggest that if losses in the transplant lines were about the same as those of seedlings in the forest, it would be cheaper to suffer these losses in the nursery.

A further illustration of the sensitivity of this species to the conditions of planting comes from experiments planted either late or early in the season. Serious losses of seedlings after late planting in a dry year have been noted in Table 25, while Table 27 brings out the disaster which followed autumn planting at Broxa on an occasion when losses of Scots pine were not unduly high, while those of Sitka spruce were negligible. In this table are presented the losses in all the experiments at Allerston which combine the use of one-plus-one transplants from local heathland nurseries, adequate ground preparation, and the application of phosphate. Provided that planting is at the right time (February-March appears to be the optimum) it is clear that losses can be reduced to a reasonably consistent low level, and a major difficulty to the employment of this species for afforestation is thus avoided.

TABLE 26: CORSICAN PINE TRANSPLANTS

Mean heights and losses twelve years after planting at Harwood Dale of 1+1 plants raised in different types of nursery.

Height in feet; losses per cent.

Raised Seedbed	L.O.	23.P.39 Ft.	%	26.P.40 Ft.	%†	29.P.41 Ft.	%
Est.	Est.	5.9	2	4.0	38+16	3.8	18
HLN	Est.	6.0	Nil	4.0	18+12	—	—
HLN	HLN	6.0	2	4.8	8+ 8	4.6	8

Notes: Est. = Established agricultural type nursery.
HLN = Heathland nursery.
† = Heavy losses of the 1st year were replaced with comparable plants and the further losses shown have occurred since.
N.B. Plantings of roughly comparable 2+1 stock the previous year suffered few losses (Wykeham 20.P.38).

Use in Mixture

Corsican pine has been planted as a nurse to Sitka spruce in several experiments in comparison with Scots pine (Chapter 9). As it shows no superiority as a nurse over the latter species, its use cannot be recommended, in that a mixture with Sitka spruce involves the planting of two relatively untried species, in place of one certain and one untried. Of true long-term mixtures there are few examples in the experiments. Early mixtures of Corsican pine and Japanese larch at Wykeham have become virtually pure pine, through the failure of the larch owing to inadequate ground preparation (2.P.28 and 9.P.29). A like fate is overtaking a Corsican pine/birch mixture planted on old ploughing without phosphate, where the birch is being suppressed (45.P.36). The only successful mixture so far achieved is of Corsican pine and European larch at Hamsterley (10.P.40), where after fifteen years the larch has a top height of twenty-one feet and the pine seventeen and a half feet. Here there seems every chance that a successful mixture will be formed, since thinning should free the best larch while the Corsican pine can be retained between them. Recent plantings at Broxa include Corsican pine in mixture with Scots pine.

TABLE 27: LOSSES OF CORSICAN PINE AT ALLERSTON

Losses of Corsican pine from all experiments planted at Allerston 1939-51, with 1+1 transplants raised in local heathland nurseries. Good hand preparation or ploughing and phosphate throughout.

Experiment		*Planting dates*	*Losses %*
Harwood Dale	23.P.39	Mar. 13-15th	2
	26.P.40	Apr. 8-12th	16
	28.P.41	Feb. 17-18th	4
	29.P.41	Apr. 11-14th	8
Broxa	4.P.41	Apr. 21-26th	17
	8.P.43	Oct.-Nov. (1942)	46
	10.P.43	Nov. (1942)	70
	12.P.44	April	6
	80.P.51	Mid March	6
Mean Loss			19%
Average excluding autumn planting			8%

In two instances, young Corsican pine plantations at Allerston have been opened and interplanted with Sitka spruce. It has been found possible to bring the latter into canopy in groups among the pine in the first experiment (Wykeham 50.P.38), while this seems likely to occur in the second case also (Harwood Dale 39.P.45).

Summary

In conclusion it is apparent that further planting of this species cannot be recommended, even in the limited areas where establishment and early growth are rapid, until it is known whether the existing plantations are going to survive the critical pole stage.

LODGEPOLE PINE

Pinus contorta Doug.

Lodgepole pine has had an interesting history on the heaths since its first employment about 1922. It is undoubtedly the easiest species to establish under difficult conditions of soil, altitude, or exposure, and for almost thirty years it has been used experimentally on the most difficult planting sites taken in hand at any time. Since, however, its timber is relatively unknown, as technique has improved, so lodgepole pine has been pushed on to ever-poorer sites; very little produce has been obtained as yet, and there has been reluctance to accept pure crops as economic. Edwards (1954-55) has summarised information on this species and concludes it may be used for pulp, pitwood, boxwood, transmission poles and small saw timber. Lodgepole pine may never become a substitute for the higher grades of Scots pine, and current practice is to plant the former only on sites where the latter cannot be grown. The area of lodgepole pine planted on the heaths now amounts to several thousand acres, perhaps five per cent of the total, and many of the plantations are mixed, either with Sitka spruce on wetter sites, or with Scots pine on sites marginal for that species. The greater part of these plantations are under twenty years old, and it is too early to draw conclusions as to yield and quality of their timber. The early experimental plantings were often on rather better ground than would be used for the species today, and provide comparable plots with other species which demonstrate its superior early growth over a wide range of conditions. This feature, added to its relative resistance to exposure, has led to its use as the major species in the trial plantations described in Chapter 11, which seek to extend the limits of plantability on to more difficult sites. Similarly lodgepole pine is an important component in shelter belts and in shelter strips around plantations.

Its relatively rapid early growth has resulted in the use of lodgepole pine on a small scale for beating-up plantations of pine or larch. Two experiments at Teindland compared various species for beating-up three-to-five-year-old Scots pine, and showed that lodgepole pine had more chance of drawing level than additional Scots pine or hemlock (54 & 55.P.34). This was on poor ground without ploughing, but on richer heaths even fast-growing lodgepole pine could not form canopy with three-year-old Scots pine at Inglismaldie (1 & 2.P.34), or with three-year-old Japanese larch at Inchnacardoch (110 & 111.P.34); the conclusion being drawn that only very large gaps were worth beating-up on such sites.

Provenance

The provenance of lodgepole pine to be used in heath planting is a matter of some importance, owing to the variation in form of the species according to origin. In a recent review of the literature and the information available from experiments in Britain, Edwards (1954-5) concludes that this species is 'a polymorphic species differentiated into ecotypes which form an ecocline, ranging from the coastal shore pine to the most continental form of lodgepole pine growing east of the Rocky mountains'.

The characters used in distinguishing the extreme botanical type, shore pine, from lodgepole pine (var. *latifolia* S. Watson), are the bushy green crown, heavy branches, rough bark and short needles. Typical lodgepole pine (var. *latifolia*) is slender, light-branched, smooth-barked, with longer, often yellow-green, needles. In the early years of heath planting various seed origins were used without critical comparison, since the variation within the species was not realised.

One of the early large importations of seed was of the most extreme inland provenance from Alberta; this was widely planted in experiments and the heath forests from 1928-31, but nowhere was it critically compared with other provenances, though by broad comparisons it is found to be slower-growing than most lodgepole pine. Though of good habit, there has been some dieback in Dornoch Forest, and seed collection from this race is at present restricted in view of its extreme continental origin.

The same lack of knowledge of the range of form has led, from time to time, to the use of heavily-branched coastal provenances in intensive mixtures, with consequent suppression of the other species. The bulk of the seed imported before the war came, however, from central British Columbia, and early provenance trials compared plants from seed from fairly limited areas in this region, and have in most cases shown little difference in habit or rate of growth (Wykeham 2A.P.28, Teindland 32.P.28, 44 & 45.P.31). An exception is that single plots at 1,700 feet elevation at Clashindarroch suggest the superiority under these circumstances of the provenance 'Hat Creek', coming from an elevation of 5,000 feet in British Columbia, as compared to several others from 3-4,000 feet (Clashindarroch 11.P.31).

Collections from a wider range of origins were built up at Clashindarroch (15.P.34-41) and Teindland (51.P.34-37), and clearly show differences in habit; but since the different provenance lots were added year by year much of the data from these experiments is still too much affected by date of planting to allow conclusions to be drawn as to growth. The first comprehensive experiments were laid out at Millbuie and Wykeham in 1938, and the heights and the number of growing points per lower branch, taken as a measure of crown density, have been grouped geographically in Table 28; the regions distinguished are fairly clearly differentiated on a map covering all the seed origins. This information is part of a considerable accumulation of data which has still to be worked up and collated, so that the results presented here must be regarded as tentative. In Table 28 the southern coastal lots stand out from the remainder in height growth and crown density, while more northern coastal origins, including those from Queen Charlotte Islands, are slower growing than the inland provenances, though still of bushy habit as witnessed by the number of growing points. The inland British Columbian lots are themselves variable, and show some falling-off in growth towards the north, while the southern inland lots from the United States emerge as relatively slow in growth and have thin crowns. The Alberta lot already mentioned would appear to rank in rate of growth with these last, and estimates from neighbouring plots in various experimental areas suggest trees of this origin will lag behind those from central British Columbia by twenty per cent, or about five feet in twenty-five years. This is as great

TABLE 28: PROVENANCE OF LODGEPOLE PINE

Selected results from provenance experiments to show the range of height growth and form 16-17 years after planting at Millbuie, Wykeham and Clashindarroch.

Region and extreme provenances included in it	*No. of seed lots*	*Range of values and means at 17 years*			
		Millbuie 1.P.38		*Wykeham* 55.P.38	
		Heights in feet	*No. of growing points*	*Heights in feet*	*No. of growing points*
Northern British Columbia (Hazelton-Prince George)	4	21.3 (20.9–21.9)	11½ (9–13½)	22.0 (21.2–22.6)	22 (20–23)
Central British Columbia (Williams Lake–Shuswap Lake)	4	22.1 (20.8–32.2)	8½ (8–10)	23.2 (21.6–24.6)	24 (19–29)
Coastal British Columbia (Leeward of Vancouver Isle)	1	20.9	13	20.6	39
Coastal U.S. (Olympic peninsula–Lincoln County)	2	23.4 (23.4–23.4)	22 (22–23)	25.2 (24.5–25.8)	66 (52–80)
Inland U.S.					
Priest River, Idaho	1	20.3	10	21.9	20
Williamson River, Oregon	1	17.3	7½	18.5	19
Standard error (for individual provenances)		±0.49**	**	±0.42**	**
Difference for significance 5%		1.4	—	1.2	—
1%		1.8	—	1.6	—

Region and provenance	*No. of seed lots*	*Range of values and means at 16 years*			
		Millbuie 1.P.39 *Section*		*Clashindarroch* 15.P.39 *Section*	
		Heights in feet	*No. of growing points*	*Heights in feet*	*No. of growing points*
Queen Charlotte Islands	1	17.8	22	12.4	34
Northern British Columbia (Terrace—Prince George)	4	19.1 (18.8–19.2)	12 (9–13½)	12.3 (11.7–13.3)	19 (17–23)
Home collected shore pine†	1	20.8	25	15.1	43
Standard error (for individual provenances)		±0.35**	**	±0.6 **	**
Difference for significance 5%		1.05	—	1.8	—
1%		1.4	—	2.5	—

Notes: The heights given are the means of plot averages, and the ranges in brackets are those of the extreme values included in the group, and do not necessarily correspond with the provenances given in the first column.

The number of growing points was measured on the last five years growth of the most vigorous side branch at about breast height. Analysis after transformation shows differences are highly significant.

† The parent stand is 2nd generation British, the original provenance was probably coastal U.S.A.

** Highly significant.

TABLE 29: COMPARISON OF HEIGHTS OF SCOTS AND LODGEPOLE PINES AND JAPANESE LARCH

Mainly at twenty-five years from planting, at the principal experimental areas.

Dominant heights in feet

Forest and Experiment	Age	Phosphate	Species: Scots pine	Lodgepole pine	Japanese larch	Notes
‡Millbuie P.38	17	+	18	20½	25½	Single plots
Teindland 23.P.28	25	+	24	25	—	Lodgepole pine thinned to aid Sitka spruce in mixture
øInchnacardoch 69.P.28	25	—	30	38	37	—
øClashindarroch 5.P.31	25	—	26	30	32	Crops damaged by snow
Staindale 1A.P.31	25	—	24½	26	23	—
Wykeham 6.P.28	25	—	26½	—	28½	Shallow ploughing
øWykeham 9.P.29	25	—	29½	36	Failed	Shallow ploughing
Wykeham 11.P.31	25	+	—	34	36	Deeper ploughing
†Harwood Dale 6, 18–20, 22, P.32–37	20	—	17½–24	19–26	20	Hand preparation

Notes: ‡ Conservancy experiment.
ø Stand data for these plots is given in Tables 36 and 37.
† Figures obtained by graphing and exterpolating experimental data.
All areas were shallow to moderately deeply ploughed, except Harwood Dale.

a difference in growth as that between lodgepole pine and Scots pine, as shown in Table 29.

It may be taken therefore, that throughout this work "lodgepole pine" generally refers to lots from British Columbia, though it is also used in the wide sense for the species as a whole. The presence of provenances from the coast of the United States notable for their rapid growth and heavy crowns, and also of the slow-growing Alberta provenance, is noted where it affects results.

In recent years an attempt has been made to distinguish the form of pine, both in imported seed and home collections. Coastal provenances are being used mainly in the wetter western districts, while in the drier east, including the heaths, the seed used comes from the interior region of the Skeena River and Prince George, British Columbia.

Comparative Growth

Table 29 compares the heights attained by the three main conifers in all the older experimental areas, from which it is clear that lodgepole pine grows at about the same rate as Japanese larch and that both are faster growing than is Scots pine. It is also clear that lodgepole pine exceeds the larch in certain of the earlier trials with less intensive ploughing or without phosphate, indicating its greater tolerance of difficult conditions for establishment. Only in recent years have the trials moved on to land where exposure is the dominant factor, and the early growth of larch is there poorer than that of lodgepole pine, even though intensive ground preparation and phosphate have been employed. Though a phenomenon not often seen on the true heath, reference must be made to the very poor form and heavy branching found when lodgepole pine, particularly the "shore type", is employed on richer land, since the coarse growth found there has led some foresters to condemn the species as a whole.

Conclusions on the productivity of lodgepole pine compared to the other species are difficult in the absence of yield tables for this species, but the main conclusions drawn from the examination of the results given in Tables 36 and 38 (pages 85 and 86) are that on the earlier-planted heath sites height growth and production correspond to an increase of at least half a quality class over Scots pine.

Reaction to Treatment

Enough data has been given above, and in the chapters on ground preparation and manuring, to show that while lodgepole pine is relatively insensitive to changing conditions, the early rate of growth may yet be greatly increased by stimulatory treatment. Thus the figures for growth in ten-year-old experiments at Allerston (Table 11, p. 45) show a forty per cent increase over the limited range covered, though the comparable figure for Japanese larch was one hundred and fifty per cent. The figures for the effect of phosphate (Table 49, p. 111) show a more variable response, generally small at Allerston but substantial on the poorer site at Teindland.

Type of Planting Stock

As with Scots pine, there has been a steady reduction in the age of planting stock, two-plus-one or older transplants having been replaced by one-plus-one, and Table 30 summarises the various trials that have been made using different ages of plant. The earliest trial compared plants from two seed lots when set out after two or three years in the nursery; two year seedlings were in one case inferior in growth, and transplanting after two years not worthwhile, one-plus-one giving the best results. The Wykeham trials show how site conditions can outweigh any differences in age of stock; one-year seedlings did very well under ideal conditions, while older plants died on fresh ploughing in a dry year. The comprehensive trial of one-year seedlings carried out at Fetteresso over the five years 1951-55 gives little hope, however, that seedlings can be used on a wide scale.

Further trials tested seedlings from the early heathland nurseries which had later been lined-out in established nurseries, but they revealed no difference in results from plants raised entirely in the established nurseries. (Wykeham 48.P.37, Harwood Dale 16 & 19.P.37-38). At the present time lodgepole pine is generally raised as seedlings in heathland nurseries and lined-out to become 1+1 transplants in agricultural-type nurseries.

Use in Mixture

Lodgepole pine has been used in a number of trials as a nurse, generally for Sitka spruce as an alternative to Scots pine and Japanese larch; these trials are considered in detail in Chapter 9. In general it may be stated that lodgepole pine is not a very suitable species for nursing, owing to its over-rapid early growth and dense canopy; Scots pine and Japanese larch are to be preferred. However where these species do not grow there is no alternative but to fall back on lodgepole pine, but the instances of its successful use are few.

Mixtures with Scots pine and Japanese larch are more fully described under those species, but mention may be made of an example at Hamsterley where the larch is in danger of suppression by "shore pine" when planted in intimate mixture. As with all plant-by-plant mixtures, the balance may easily swing in the opposite direction, for at Clashindarroch, in alternate line mixture, the pine, here "true" lodgepole, was threatened with suppression by the larch.

Thinning

As yet no yield tables exist for lodgepole pine, but the plots established on the heath to obtain stand data indicate that thinning of this species may present a problem. Stands have so far been thinned silviculturally (C–D grade) by foresters accustomed

TABLE 30: AGE AND TYPE OF LODGEPOLE PINE

Losses and mean heights in a number of experiments.

Age and type of plant		*Seedlings*			*Transplants*		
Experiment. (No phosphate unless shown)	*Age*	*Age*	%	*Feet*	*Age*	%	*Feet*
Teindland 33.P.30–32							
Lodgepole P.30	12	2+0	22	6.7	1+1	8	8.8
P.31	11		—		2+1	4	6.7
Shore pine P.31	11	2+0	3	7.8	1+1	5	8.8
P.32	10		—		2+1	3	5.8
Wykeham 13.P.31	12	1+0	6	9.1		—	
Wykeham 26.P.33† Nil	8	2+0	24	3.8	2+1	45	5.1
1 oz.			27	5.9		40	6.1
Fetteresso 3.P.51 2 ozs.	3	1+0	34	—	1+1	20	—
(Samples of 52 „	3		61	—		14	—
seedlings 53 „	3		39	—		13	—
planted over 54 „	3		30	—		36	—
large areas) 55 „	1		51	—		20	—
Mean of 5 seasons	—		42%			19%	

† Planted on fresh rough ploughing.

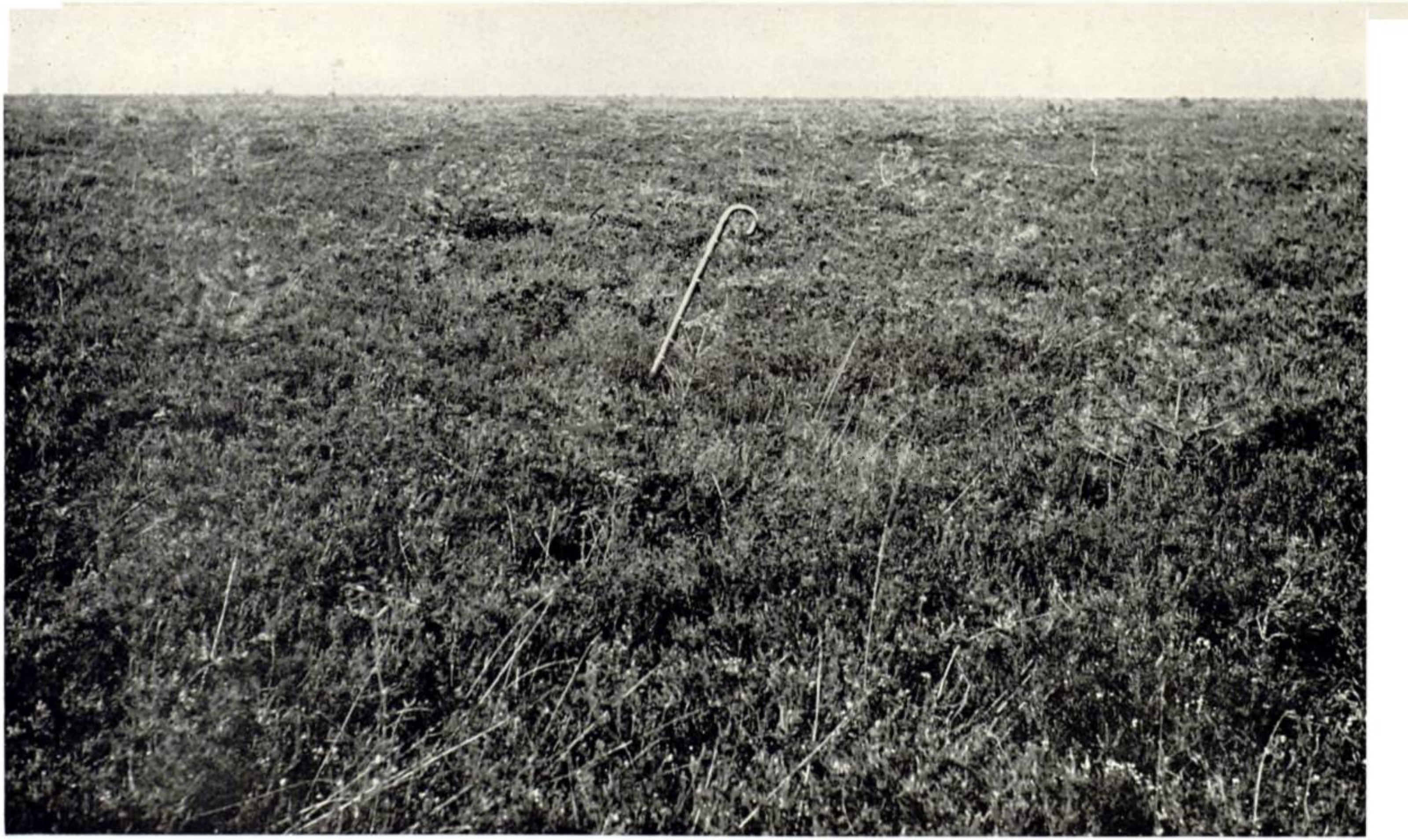

Plate 1. Typical upland heath, Wykeham Moor, Allerston Forest, in 1933. This area had been planted without ploughing in 1927 using Scots pine and Norway spruce. The latter had failed and the crop had been beaten up with further pine.

Plate 2. Part of Dalby beat, Allerston Forest, in 1933. This area, White Cliff Rigg, Sandale and Hawdale, had been planted between 1921 and 1928. Corsican pine in the foreground.

Plate 3. As Plate 2, but taken in 1955; canopy has formed over the whole area. Beyond the Corsican pine may be seen, from left to right, Douglas fir, Scots pine, Douglas fir again and Japanese larch. The crop on the plateau is mainly pine.

Plate 4. Findlay's Scat, Teindland, 1951. These survivors of the 100-year-old planting rarely exceed twelve feet in height; the trees in the background were killed in the 1942 fire. *Calluna–Trichophorum* vegetation.

Plate 5. Root system of old Scots pine from Findlay's Seat—showing two levels of rooting, one in the surface peat and the other above the pan at about one foot depth.

Plate 6. Teindland 1931. Ploughing with the three-horse plough.

Plate 7. Ground ploughed by horses at Teindland, 1932.

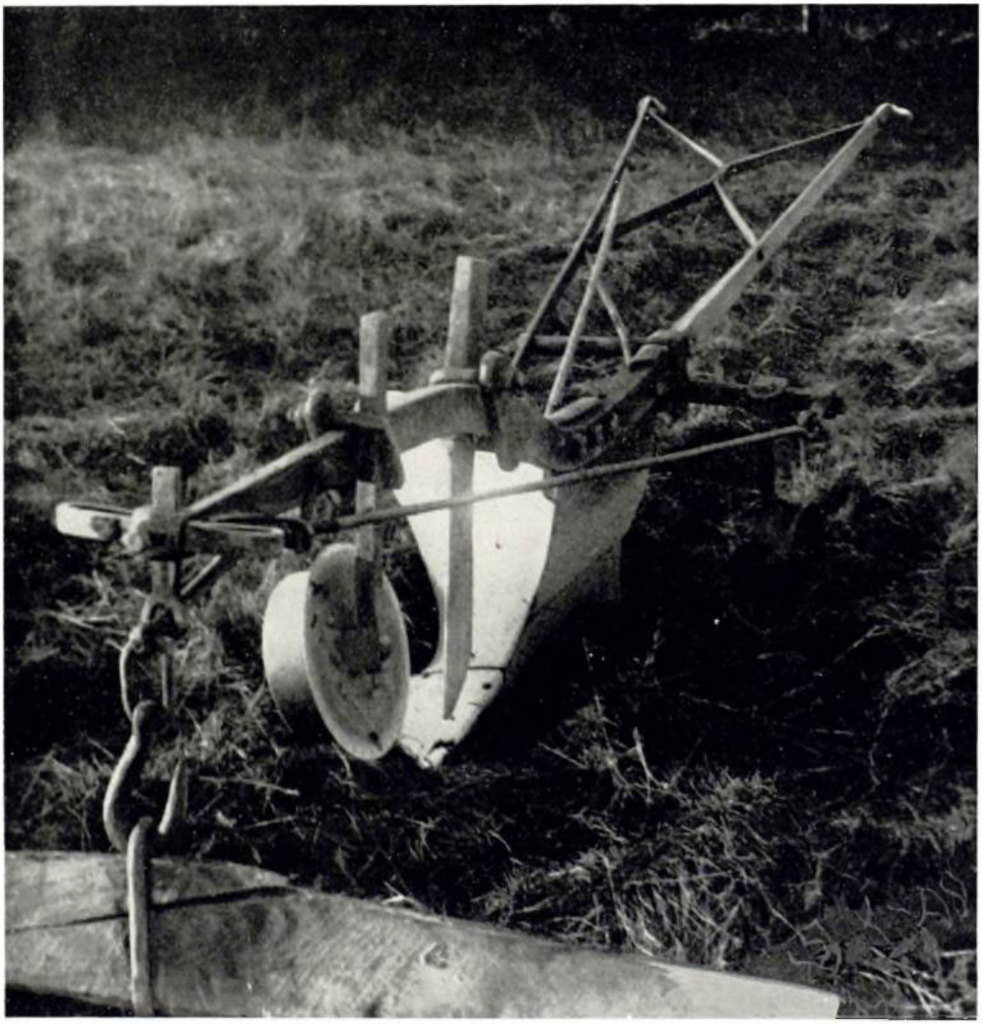

Plate 8. The specially-built horse-drawn plough used at Teindland, 1928–32.

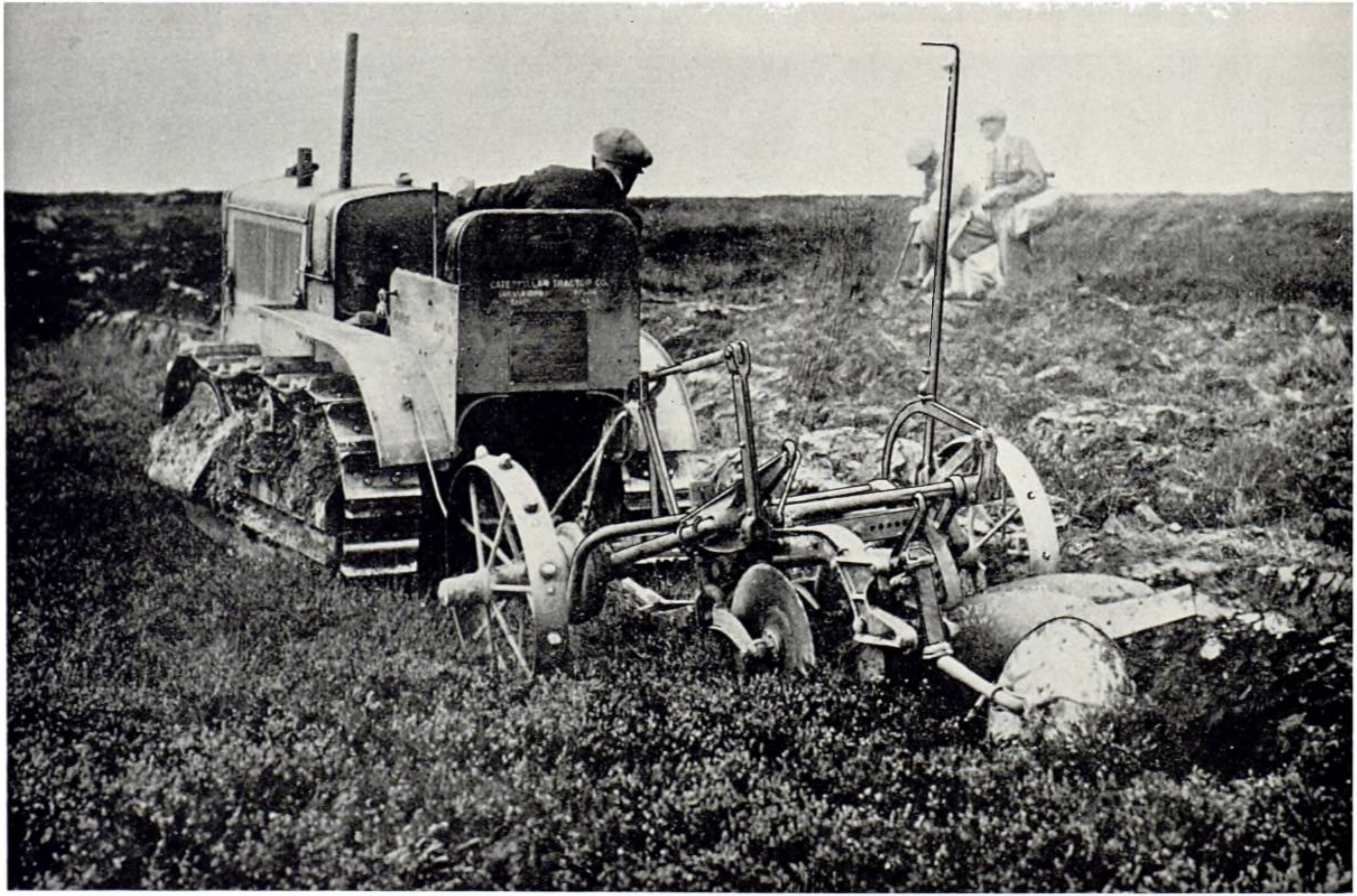

Plate 9. Ploughing with the Caterpillar 'Twenty' tractor and Oliver double-furrow plough at Wykeham, Allerston, 1930.

Plate 10. R.L.R. Heavy single-furrow plough drawn by a crawler tractor of 40 draw-bar horsepower; rear view of outfit at work.

Plate 11. Ground ploughed by the R.L.R. single-furrow plough at Broxa, Langdale Forest, 1954. Note Japanese larch planted in the furrow sides.

Plate 12. International T.D.9 tractor with mounted tine plough and hydraulic lift, Strathdearn Forest, 1952.

Plate 13. Trailed tine plough, Black Isle, 1957. The most widely used plough for heathlands at the present time (1959). Note the sock at the rear, which carries the actual tine.

Plate 14. Ground tine-ploughed at Harwood Dale, Langdale, in 1954 without damage to the equipment. (Experiment 41.P.54). An unploughed ride can be seen on the left.

Plate 15. Findlay's Seat, Teindland. Experiment 13.P.26, photographed 1958. Scots pine directly notched in foreground, drains at 16 feet intervals beyond.

Plate 16. Broxa, Langdale Forest, Experiment 8.P.43, photographed 1952. Ten-year-old plantation of Corsican pine and Sitka spruce, with phosphates. Ploughed on left, control on right.

Plate 17. Findon Forest, Experiment 1.P.29, photographed 1958. Provenance of Scots pine. Directly planted on old pine site. Foreground plants from Sierra Nevada, Spain, background from Strathconon, Scotland; between these two a plot from Borzhia, Russia, has failed.

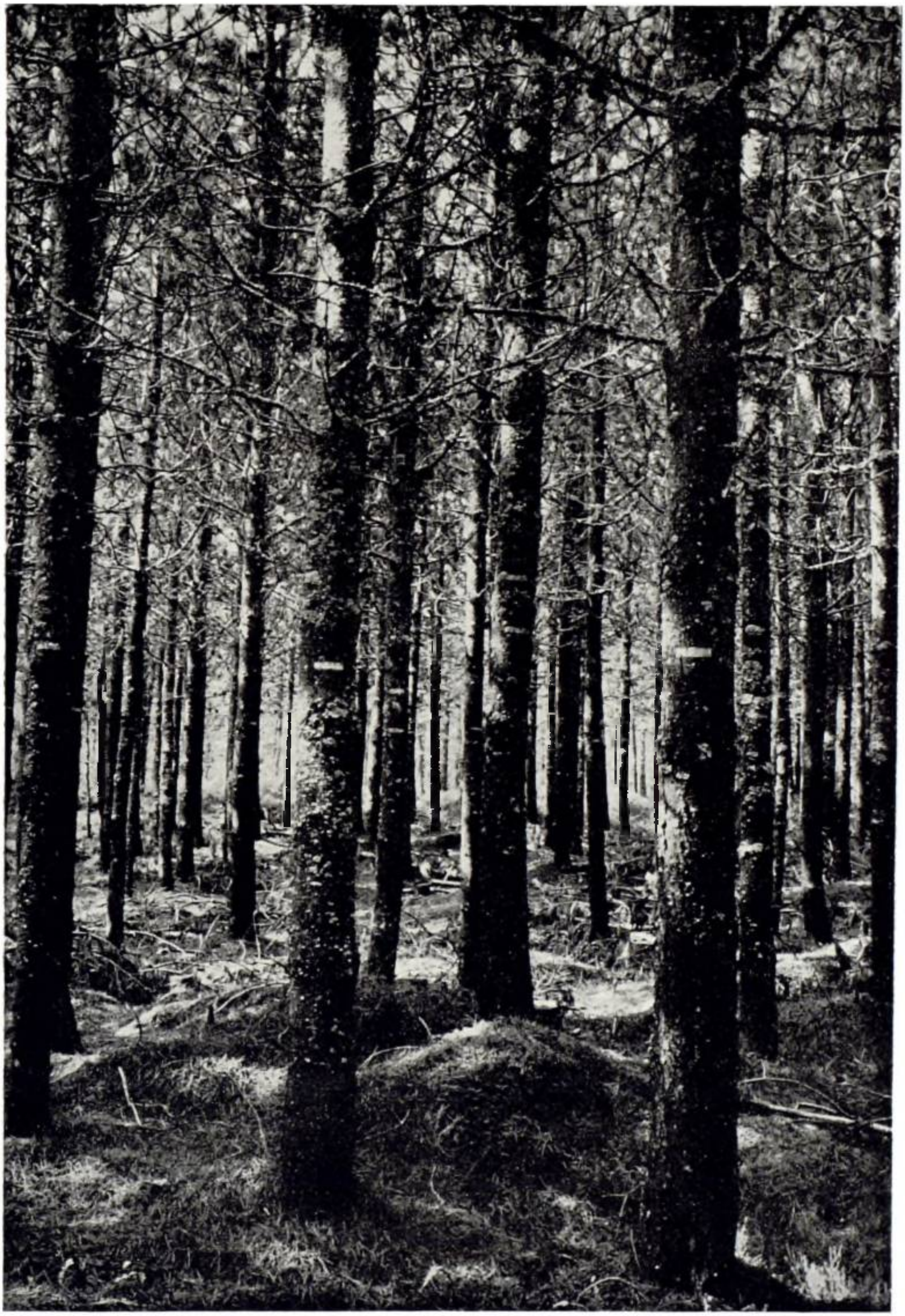

Plate 18. Teindland Experiment 41.P.29, photographed 1958. Lodgepole pine of the slow-growing 'Alberta' provenance on shallow triple-furrow ploughing with phosphates. (Stand data in Table 50.)

Plate 19. Wykeham, Allerston, Experiment 14.P.31, photographed 1957. Japanese larch on moderately deep double-furrow ploughed land, with phosphate. Quality Class IV at 26 years. (Stand data in Table 14.)

Plate 20. Broxa, Langdale, Experiment 11.P.43. Ten-year-old *Abies grandis* nursed by broom and Scots pine; planted with phosphate on ploughed ground. (Data in Table 40.)

Plate 21. Wykeham 23.P.32. One of the best birch plots on the heaths, aged 27 years.

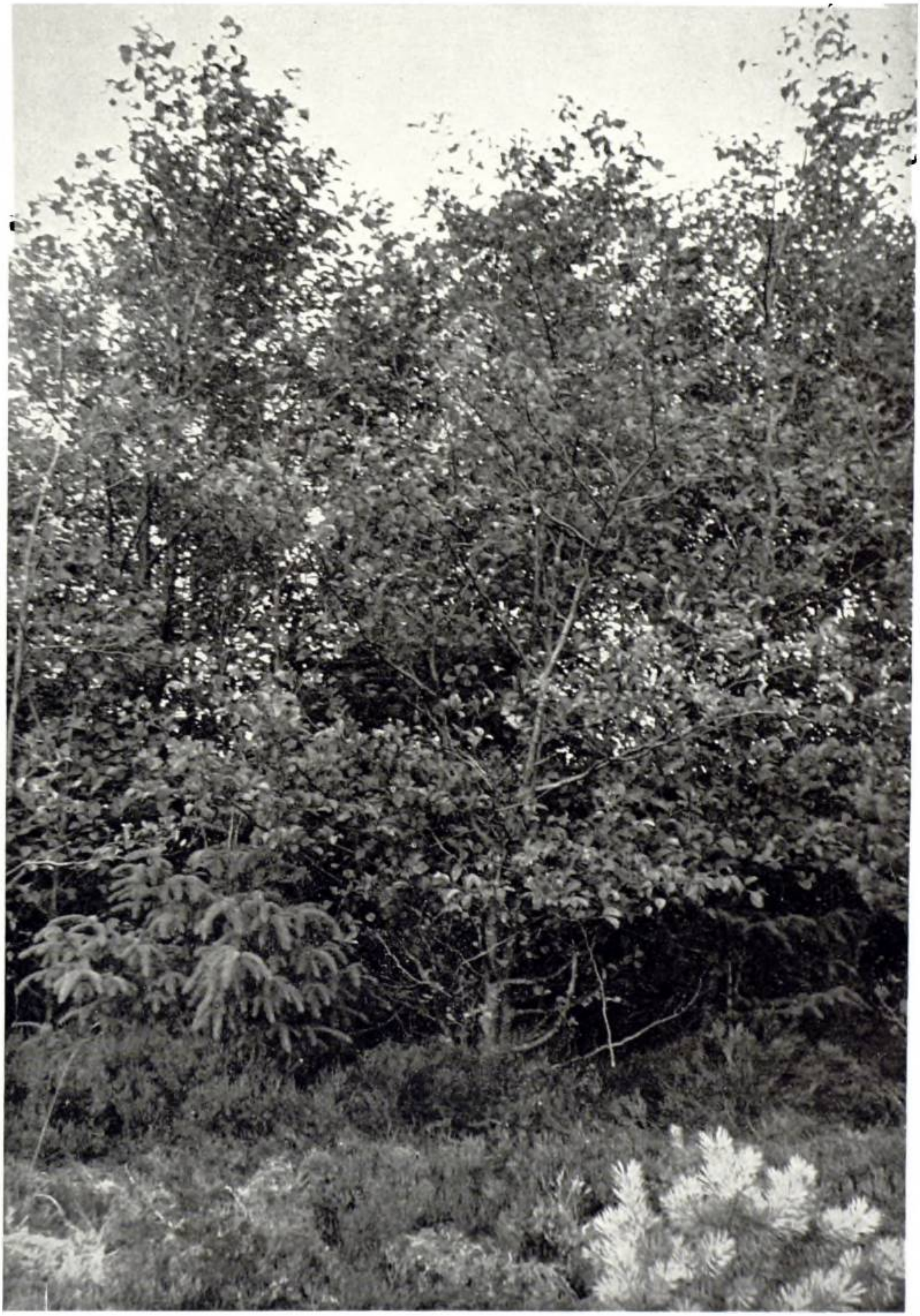

Plate 22. Dornoch 1.P.36, photographed 1952. Oregon alder growing where three-feet deep drains were cut and soil spread. (Data in Table 8.)

Plate 23. Teindland, Experiment 23.P.27, photographed 1958. Western hemlock and lodgepole pine on shallow ploughing. Right to left: phosphate at 5 cwt. per acre; control; phosphate. (Data in Figure 9.)

Plate 24. Teindland, Experiment 41.P.29, photographed 1958. Lodgepole pine on shallow triple-furrow ploughing. On left control, on right with one ounce phosphate. (Stand data in Table 50.)

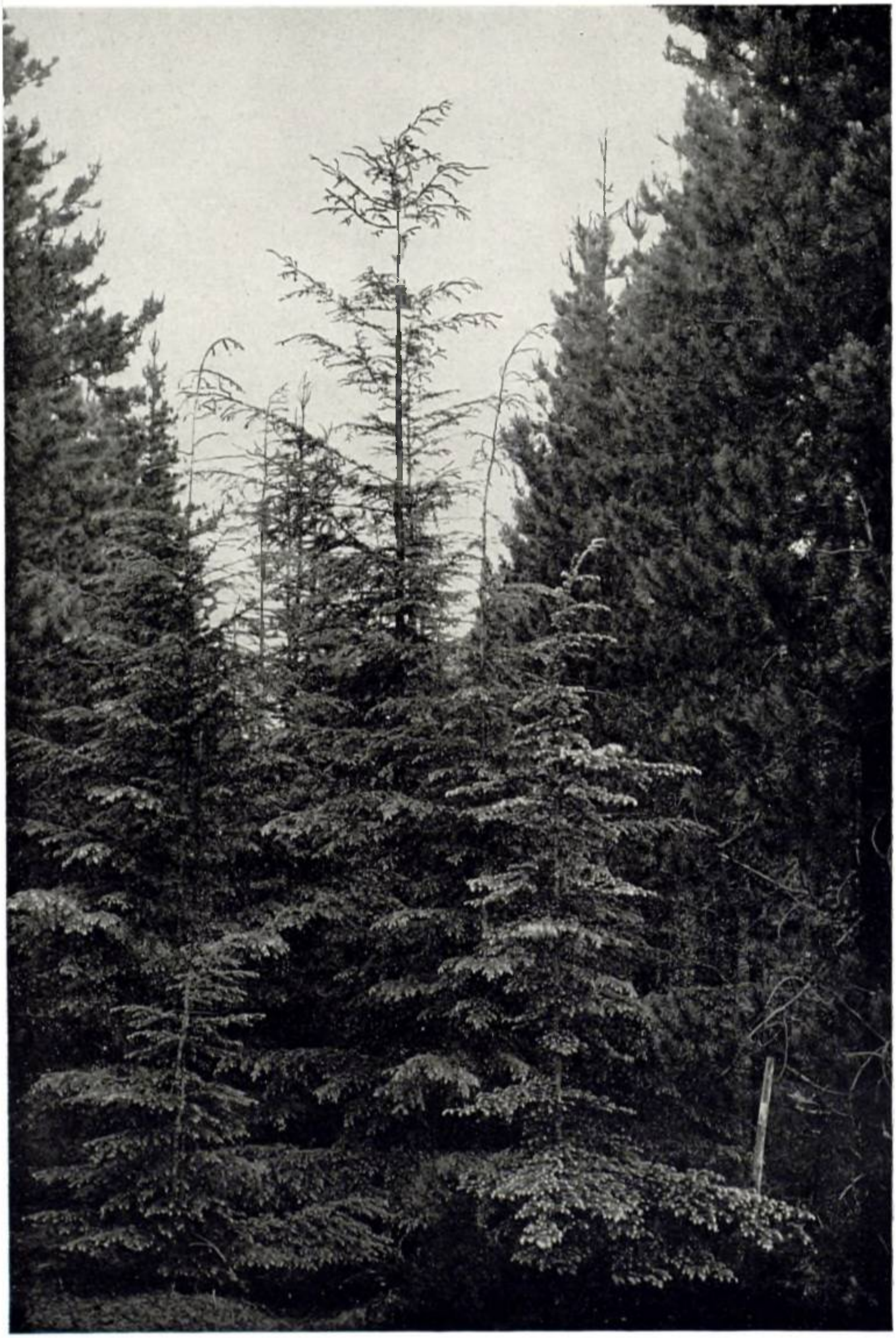

Plate 25. Teindland, Experiment 41.P.29, photographed 1958. Twenty-year-old western hemlock, between strips of thirty-year-old lodgepole pine. The hemlock was introduced on fresh ploughing in 1939.

Plate 26. Clashindarroch. 5.P.31, photographed 1952. A saucer-shaped crop of Sitka spruce surrounded by lodgepole pine; both are on ploughed ground with phosphate. (In the foreground notch-planted Sitka spruce are seen in check.)

Plate 27. Wykeham. 6.P.28, photographed 1952. Intimate mixture of Scots pine and Sitka spruce on shallow ploughing with phosphate. In spite of thinning and cutting back of pine, the spruce is barely keeping pace with it.

Plate 28. Wykeham, 6.P.28, photographed 1952. Strips of Sitka spruce originally forming the 'pure' plots as controls to mixture shown in Plate 27, flanked by Corsican pine to left and Scots pine to right. In foreground notched spruce, in background shallow ploughing with phosphate. (Data in Figure 5.)

Plate 29. Wykeham, Allerston. 11.P.31, photographed 1940. Adjacent plots of Japanese larch (left) and Sitka spruce on complete moderately deep ploughing with one ounce phosphate. The vigour of the spruce increases greatly with proximity to the larch.

Plate 30. Wykeham. 58.P.39. Lawson cypress were planted on ploughed ground with phosphate in 1939, those at left were heavily mulched with cut heather in 1944. Photograph taken in 1958.

Plate 31. Clashindarroch. 11.P.33. Shelter strips on an exposed ridge at 1,260 feet elevation. In foreground Scots pine. In rear mountain pine. (Data in Table 42.) Photograph taken in 1958.

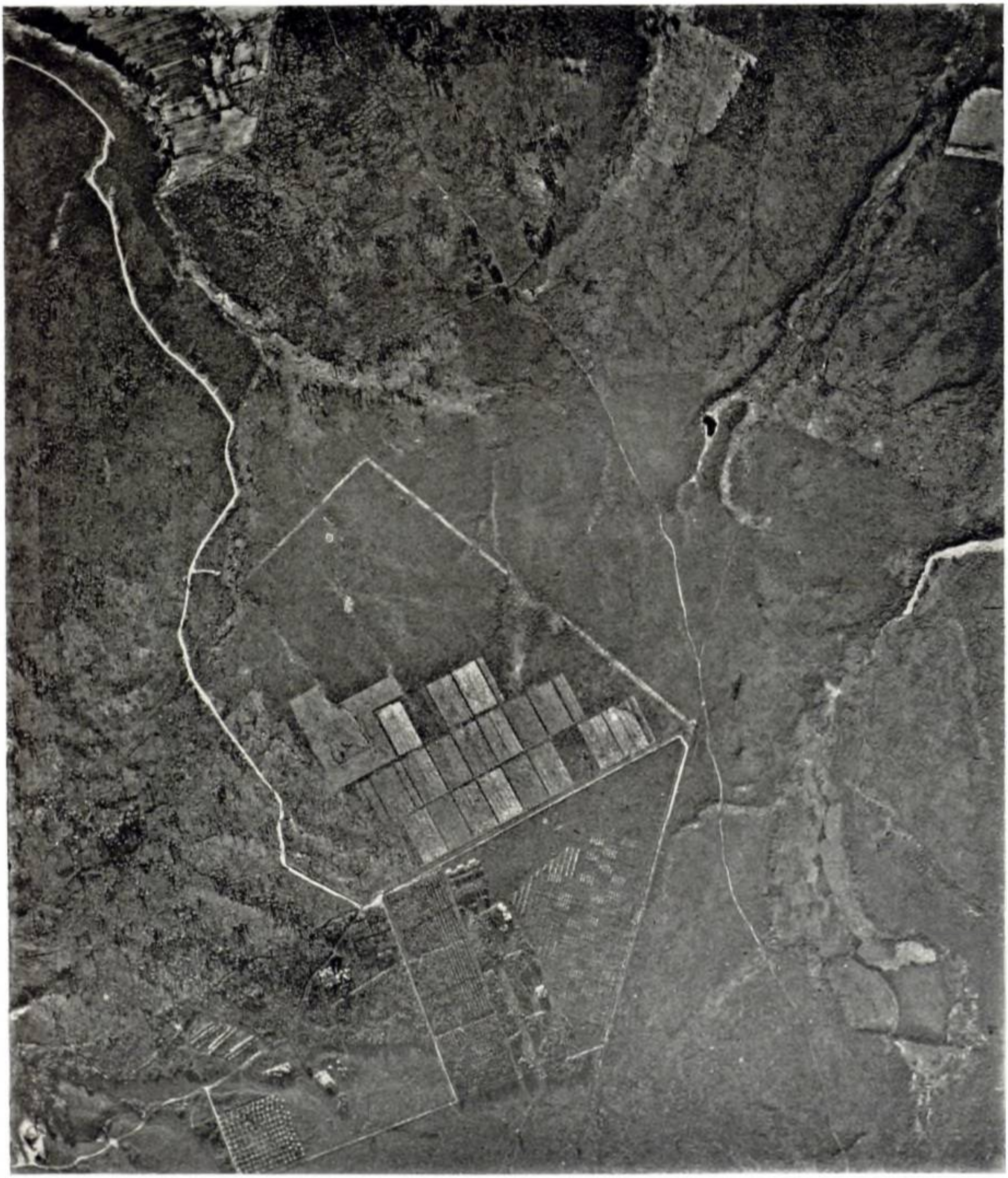

Plate 32. Teindland, 1954. Aerial view of Findlay's Seat. (Scale approx. 6 inches to one mile.) The older experiments which survived the fire of 1942 are at lower left. The eighteen plots of the major ploughing experiment planted in 1952 are clearly seen. (See Key in Plate 33.) (Royal Air Force Photograph.)

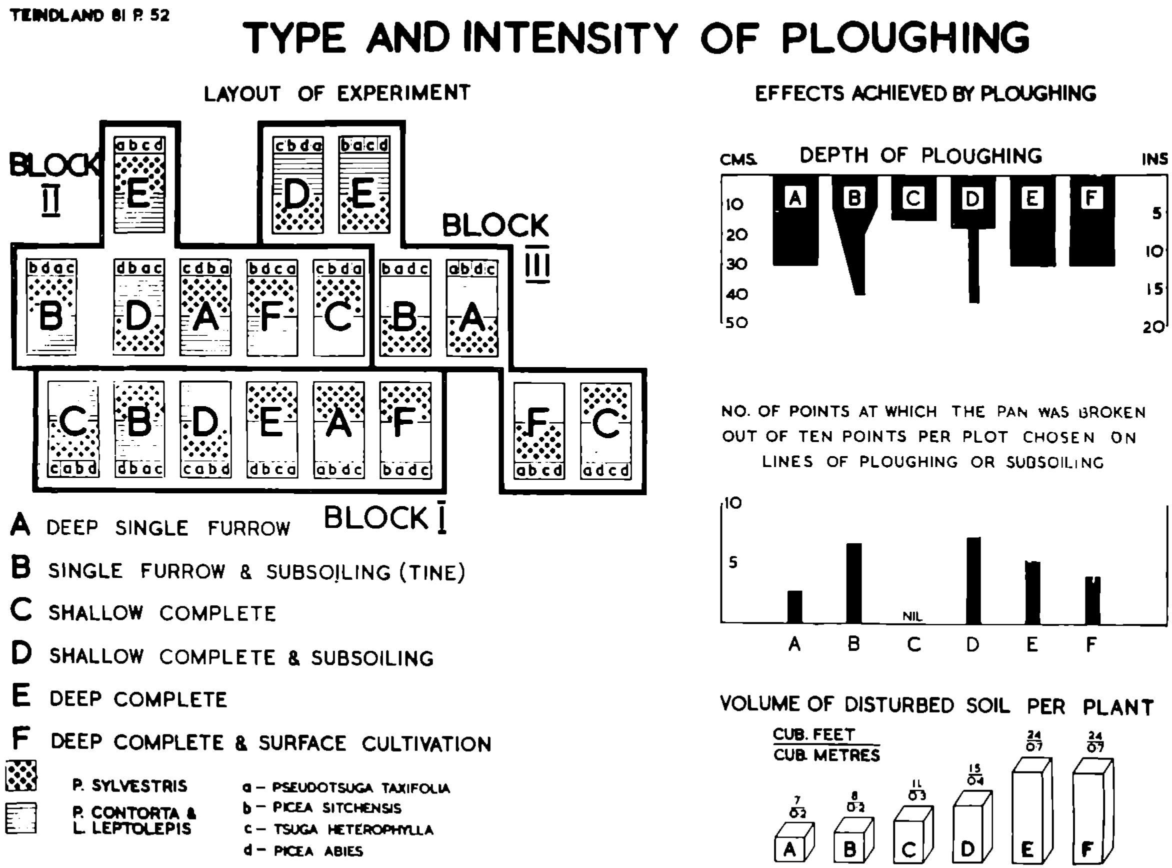

Plate 33. Scheme of the Major ploughing experiment: Teindland, 81.P.52, showing layout and effects achieved. Certain treatments are readily distinguished in the aerial photograph, Plate 32 above.

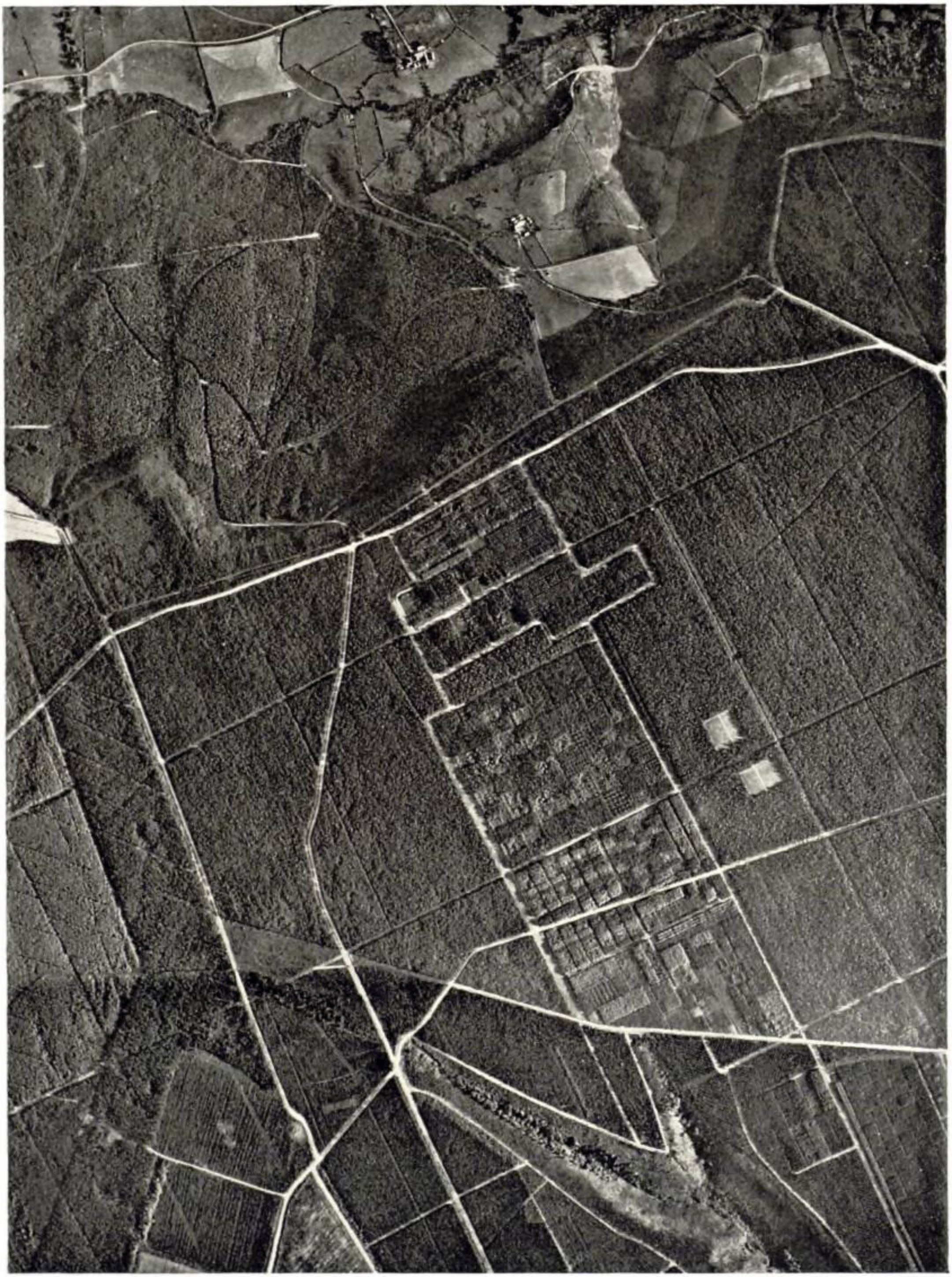

Plate 34. Wykeham, Allerston, 1953. Aerial view showing the main research area containing some 60 experiments, comprising many hundreds of plots. (Scale approx. 6 inches to one mile.) The shadow cast by the 400-foot escarpment may be seen at the top, while at the foot a dale head reaches the experimental area. (Royal Air Force Photograph.)

to thinning Scots pine and other common conifers. The data given in Table 36 (page 85) show that this procedure leaves stands with very high numbers of stems, as compared to Scots pine stands of the same height. It seems unlikely that such high basal areas are necessary to maintain increment, and that, judged by the density of canopy, an apparently heavier thinning is required to make the best use of the vigorous growth of this species. It is noteworthy that the finest experimental stand on a heath, that at Inchnacardoch, is the only one where the number of stems falls near that of the Scots pine yield tables.

Natural Regeneration

Profuse natural regeneration of lodgepole pine has occurred on areas of soil disturbance at Inchnacardoch and Wykeham.

Summary

It may be concluded that this species is of great potential use in the afforestation of all the more difficult heaths, both on poor land dominated by *Trichophorum caespitosum* and also in exposure beyond the limits of Scots pine. While lodgepole pine is being used on an increasing scale, some doubts remain as to the value of its timber.

EUROPEAN LARCH

Larix decidua Mill.

European larch was commonly used in mixture with Scots pine on the heaths long before the Forestry Commission started work. It had succeeded on the more favourable sites, but had failed on others, such as the middle slopes of Teindland, where Scots pine formed a crop. Its use was extended in the period 1920-35, but unfortunately many of the plants were raised from seed of unsuitable foreign origin. From about 1935-45 promising young plantations were ravaged with dieback; Clashindarroch Forest suffering particularly severely. As a result, planting of the species was virtually abandoned, and many of the diseased plantations were underplanted, mainly with Sitka spruce. The attack however died down, and the survivors have made a remarkable recovery over large areas, though in some stands not enough trees of good form remained to form a full final crop. Gradually planting has been resumed, and today the limiting factor in the employment of European larch is often the availability of seed of proven good origin. A great deal of evidence is available on this subject, and only a brief resumé is given below.

Provenance

The position may be summarised in that seed of Alpine origin is likely to give poor results, but that good plantations have been raised from European larch seed collected in Scotland. The original provenance of the parent stands is still unknown, even after intensive research over many years. Edwards (1954) has shown that the difference between poor Alpine and good provenances is accentuated under adverse conditions, typified by the heathland forests. Thus larch of Swiss, Silesian and Scottish origin all grew well at Lael Forest, Ross-shire, and Drummond Hill Forest, Perthshire, both areas which had previously borne excellent crops of larch. On the other hand, in an identical experiment under heath conditions at Clashindarroch (1.P.31), the growth of the best Scottish provenance was fifty per cent superior to Alpine, while the incidence of canker and the number of failures were much greater in the Alpine plots.

The main provenance collections from which results are available lie at Clashindarroch (1, 8, 18, 19 & 21.P.31-38), which for the most part are on good heath sites without a marked pan, though in certain cases they extend on to poor land and into considerable exposure. Other important experiments are a comparison of four selected provenances at Durris (1.P.40), where Scottish, Italian, Austrian and Sudeten larch are compared in half-acre plots; and a replanting of an area of severe die-back with various provenances and other species of larch at Drumtochty (4.P.51). All these experiments were planted with hand methods of ground preparation, and in most cases without phosphate.

In the earlier experiments on the heaths of northern England, plants from Alpine seed were used almost exclusively, and considerable failures took place (Wykeham 2.P.28 and Hamsterley 1 & 5.P.29-30). With shallow ploughing there was rather better survival, but crops of poor form have been obtained (Wykeham 8.P.29), or the slow growth has led to the suppression of the larch by pine nurses (Wykeham 9.P.29). With deeper ploughing and phosphate, even Alpine larch can form passable crops, as seen in the second major ploughing trial at Wykeham (Figure 6, p. 46). Clearly it is not only site that influences the relative growth of various provenances, but also the ground preparation and manurial treatment.

It may also be seen from provenance collections that certain imported provenances appear to be suitable for the more difficult sites, and in particular the variety *sudetica* Domin., may be mentioned. A further point is that not all Scottish origins have proved satisfactory, and it is probable that some stands used for collection are themselves of Alpine origin. In the notes which follow reference is made exclusively to the behaviour of larch from Scottish seed unless stated to the contrary.

Comparative Growth

Table 31 sets out the heights attained by European larch in a number of experiments where it can be compared with Scots pine or Japanese larch. The growth rate is clearly intermediate, being faster than the pine but slower than Japanese larch. The examples from Clashindarroch bring out the rapid fall-off in growth with increasing altitude which is associated with poorer soils, greater exposure, and more rigorous climate. A further experiment on the spacing at planting of European larch on the steep face of the Mytice experimental area suggests a negative correlation between spacing and top height. In addition, regardless of spacing, the top height at twenty years falls by six feet per hundred feet of elevation over the range covered of 900–1,150 feet (Clashindarroch 26.P.37, see footnote to Table 31).

At Wykeham, where conditions are relatively uniform, the quality class of European larch at twenty-five years may be expected to be about 1½ classes below that of Scots pine; if this is still true at the age of fifty years, then production in pure plots would be only half that of Scots pine. Japanese larch is slightly taller than European, and the quality class is about the same (Japanese larch Q.C.I=90 ft., European larch Q.C.I=80 ft.). If continued, this means that the production of European larch at fifty years would be only two-thirds that of Japanese.

These figures strongly support the view that there is little point is making pure plantations of European larch on the heaths, where production will be low. On the other hand the good form seen in some of the mixed plots, and the continued existence of a price differential for the timber, supports the view that this species should be widely planted as a small proportion in predominantly pine crops. If growth is good it may, by judicious thinning, come to form a fair proportion of the final crop.

Reaction to Treatment

There are no experiments comparing the effects of various intensities of ground preparation for larch of Scottish origins. Three experiments investigated the response of larch to phosphate. At Wykeham, a 30 to 50 per cent increase in height was obtained over the first seven years, the actual increase in growth being 1½ to 2 feet (23.P.32 & 56.P.39); at Hamsterley, however, the response was only 20 per cent (10.P.40). No long-term plots have been laid out for this species, the largest being those of Alpine larch, for which results are given in Figure 6, which is discussed on page 46. It seems that manuring is not normally necessary, as in general European larch is employed on better ground than is Japanese.

TABLE 31: EUROPEAN LARCH

Comparison of the growth of European larch with that of Japanese larch and Scots pine in various experimental areas.

Experiment and treatment	*Age yrs.*	*Provenance of European larch*	*Dominant Height and Quality Class*		
			European larch	*Japanese larch*	*Scots pine*
Clashindarroch. Notched, no manure					
2 & 3.P.31 1,300 ft.	25	East Scotland	4.6	—	3.4
24 & 25.P.37 700 ft.	20	N.E. Scotland	23 IV–V	—	22 II–III
Wykeham					
4A.P.32 Dug patches+phosphate .... Species in mixed groups	25	Blervie, Moray	30 IV	—	30 II
22 & 23.P.32 Ploughed+phosphate	25	Cawdor, Nairn	36 III	38 IV	—
41.P.36 (SP 43.P.35) Ploughed+phosphate	18	Ebberston, Yorks.	24 IV	—	19 II–III
56 & 57.P.39 Ploughed+phosphate	17	North Tyrol, Austria	26 III–IV	28 III–IV	—
Hamsterley, Ploughed+phosphate 10.P.40	15	Darnaway, Moray	21 IV	22 IV	18 II

Note: Dominant heights at 20 years in Clashindarroch 26.P.37 at 1,100 ft.

Spacing:— 3 x 3 ft. 14 ft.
4½ x 4½ ft. 12½ ft.
6 x 6 ft. 11 ft.
8 x 8 ft. 9 ft. } European larch.

At 950 ft. in the same experiment spacing has now no effect, though at 12 years old there was, here also, an apparent increase in height with closer spacing.

Type of Planting Stock

In the earlier experiments, 2+1 or 2+2 transplants were used, but as early as 1931 trials were made with one-year seedlings on ploughing, and seedlings were also tested in the provenance trials discussed above. One-year seedlings of Alpine provenance "extended" from nursery experiments grew well on moderately deep ploughing at Wykeham (16.P.31), but without ploughing and in exposure at Clashindarroch, two-year seedlings lagged behind 2+1 transplants, even though planted a year earlier (1.P.31). The present practice is to use 1+1 transplants almost entirely.

Growth in Mixture

European larch has traditionally been grown in mixture with Scots pine, and after the disastrous die-back in pure crops, and with shortage of plants, this method of planting is now almost the rule on the heaths. Comprehensive early experiments at Hamsterley aimed at comparing mixtures in varying proportions of these species, but the trials were vitiated by the use of Alpine larch. Unfortunately, they have not been repeated, and the experimental evidence is meagre. There is one successful trial using dug-over patches with phosphate to raise Scots pine and European larch in mixture in spaced groups at Wykeham (4A.P.32). Here the top heights are exactly even, some groups being dominated by pine and others by larch, which is of good form. Different thinning regimes are now being employed in the plantation, either to favour the larch, or to favour the best tree regardless of species, while controls remain unthinned in order to test the theories underlying the spaced group method (Chapter 12). The only other relevant experiment is at Clashindarroch (4.P.31); it compares various methods of raising European larch in exposure and high altitude, with particular reference to the spaced group method, and is further discussed in that connection; growth so far has been very slow, and the Scots pine planted as a nurse has fallen behind the larch.

On the Scottish heaths at the present time (1958) a system is in use on some scale whereby a small proportion of larch at wide spacing are planted through pine crops (15 ft. × 15 ft. = 200 per acre). This makes the best use of the limited supplies and few should be cut in early thinnings, since the larch almost always grows faster than the pine at the start, so that the final crop may be as high as fifty per cent larch.

The single promising trial of European larch in mixture with Corsican pine at Hamsterley has been noted in the section on the latter species.

Thinning

The only differential thinning undertaken with European larch on the heaths has been the use of light to very heavy low thinnings in an area severely attacked by die-back at Clashindarroch (Experiment 32). Thinning was begun in 1944 when the crop was nine years old, but so far no effect on the growth of the dominants has been recorded, though in the meanwhile the crop as a whole has recovered from the attack and deaths have ceased.

Summary

The limits to which European larch may be grown with modern techniques of establishment have not been determined, but the more extensive plantings now in hand should provide information in due course. There is room for the extension of experimental work on its use in mixture with pine, which is the present practice. It would appear that a proportion of larch could be grown in a large part of the areas planted in the past with pure pine, and that in view of the known value of the timber this would be economic. The amount of natural regeneration found near old stands on the heaths suggests that, if introduced in the first rotation, European larch would maintain its position thereafter.

JAPANESE LARCH

Larix leptolepis Murray

Japanese larch is one of the important new species brought on to the heaths during the present century. It is now playing a varied role: as a crop in its own right; as an alternative to European larch; a beat-up species for Scots pine; a nurse for Sitka spruce, and as the most efficient species for forming fire-belts. As a result of this variety of employment, it is found in every heath forest, often widely dispersed in its different roles, and although there are few large pure blocks, it ranks second to Scots pine in total area, forming about 15 per cent of the stocking at the present time. This proportion however varies considerably from place to place, being very much less on the northern heaths beyond the Great Glen.

The future position of Japanese larch is not so easy to determine. There are in some quarters doubts as to the value of its timber as an alternative to that of European larch, though in some areas it is readily accepted. There have also been doubts as to the continuance of the rapid early growth so far seen, and a falling-off in height increment was shown in early yield tables; but with the accumulation of additional data, this feature was first reduced and finally eliminated in the latest edition (*Revised Yield Tables for Conifers*. Forest Record 24, 1953). The value of this species should be resolved as more timber becomes available in the next decade or so, since enough was planted, both on heaths and elsewhere, in the early days of the Forestry Commission for there to be a steady supply on which its merits may be judged. It is fortunate that Japanese larch has escaped a period of over-planting followed by the inevitable reaction, such as has occurred in turn with European larch, Corsican pine and Sitka spruce on the heaths. As its silvicultural value has emerged, planting has been steadily increasing, with a break from 1942 to 1948, when only limited amounts of seed (all of it home-collected) were available.

Comparative Growth

Failures of Japanese larch occurred in early experiments at Allerston and Hamsterley, where the ground was prepared by hand (Wykeham 2.P.28 & Hamsterley 1. & 5. P.29-30), or with shallow ploughing (Wykeham 9.P.29), though other plots on shallow ploughing grew quite well (Wykeham 6.P.28). It was not until deeper ploughing and phosphate were used that very rapid growth and early closure of canopy became common. From this has emerged the use of Japanese larch as a nurse and as a fire-belt species, both of which functions have been shown to depend largely on the rapid suppression of the heather.

Tables 29 (p. 73), already discussed in connection with lodgepole pine, and 36 (p. 85), provide also comparable figures where available, of height growth and stand data for Japanese larch. Clearly, once the initial establishment problems had been solved, it grew rapidly, and produced twice the volume that Scots pine did, on the sites covered by the earlier research plantings, and it maintains this position up to an age of at least thirty years. That this conclusion may not hold in later years is suggested by the data in Table 38 discussed on page 85. On the more difficult heath sites now being planted Japanese larch suffers more from exposure, and early results from the newer plantings show that lodgepole pine is the fastest species. It is to be hoped that the larch will make better growth when the pine with which they are mixed are large enough to provide shelter.

Reaction to Treatment

The reasons for the rise of this species to prominence on the heaths is well illustrated by the experiments, for the summaries of ploughing results in Table 11 (p. 45) and manuring results in Table 49 (p. 111) show how strongly Japanese larch responds to increased intensity of ground preparation, and to phosphatic manuring. By their combination, the early growth rate may be increased two to three times, while the early heavy failures are at the same time reduced to negligible proportions. For this reason it has been widely used as an indicator species for all the experiments concerned with establishment, since both losses and early growth provide an early indication of the effectiveness, or otherwise, of the experimental treatments.

Provenance

The single provenance trial of this species is at Clashindarroch, and compares progeny from individual parent trees in Japan. Differences in form and vigour have been observed, but they are not great and there appears to be as much variation in form between trees from one seed source as between those from different sources (23.P.38).

Type of Planting Stock

Japanese larch suffered severe losses in early trials comparable to those of Corsican pine. The causes however were found to be different and data given in Chapter 5 have shown adequate ground preparation to be the outstanding need of this species, while results to be given in Chapter 8 show that phosphatic manuring plays almost as important a part. There have been, however, a number of straightforward comparisons of different ages of planting stock and these are summarised in Table 32. Transplants have always been superior to seedlings and 1+1 stock is now generally used.

The extensive trials at Fetteresso have shown, as with pine, very heavy losses even with carefully selected seedlings, while losses of transplants leave little room for complacency. In recent years, tests of two-year-old plants undercut in their second season (1-U-1) have been made, in comparison with seedlings and transplants of identical age and origin (2+0 and 1+1). These trials have shown that the undercut plants are rather poorer than the transplants, and until losses of the latter can be kept consistently below 10 per cent it would appear rash to employ, on a large scale, any type of plant known to be inferior.

From time to time, in a favourable season, larch transplants are likely to become overgrown in the nursery or, on the other hand, seedlings too small to handle at one year may be too large after a second season. Two experiments tested the response to cutting back at planting in the forest. At Wykeham 2+1 transplants up to two feet tall were cut back to six inches (21.P.32). The first season was favourable and losses of both pruned plants and controls were negligible, but the latter suffered some distortion by wind-sway. After seven years the controls were still taller, so that in this case there was no need to have tried pruning. In a somewhat similar trial at Teindland, 1+1+1 plants were cut back at planting, or one year later (PT. 37/4). Here cutting-back doubled losses, reduced height growth, while in addition many of the pruned plants formed

TABLE 32: AGE AND TYPE OF JAPANESE LARCH

Losses and mean heights in a number of experiments.

Age and type of plants			*Seedlings* (1+0 *unless noted*)			*Transplants* (1+1 *unless noted*)		
Experiment	*Phosphate*	*Age yrs.*		%	*Feet*		%	*Feet*
Wykeham 22.P.32	1 oz.	8		8‡	5.4	2+1	10	7.7
Wykeham 20.P.32	1 oz.	8		28‡	4.8		—	—
puddled before dispatch				16	5.4		—	—
Wykeham 26.P.33†	Nil	8		59	1.4		28	6.9
	1 oz.			30	5.9		11	11.4
Clashindarroch 5.P.31	Nil	6	2+0	24	3.2	2+1	2	5.4
Fetteresso 3.P.51	2 ozs.	3		52	—		16	—
(Samples of 52	,,	3		48	—		8	—
seedlings 53	,,	3		37	—		28	—
planted over 54	,,	3		54	—		10	—
large areas) 55	,,	1		51	—		32	—
Mean of 5 seasons	—	—		44	—		18	—

Notes: All experiments were on ploughed ground.
‡ Identical planting stock planted in the first experiment on Feb. 19th and in the second on March 14th.
† Rough fresh ploughing.

multiple leaders or were otherwise of poor form, a feature not seen at Wykeham where the majority formed a satisfactory leader. These trials do not lend any support to the belief that cutting back may assist overgrown stock, but much more evidence would be required to draw a firm conclusion.

Use in Mixture

Japanese larch has been widely used as a nurse, particularly for Sitka spruce, following the demonstration from contiguous experimental plots of the remarkable recovery from check made by adjacent spruce. This phenomenon is considered in Chapter 9 together with the whole problem of the use of nurse crops.

Of long-term mixtures there are only a few plots in mixture with lodgepole pine. Early attempts to form this mixture at Hamsterley failed, as did plots mixed with Corsican pine, owing to severe attacks of blackgame coupled with the use of hand preparation. At Clashindarroch, there are plots of lodgepole pine and Japanese larch where, planted in alternate single lines, the larch outgrew the pine, but are of poor form so that the crop has been thinned to retain the best-formed trees regardless of species, which means in this case the best larch with pine as a filler; stand data is given in Table 36 (p. 85). In contrast, at Hamsterley, in alternate plant mixtures with very vigorous shore pine, the larch has been outgrown, and it seems unlikely that application of the same principle of thinning will save more than a small proportion of larch (Hamsterley 10.P.40).

In recent years mixtures of lodgepole pine and Japanese larch have been planted on several of the poorer heaths or in pilot plantations, either in close admixture, with one larch to three pine, or on rather better sites with alternating bands of three lines of each species. Since the growth rates have been shown to be similar, it is hoped to shelter the larch with the pine, so that the crop should be of better form than if pure larch was used, and of more value than pure lodgepole pine. For the large scale ploughing experiment recently carried out at Teindland, this mixture was used as a possible 'economic' crop to compare with the native Scots pine (Teindland 81.P.52).

Thinning

A single small-scale trial has been made at Wykeham in order to see how far the diameter growth of the larch could be increased on a heath. This trial was made because of fears that the rapid height increment made by pole-stage crops might not continue, and also because long rotations are not expected to be economic for this species. Differential thinning was started in 1944 in a close-spaced thirteen-year-old plantation then about twenty feet tall. Frequent thinnings have been made, and after nine years, aged twenty-two years, the top height was thirty-three feet (=Q.C. IV); while the girth of the 100 largest trees per acre had reached twenty-one inches in heavily thinned plots, as opposed to eighteen and a half in moderately and lightly thinned sections. This latter girth exceeds the girth shown in the current yield tables, and shows that there can be considerable flexibility in thinning, even on these sites of low fertility. These figures and estimates of basal area and volume, suggest that regardless of thinning treatment, height is low in relation to basal area and production, presumably due to exposure. Few if any plots from heath sites will in fact have supplied data for the present yield tables.

Underplanting

The belief that Japanese larch might be used on short rotations on the heath led also to underplanting trials in some of the first plots which closed canopy at Wykeham. This operation was carried out far earlier than would be used in general practice, and was followed by the slaughter of the overcrop at an uneconomic age. The detailed results of these trials are considered in Chapter 7, as trials of the various underplant species, but in general it may be said that the bare forest floor with thin needle litter of Japanese larch has proved a very suitable medium for underplanting, and that a variety of species can be grown that cannot be used in the open moor without intensive methods, such as the raising of broom as a nurse.

Summary

It is clear that this species is playing an important part in the heathland afforestations, but that its future will only be clear when longer term results are available, particularly as regards productivity.

HYBRID LARCH

Larix eurolepis A. Henry

Hybrid larch has been planted on a small scale in most of the experimental areas, particularly in the provenance collections, and has also been used as an indicator in a number of experiments. But owing to shortage of plants of the first generation, or of seed from hybrid stands, it does not play a great part in the heath forests. There are in all perhaps 500 acres of hybrid larch plantations in the widest sense of the word. There is a considerable amount of evidence to show that the early growth rate is faster than that of either parent, and it has recently been shown by Edwards (1956), that this is partly due to the method of selecting heterotic plants in the seed-beds to form the first generation hybrid stands.

There are in the heath experiments one or two cases of outstandingly better growth by the hybrid larch, as in certain early experiments at Teindland, (47 & 48.P.32) but in general the growth is only a little superior to that of Japanese larch. Hybrid individuals showing heterotic vigour are a common feature in many plantations of Japanese larch, and also in some European larch stands. In addition what is apparently hybrid regeneration is taking place where soil is disturbed and both parents are present, as on bull-dozed fire rides at Wykeham.

As thinning will tend to preserve these vigorous hybrid individuals, even where only a small number are present, it is to be expected that they will come to form a much higher proportion of the final crop. It is indeed doubtful whether in later rotations on the heathlands any plantations of pure European or Japanese larch will be distinguishable, except where the plants are the products of controlled pollination. The future policy with regard to the use of these species must depend on the relative production and on the value placed on the timber of the hybrid, as compared to that of the parents.

SITKA SPRUCE

Picea sitchensis Carr

Sitka spruce, though widely planted on the heaths, is in rather a different category to the other species considered in this chapter. More experiments have been devoted to its establishment than to any other problem, but the reason for the persistence with this species is not far to seek. Firstly, Sitka spruce is known to be relatively more productive than other species on many poor sites, especially wet and peaty areas, to which the wetter heaths bear a strong, though sometimes only superficial, resemblance. Secondly, this species is second to none in its resistance and good form, under conditions of severe exposure, which are a marked feature of so many of the heathland forests. Finally, though there have been many disappointments through the onset of the checked condition often found when spruces are planted on heathlands, there have been for twenty years outstanding examples where check has been reduced or overcome, so that good early growth has been obtained.

Thus it is that the establishment of Sitka spruce has played such a large and in some cases perhaps a disproportionate part in the research on heathland planting. Virtually every experiment containing mixtures, or testing the use of nurse crops, contains Sitka spruce as the principal successor species. These experiments form the subject of Chapter 9, and the sections which follow deal only with the other aspects of experimental work on this species.

Comparative Growth and Reaction to Treatment

The early growth rate of Sitka spruce depends entirely on the conditions of establishment. It ranges from complete check, during which the plant becomes yellow and all but ceases growth, though it may live for many years, up to extremely rapid growth when all the conditions of establishment are favourable. These conditions may be defined as the

TABLE 33: SITKA SPRUCE: BEST GROWTH OBTAINED

The best growth obtained at the various experimental areas, all results are from small units mixed with, or adjacent to other species.

Experiment	*Treatment (all received phosphate)*	*Age*	*Sitka spruce*		*Adjacent species*	
			Ht. Ft.	*Q.C.*	*Ht. Ft.*	*Q.C.*
Inchnacardoch .... PT. 34/6	Intensive hand digging (4 times) Mixed Scots pine, Japanese larch	20	20	V–VI	—	—
Teindland 23.P.28	Completely ploughed, heavy phosphate, redug, re-slagged 1935. Adjacent Scots pine	25	23	Below VI	Scots pine 24	III
Clashindarroch 7.P.31	Burnt over, completely ploughed, mixed with lodgepole pine in alternate lines	25	29	V–VI	Lodgepole pine† 29	II–III (S.P.)
Hamsterley‡ 5.P.30	Hand prepared positions, mixed with lodgepole pine, alternate plants	25	22	Below VI	Lodgepole pine† 22½	III (S.P.)
Wykeham 11.P.31	Complete ploughed, adjacent to Japanese larch	25	35	V	Japanese larch 36	IV
Broxa 9.P.43	Deep ploughing, broom and Scots pine nurses	13	15	—	Scots pine 13½	—

Notes: ‡ Only half the plants in this experiment received phosphate, but there was no increase in early growth in these sections, probably owing to the general heavy cropping by black game.
† The Quality Class set against these lodgepole pine entries relates to Scots pine, since no Classes have been defined for the former species in Britain.

elimination of heather competition by ploughing, and suppression of heather regrowth by a nurse crop, the stimulation of the spruce by phosphatic manuring or the use of legumes, together with the use of really vigorous, well balanced planting stock. Almost all the early trials of Sitka spruce on the heaths failed to meet these conditions; in particular the ploughing was inadequate to suppress the heather for more than a year or two, and checking of the spruce followed the re-invasion of the heather, now far more vigorous than before ploughing. The first signs that Sitka spruce might be successful were seen in experiments where it was planted in close proximity with other species, generally on complete ploughing or where additional cultiva ion was carried out after planting. It is in these early experiments that the largest Sitka spruce now on the heaths have been obtained. Table 33 lists them in comparison with the adjacent species. The growth of the spruce is in several cases just below that covered by the published yield tables (1953) and has been noted as equivalent to Quality Class V to VI. A calculation shows that the estimated yield for this quality at fifty years is 5,900 Hoppus feet per acre, which exceeds the yield of either Quality Class II Scots pine, or Quality Class II Japanese larch. Since the growth of these last species nowhere reaches this level in the experiments quoted, it would appear that on these sites the production of Sitka spruce may yet be superior to that of any other species. However it is not possible to raise the spruce pure, as will be shown in Chapter 9, and this may in any case be undesirable on the grounds of fertility maintenance. These experiments however are for many sites the justification of the use of spruce in mixtures, which has been such a prominent feature of heath planting in recent years.

Provenance

Nothing is known of the role which provenance differences may play on the heaths, and there are no provenance collections. The majority of the plants in the experiments have been raised from seed from the Queen Charlotte Islands.

Type of Planting Stock

Two-plus-one and two-plus-two transplants were used in all the earlier experiments. A series of trials using seedlings were planted at Wykeham when ploughing became the normal method, but in all cases the plants checked for several years when heather re-invaded (Wykeham 12, 13, 16-18, and 26.P.31-32). At Clashindarroch, on completely ploughed ground, although checking took place at a later stage, after six years the transplants, 2½ feet tall, were twice the size of seedlings (Clashindarroch 5.P.31).

TABLE 34: SITKA SPRUCE: NURSERY ORIGIN

Heights of plants raised in different nursery types, ten years after planting.

Heights in feet

Nursery type:—		Raised as seedlings:— Lined out in:—	Estab. Estab.	Heath Estab.	Heath Heath
	Experiment	Age of plant			
Rosedale	2.P.44	2+1	4.3	—	4.5
Broxa	13.P.44	2+1	3.9	—	4.3
„	16.P.45	1+1	4.4	5.4	6.0
„	19.P.46	1+0	5.1	—	5.4

Losses under 2 per cent. throughout.
Estab. =Established agricultural type nursery.
Heath = Heathland nursery with compost.

Such trials then ceased for over ten years, two-plus-one being the youngest stock used during this period. Then about 1943 trials were re-started with stock raised in the new heathland nurseries. Table 34 shows results, and demonstrates the superiority of the plants raised with compost on the heathland nurseries. Lining-out in heathland nurseries was not economic owing to the limited areas available. The practice therefore grew up of lining-out in established nurseries, plants raised as seedlings in heathland nurseries. Later experiments mainly compared this type of plant with seedlings and the traditional older transplants. Results given in Table 35 show that the 1+1 transplant may compare with a 2+1, but that the one-year seedling, though successful at Broxa, is quite useless in more extreme conditions, as at Fetteresso, owing to high losses in the early years. In fact the 2+1 and 2+2 transplant is still the most widely used though the quantities of 1+1 produced are increasing slowly.

TABLE 35: AGE AND TYPE OF SITKA SPRUCE

Losses and heights of plants in a number of experiments comparing different planting stock.

	Nursery type	Seedlings			Transplants		
		Age when planted	Ht. ft.	Loss	Age when planted	Ht. ft.	Loss
6-year result:							
Broxa 31.P.48	Heath	1+0	4.9	4%	1+1	5.2	6%
	Estab.	—	—	—	2+1	5.4	Nil
6-year result:							
Fetteresso 2.P.50	Heath	1+0	2.2	3%	1+1	2.5	3%
	Estab.	—	—	—	2+1	2.6	1%
Losses only:			Aged			Aged	
Fetteresso 3.P.51	Various	1+0	3	40%	1+1	3	4%
(Samples of 52			3	21%		3	9%
seedlings 53			3	22%		3	5%
planted over 54			3	22%		3	6%
large areas) 55			1	52%		1	17%
Mean of 5 seasons				31%			8%

The seedlings were all from heathland nurseries, the 'Heath' transplants were mainly raised in heathland and lined out in agricultural type nurseries.

Interplanting

From an early date attempts have been made to enrich pine crops by introducing Sitka spruce before canopy closed, which is here termed "interplanting" to distinguish it from the underplanting attempts made at a later stage, after closure of the canopy. Most of these early introductions were made among six- to ten-year-old pine crops of from four to six feet in height. In virtually every case these attempts failed, in spite of the use of intensive hand preparation, phosphate and in some cases of compost, and in certain cases of large vigorous planting stock. The failures include interplanting of six-year-old Scots and lodgepole pines at Inchnacardoch (65 and 67.P. 28), Wykeham (73.P.42), and Harwood Dale (38.P. 43), and also ten-year-old Scots pine at this last forest (37.P.43).

That Sitka spruce is in fact among the most difficult species to use in this manner is demonstrated in a further experiment at Wykeham (74.P.42), where it is one of the poorest of eight species introduced in this manner (Table 40, p. 91). The only case where the spruce is doing relatively well is where it was introduced in Corsican pine, the slowest-starting of the timber species, when the latter was only four years old. By use of intensive hand preparation and manuring, the spruce is now over half the height of the pine, is growing as fast, and seems likely to come through (Harwood Dale 39.P.45).

A group of experiments at Allerston dating from 1938 have been somewhat more successful, but even so they demonstrate the difficulties of interplanting, rather than a successful method. In these cases much more drastic action was taken at an early date to open up the pine crop. The results have been summarised graphically in Figure 8.

Consider first the upper graph, which gives two examples of interplanting a pine crop after removal of nearly half the pine. This was followed at first by pruning back of branches, and later the best groups were favoured by thinning out the pine. In one case this treatment was successful, and the spruce has come into canopy at a density of about forty groups per acre. Here the height of dominant spruce is now only four feet below that of the pine; the gaps in the pine canopy have been maintained at five yards across, to make this possible (Wykeham 50.P.38). In the other case the same treatment has been unsuccessful (51.P.38). Two differences may be noted; in the successful experiment the ground was originally completely ploughed, and the interplants were of very good quality, while in the unsuccessful case two-furrow ploughing was employed and the spruce plants were noted as of poorer quality; on such points depends the success or failure of such a finely balanced operation as interplanting.

The lower graph illustrates a case where, nine years after interplanting, half the spruce was abandoned and half favoured by conversion to a strip mixture, first one line and then further pine being removed as the spruce improved (52.P.38). Here there is nearby a spruce experiment planted under exactly comparable conditions to the pine and its growth curve is also shown (18.P.32). In spite of the early slow growth, always appearing likely to deteriorate into check, the older pure spruce crop still maintains a lead over that introduced into the pine six years later, although age-for-age the introduced crop has been somewhat faster growing. It should be noted that the pure spruce was planted at very close spacing of five × two feet (4,300 per acre) but even so it is doubtful whether this would be more expensive than the double planting and tending expenses in the second experiment.

None of these experiments tested planting into mountain pine crops, a very successful example of which is to be found in Drumtochty forest and is described on page 97.

Summary

The future of Sitka spruce would appear to be assured on the upper wetter heaths such as Clashindarroch and possibly Hamsterley, where the rainfall is higher and the temperature lower and risk of drought less. This is fortunate in that here the resistance to exposure shown by this species will be of most value. On the heaths with lower rainfall, and particularly those with a risk of drought, it would appear unwise to extend the use of a species known to be susceptible and relatively unproven. Probably no more than small poles have yet been removed from the heaths, although the species has been widely planted, not everywhere perhaps with sufficient evidence of its chances of success.

COMPARISON OF THE PRODUCTION OF THE MAJOR SPECIES

The sections above have outlined the effects of treatment on the various species, and have compared their early growth rates. Many of the earliest experiments have now reached the thinning stage, and it becomes possible for the first time to compare the production of the various species included. These comparisons must however be made with several reservations, the first of which is that the plots concerned are generally small, leading to unreliability in the volume comparisons and to the possibility of interaction between the species. A further point is that the methods by which the plots were planted represent only the earliest improvements in technique, owing to the delay before figures for production become available. Nevertheless comparative

Fig. 8. INTERPLANTING OF YOUNG PINE CROPS AT WYKEHAM WITH SITKA SPRUCE

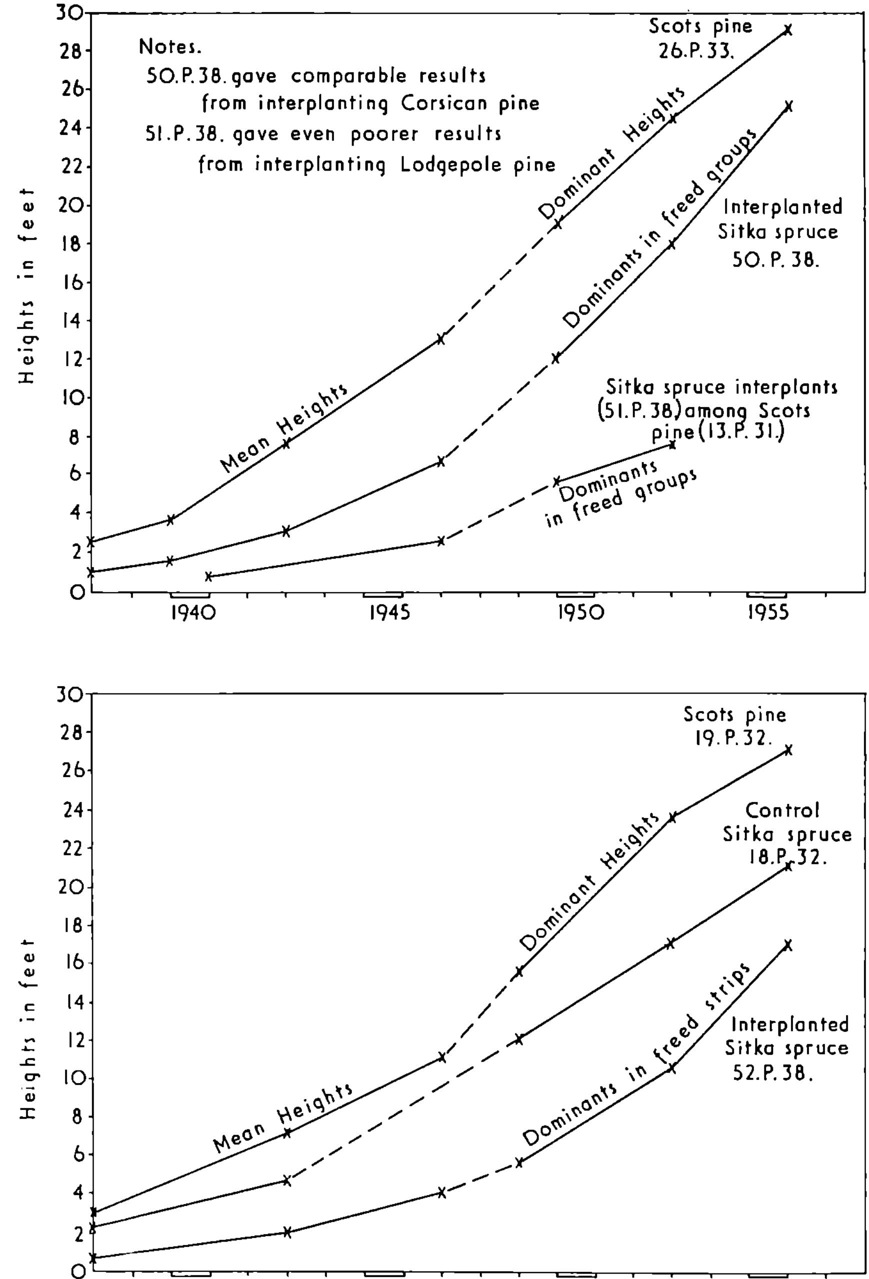

Fig. 8. Interplanting of Young Pine Crops with Sitka spruce at Wykeham.

TABLE 36: PRODUCTION OF SCOTS PINE, LODGEPOLE PINE AND JAPANESE LARCH

Comparison of stand data per acre of Scots and lodgepole pines with Japanese larch at Inchnacardoch, Clashindarroch and Wykeham.

Basal area in quarter girth measure and Volumes in Hoppus measure, both over bark

Experiment Ground Preparation	Species and Age		100 largest trees per acre Top Ht. feet	Stems per acre	Main Crop: Mean girth ins.	Main Crop: Basal area	Main Crop: Est. volume	Total Crop: Basal area	Total Crop: Volume	Mean Ann. Inc.	Approximate Quality Class from Top Ht.	Estimated Total crop from Yield Tables at 25/28 yrs. for the Qual. Class indicated by Top Ht.
Inchnacardoch 69.P.28	Scots pine	28	32	820	13	65	750	92	1,050	37	II–III	1,200
Shallow	Lodgepole pine	28	45	620	16	76	1,500	103	2,100	75	=I (S.P.)	2,700
ploughing	Jap. larch	28	41	520	16	62	950	87	1,300	46	IV	1,600
Clashindarroch 5.P.31 †	Scots pine	25	26	1,190	13	96	1,080	121	1,350	54	II–III	800
Shallow	Lodgepole pine	25	30	1,520	14	127	1,650	160	2,060	82	=II (S.P.)	1,200
ploughing	Jap. Larch	25	32	1,190	13	93	1,270	122	1,620	65	IV	1,150
Clashindarroch 7.P.31	Lodgepole pine } Mixture	25	30	480 }	15	47 }	660 }	93 }	1,140 }	45 }	—	—
Shallow Ploughing	Jap. larch }	§	31	570 }	15	56 }	860 }	88 }	1,300 }	52 }	—	—
Wykeham 13 & 14.P.31	Scots pine	26	34	760	17	98	1,300	117	1,500	58	II	1,360
Mod. deep	Lodgepole pine	26	34	950	16	106	1,400	144	1,800	70	=II (S.P.)	1,360
ploughing	Jap. larch‡	26	39	450	19	68	1,150	125	1,950	74	IV	1,360

Notes: Except at Inchnacardoch figures are means from 2 assessment plots in different experimental units.

† This experiment was planted at 3′ x 3′ and was badly laid by snow in 1931, the Scots pine and Japanese larch being particularly badly damaged; the figures for these species are from the two replications least damaged out of six planted.

‡ These Japanese larch plots received phosphate.

§ These plots were planted with alternate lines of lodgepole pine and Japanese larch at 4½′ x 4½′.

Quality Classes set against lodgepole pine are derived from Yield Tables for Scots Pine.

material for assessing the growth of two or more species on the same site is so rare, that the results are presented in some detail. As the plots grow older, their value should increase as the various more or less accidental circumstances of their establishment becomes less important relative to the influence of the site.

Two groups of these plots have been recognised. The first table includes fully-stocked plots, from which the growth of Scots pine, lodgepole pine and Japanese larch may be compared at Inchnacardoch, Clashindarroch and Wykeham (Table 36). In the second table a series of plots at Wykeham are considered which, while now of pure pine, originally included a second species which failed, so that full stocking was achieved only slowly and the crops are all to some degree abnormal (Table 37). The three species are however directly comparable since the history of each set of plots is the same.

In the tables, the quality classes have been taken from the yield tables to correspond with the top height, working to the nearest half quality-class. The total crop expected has then been calculated. At Clashindarroch, and in the set of plots at Wykeham in Table 36, the estimated crop volume is much higher than the yield table figure. A possible explanation is that the height growth of crops in the exposed heaths, especially experimental crops which are small in extent, is reduced in comparison with normal stands and the volume then appears abnormally high. The lower volume in the Wykeham plots in Table 37, is accounted for by the initial low stocking, while that at Inchnacardoch is partly due to wind-blow and possibly paradoxically to the general lesser exposure giving more normal height growth and lower form factor. The most important feature however is that the order of volumes corresponding to the quality classes are the same as the estimates from the actual stands; that Scots pine is always the lowest and lodgepole generally the highest, with Japanese larch moving into first place at Wykeham.

The main conclusion from these tables is that nowhere has the Quality Class of Scots pine reached I–II, the best being somewhat above II at Wykeham. In general the height growth of lodgepole corresponds to that of Scots pine of half a quality class higher at any site, than that achieved by Scots pine itself. There are exceptions at Inchnacardoch, where the Scots pine is relatively poorer, and at Wykeham where it is relatively better. On the other hand the quality class of Japanese larch is in each case one-and-a-half quality classes below that of Scots pine. The implications of these results are shown in Table 38 which sets out figures derived from yield tables for total production at twenty-five years, the stage the heathland plantations have reached, and also at fifty years.

From Table 38 it is clear that, if the existing growth pattern continues, Scots pine production

TABLE 37: PRODUCTION OF SCOTS, CORSICAN, AND LODGEPOLE PINES

Comparison of stand data per acre of Scots, Corsican and lodgepole pine 27/28 years after planting in Wykeham 2.P.28 and 9.P.29. Basal areas in quarter girth measure and volumes in Hoppus measure, both over bark

Species	100 largest trees per acre Top Ht. ft.	Main Crop Stems/acre	Main Crop Basal area	Main Crop Est. volume	Total Crop Basal area	Total Crop Volume	Mean Annual Inc.	Approximate Quality Class from Top Ht.	Estimated† Total Crop from Yield Tables at 27/28 yrs. for the Qual. Class indicated by Top Ht.
Scots pine	31.2	720	77.3	900	93.5	1,050	38	II–III	1,150
Corsican pine	32.0	760	111.4	1,550	130.2	1,750	63	III–IV	1,900
Lodgepole pine	37.9	710	100.4	1,600	123.4	1,900	69	=I–II (S.P.)	2,100
Standard Error	±0.30**	—	±3.7**	—	±4.7**	—	—	—	—
Diff. for sign. 5%	1.05	—	12.7	—	16.4	—	—	—	—
1%	1.59	—	19.3	—	24.8	—	—	—	—
Fully stocked Scots pine crop (Wykeham 7.P.29)	32	825	91.4	1,050	105.0	1,200	44	II–III	1,150

Notes: The main results are from four sets of 1/10th acre assessment plots taken in evenly stocked portions of the original replicated ¼ acre plots. The ground was hand-prepared in patches in half the plots (2.P.28) and shallow 3-furrow ploughed in the remainder. In all cases the pines were planted in intimate mixture with larch or spruce which failed. The original numbers of pines were 1,800 per acre (2.P.28) or 1,400 per acre (9.P.29) hence the rather low number of trees per acre and the small production from the first two thinnings.

† Estimates made from *Revised Yield Tables for conifers in Great Britain*, 1953.

** Highly significant.

Quality Class for lodgepole pine is derived from Yield Table for Scots pine.

may be expected to surpass that of Japanese larch, while that of Corsican and lodgepole pines will exceed Scots pine by about a quarter on the better sites. On the worst sites however lodgepole pine production would exceed Scots pine by two-fifths. It is recognised of course that any conclusions as regards lodgepole pine must be tentative in the absence of older stands or of yield tables.

The conclusion to be drawn from these data is that the role of Scots pine should not be underrated. While Japanese larch and lodgepole pines are attractive because of their early production, the former is likely to fall behind Scots pine, while the latter is of an unknown quality. This would suggest the use of mixtures with Scots pine to form a high proportion of the final crop where it is desired to make use of the special features of the other species in the early years.

TABLE 38: COMPARISON OF YIELD TABLE PRODUCTION DATA FOR MAIN SPECIES

Assuming constant differences in quality class between the various species on the same site.

Site Quality	Scots pine Standard Q.C.	Total crop 25 yrs.	Total crop 50 yrs.	Lodgepole pine ½ Q.C. above S.P. Q.C.*	Total crop 25 yrs.	Total crop 50 yrs.	Corsican pine 1 Q.C. below S.P. Q.C.	Total crop 25 yrs.	Total crop 50 yrs.	Japanese larch 1½ Q.C. below S.P. Q.C.	Total crop 25 yrs.	Total crop 50 yrs.
Good heath	II	1,200	5,350	I–II	1,650	(6,250)	III	2,050	6,220	III–IV	1,600	4,300
Moderately good heath	III	410	3,650	II–III	800	(4,500)	IV	1,050	4,510	IV–V	950	3,100
Poor heath	IV	—	2,180	III–IV	—	(2,900)	—	—	—	Below V	350	2,000

* Based on the assumption that lodgepole pine, for which there are as yet no yield tables, continues to fit the Scots pine tables reasonably well.

Chapter 7

TRIALS OF SPECIES LESS WIDELY USED ON THE HEATHS

Apart from the five species which have been used extensively throughout the experiments on the heaths, some thirty conifers and twenty hardwoods have been planted in varying numbers of experiments. The scale of the work varies from the crudest type of spot test, using a species of which stocks happened to be available at a particular time, to quite extensive trials which in some cases have led to the species being tested on a semi-field scale. The underlying object of these trials has always been the same, to diversify the forests on these rather uniform sites, and to provide an admixture of broad-leaved species, or if that proved impossible, then of conifers with soil-improving qualities.

A number of the earlier experiments, planted from 1927 to 1931, took the form of comparative trials of species, in which the object was to compare directly the early growth rates of the less common species with the commoner ones. While the more exacting species were in some cases planted pure, it was realised that in most cases this would be pointless, and a pine was used as a nurse, the crops being planted as an intimate mixture, generally with alternating plants of the two species. The vast majority of the species so tested failed, or grew so much more slowly than the pines that they were suppressed. When the failures of these early tests became apparent, about 1938, trials of interplanting and underplanting were begun, of a similar type to those already described for Sitka spruce; these have given promising results in certain cases and have been extended in recent years. Another method for growing the more difficult species was tested in 1943-5, when in view of its earlier success with Sitka spruce, broom was tried as a nurse for a variety of species. The most recent stage in the development of the attempts to raise other species is the return to planting both nurse and nursed species at the same time, but with the nurse species often altered to Japanese larch instead of pine, and separation of the species by grouping them in strips or blocks.

After this brief account of the historical development of these trials, a description of the more important experiments is followed by a summary of results, species by species.

THE SPECIES TRIALS

Teindland 23.P.28

This experiment was one of the early trials ploughed by a horse-drawn plough to a depth of four to six inches. Small plots were planted with a variety of species and mixtures, and to half of each plot basic slag was applied at the rate of ten hundredweights per acre. At the close spacing used, which varied from plot to plot according to the species, this is equivalent to four to eight ounces per tree. The ultimate unit of the experiment is approximately eleven by seven yards which means that the results, though useful, have been affected by mutual interference, and growth in the best plots has probably been reduced by exposure owing to the irregular nature of the canopy. Figure 9 presents the results after twenty-five years; clearly phosphate was here essential to reasonable growth of all species except Scots and lodgepole pines.

The absence of Japanese larch from this experiment is unfortunate, but results from a turf-planted area close by suggest that, given phosphate, this species would be superior in growth rate to all others, with the possible exception of lodgepole pine (Teindland 56.P.35). The development of western hemlock has been striking in this experiment, but as it stands next to the tall plots of lodgepole pine, this cannot be regarded as indicative of the behaviour likely in a pure crop; nevertheless the health and vigour of the species was such that an extension of its use in experiments on the northern heaths dates from its emergence, about 1936, from semi-check in this trial.

Of the spruces also, it may be said that the so-called pure plots would be poorer had they been in the open. The best plot is undoubtedly the Sitka spruce, which was slagged and recultivated; standing between pine plots, it indicates how banded mixtures are more likely to prove successful than the intimate mixtures which were in fact planted here to aid the spruce. In these intimate mixtures the nursed species has successfully come through the nurse *only* in the mountain pine/Sitka spruce plots, out of the four such mixed crops included in the experiment. The slow emergence of the pure Norway spruce plot

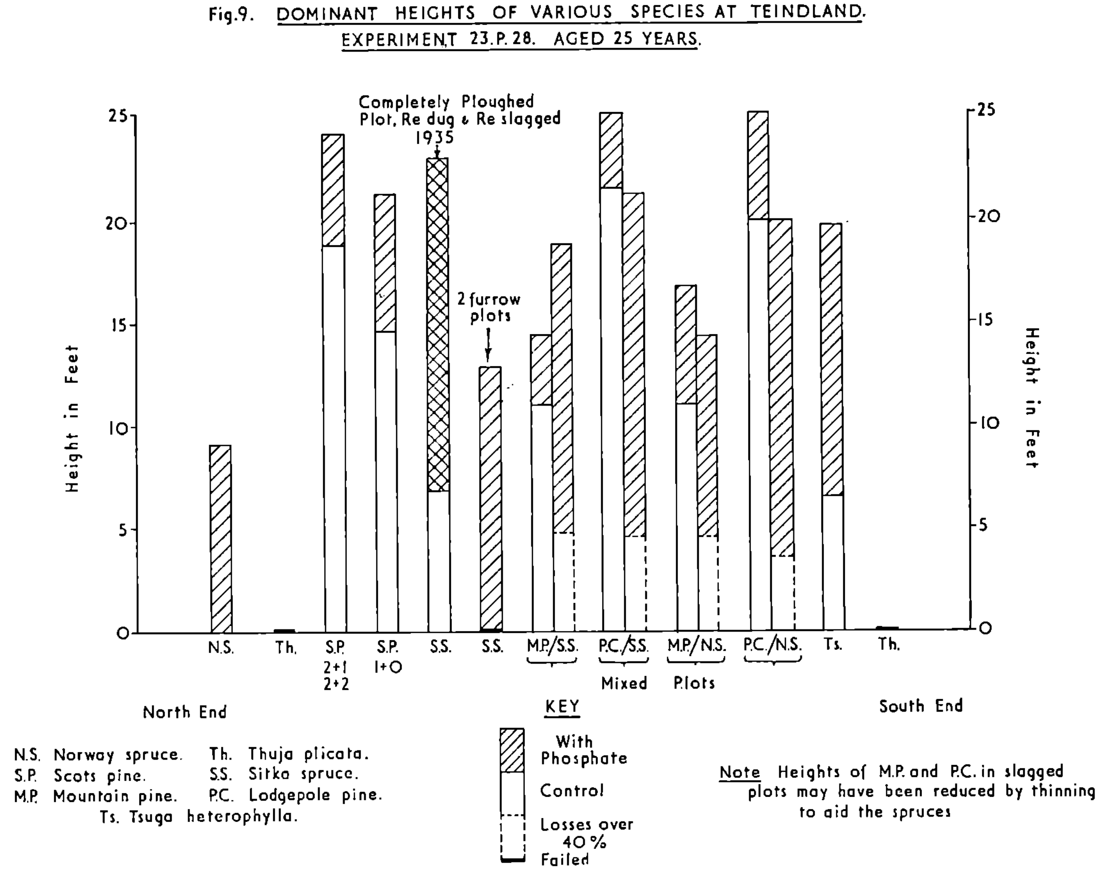

Fig. 9. Heights of Various Species at Teindland. (23.P.28.)

from check has evoked interest in the past few years; this species is further removed from possible nursing by pines than either the Sitka spruce or hemlock.

Teindland 48.P.32

This is a smaller experiment sited lower down in the forest than the Findlay's Seat area, on a very poor site where the previous crop of notched Scots pine had reached only five feet after fifty years. Shallow complete ploughing was carried out and phosphate applied, but of the species used only hybrid larch has grown well, attaining twenty-four feet in twenty years. The two spruces, alder and birch have all proved disappointing, the former have remained in check for many years and the latter, after rapid early growth, have died back or ceased to grow.

Wykeham 9.P.29

This experiment consists of large plots of many species, mainly in intimate mixture, planted on shallow three-furrow ploughing, comparable to that in the Teindland experiments; unfortunately only a tiny proportion of each plot was manured. The early results from this part of the experiment suggested that, had half been manured as at Teindland, better growth would have been obtained. Larches, Sitka spruce and several broadleaved species—beech, sweet chestnut and sycamore—all failed or were outgrown and suppressed where pines were included in the mixtures. The remaining crops were mainly of birch as nurse to Sitka spruce, noble and grand firs, and western hemlock. These species, apart from Sitka spruce, have after a long check slowly improved to form patchy crops.

Hamsterley 1-2.P.29 and 5-6.P.30

These experiments are not dissimilar from the last one but were hand-planted, mainly by the prepared patch or pit and mound methods; basic slag was however given to a good proportion of all species. These experiments suffered from the inadequate soil preparation, and were also very severely attacked over a number of years by blackgame, which almost eliminated Scots pine planted as the nurse in many of the plots. The fate of the major species has already been described (p. 31); of the others, European larch was ravaged by the insects *Argyresthia* and *Chermes*, a few western hemlock are growing well among the lodgepole pine and Sitka spruce used for repairing the plantations, while of seven species of hardwoods only a small plot of rowan survives.

Staindale 1A.P.31

After the failure of the first trial on shallow-ploughed ground at Allerston (Staindale 1.P.24), the major part of the area was re-ploughed using stronger tackle, and was planted with strips of four pines and five other species, all the latter being nursed by mountain pine. Growth has, on the whole, been fairly good as indicated in Table 39. The mountain pine, a very good erect type, appears to have played a part in nursing the other species, and is now filling gaps in the plots. The Corsican pine here shows signs of damage from the fungal disease *Brunchorstia*.

TABLE 39: SPECIES TRIAL

Top heights, equivalent Quality Class, and stocking, twenty-five years after planting in Staindale 1A.P.31 on moderately deep ploughing without phosphate.

Species	*Top Height Feet*	*Approximate Quality Class*	*% Blank*
Lodgepole pine	26.2	=III (S.P.)	—
Douglas fir†	12.2	—	60%
European larch†	20.8	V–VI	30%
Japanese larch†	22.8	VI	25%
Corsican pine	27.2	IV	—
Sitka spruce†	25.7	VI	—
Norway spruce	Failed	—	100%
Mountain pine	17.8	=IV (S.P.)	—
Scots pine	24.5	III	—

Notes: Species are in strips four plants wide replicated four times in the above order.

† Mountain pine was mixed with the larches, Sitka spruce and Douglas fir, as well as in the failed Norway spruce strips in which its height is recorded.

For mountain and lodgepole pines, a Scots pine Quality Class is used.

Wykeham 41.P.34-36

This is a small collection formed over three years. It suffered from the disadvantage that the ploughing had been carried out in 1931-32, so that heather re-invasion has been a problem, and early growth slow. This trial is notable for the excellent growth of Serbian spruce.

Clashindarroch 9.P.31

This is an even less coherent collection, consisting of a number of plots or belts of ten species, only a few of which occur more than once, scattered over the Mytice experimental area. Taken in conjunction with other experiments in the enclosure, however, the plots give an indication of the results to be expected from the species concerned in pure planting, and with a minimum of ground preparation; half the species failed completely and only small numbers of most of the others remain.

INTERPLANTING AMONG PIONEER SPECIES

By this time the difficulties of establishing species other than pines and larch were appreciated, and a start made at introducing more tender species into the earliest plots of the pioneers, which were now well established.

Teindland 1938 and 1939 Plantings into 41.P.29

The first attempt was planting among nine-year-old lodgepole pine, which had reached five feet on three-furrow shallow ploughing. A number of hardwoods were tried, of which only Oregon and grey alders have grown at all, the former being notably successful. The following year a number of conifers, grey alder, and beech, were introduced into the part of this plantation which had been ploughed in bands at the start, by ploughing new furrows between the strips of ten-year-old lodgepole pine, then three to six feet tall. This method, for which results are given in Table 40, has proved successful in certain cases, western hemlock being the outstanding species. Grey alder is not of very healthy appearance and does not compare with the Oregon alder in the previous year's planting.

Wykeham 74.P.42

This experiment was similar to the first of these two Teindland trials; a number of small groups of various species were introduced after patch preparation among seven-year-old Scots pine planted on ploughed ground, which had by then reached an average height of about three feet. Results are shown in Table 40 and Figure 10; after fifteen years, it is apparent that only western hemlock will form canopy with the Scots pine in the near future,

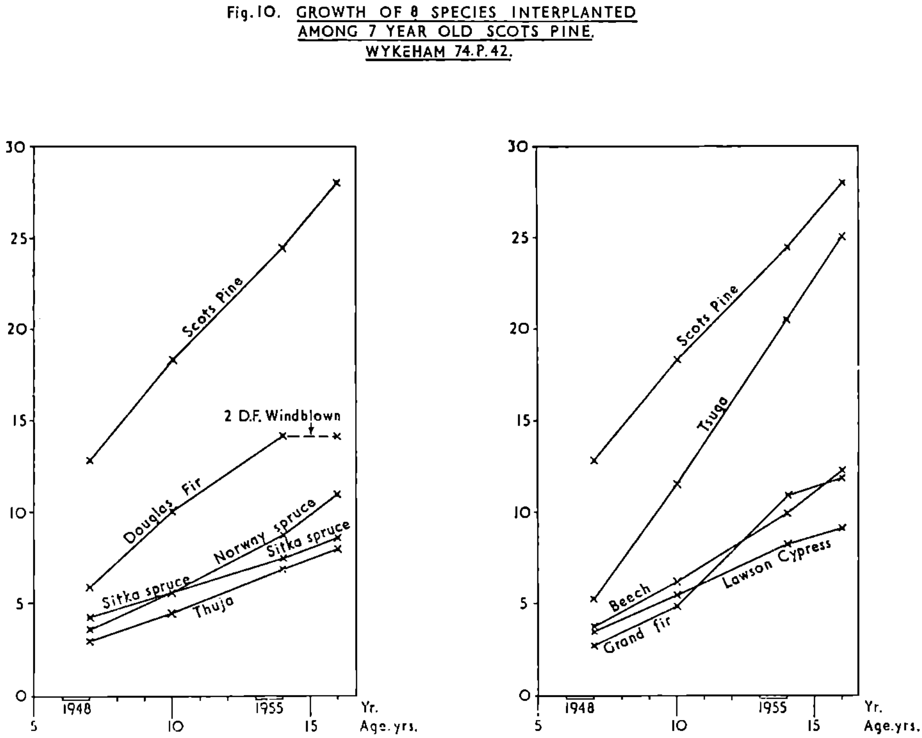

Fig. 10. Growth of Eight Species Interplanted among Scots pine at Wykeham. (74.P.42.)

though some Douglas fir and a few Norway spruce, Lawson cypress and beech will also do so eventually, as there are in these cases individual trees of double the mean heights. The graph shows that *Abies grandis* is now also rapidly improving relative to the other species, and may come into the canopy at a later stage. The remaining trees of the more tolerant species may form an under-storey, but it is to be expected that the less tolerant Sitka spruce and red cedar will be suppressed. The present policy is to open out the canopy around promising groups, and the present size of the gap in the canopy is about eight feet from crown to crown of the Scots pine. This has been a successful experiment, but the method is not to be recommended as a practical means of enriching a pine plantation, since to get one tree of another species into the canopy entails sacrificing perhaps four pines while they are still of unsaleable dimensions.

Wykeham 75-77.P.44

In this group of experiments, established crops about twelve years old, mainly of Japanese larch, were underplanted with beech and a variety of conifers; condensed results are given in Table 40. By heavy thinning, and later the virtual removal of the larch, good growth has been maintained in Expts. 75 and 77. Where this was not done, in Expt. 76, since it was not desired in this instance to remove the overcrop, only hemlock is growing under larch and birch, while under lodgepole pine the three species tried have all been abandoned. This method of group introduction would be practical for establishing areas of up to one-tenth of an acre in small pole-stage larch crops, since the larch is often readily saleable and the introduced species have made rapid growth.

BROOM AND PINE NURSES

Broxa 11.P.43 and Wykeham 70.P.44

Simultaneously with the work on introductions, the less hardy conifers and beech were re-tried at Allerston using the technique of nursing by broom worked out with Sitka spruce (see p. 118). Deep ploughing, broom, phosphate, and Scots pine as a long-term nurse, were all provided, with spectacular results. Figures given in Table 40 show Sitka spruce and hemlock growing faster than Scots pine, with grand fir and western red cedar not far behind. Unfortunately, no controls were laid out in comparable plots *without broom*, so that the relative

TABLE 40: SPECIES TRIALS MADE WITH NURSES

Results from various trials in which less hardy species have been planted with or into nurse crops. Results from pure plots at Wykeham shown for comparison.
All on well-ploughed ground and with phosphate, but in Wykeham 74-77 the ploughing was for the pioneer crop, not for the successor species.

Forest	*Teindland*	*Wykeham*					*Broxa*
Experiment	41.P.39	Various‡	74.P.42	75/77.P.44	76.P.45	70.P.44	11.P.43
Nurse Crop *Dom. Ht.* (1)	*10 yr. P.C.* *26 ft.*	Nil —	*6 yr. S.P.* *26 ft.*	*11 yr. J.L.* *Removed*†	*11 yr. J.L./Bi.* *J.L.32′ Bi.24′*	*Broom+S.P.* *S.P.14′*	*Broom+S.P.* *S.P.9.4′*
	AGED 15 YEARS			*AGED 10 YEARS*			
Other Species							
Douglas fir	10.0	6.0	14.0	9½	—	14.2	10.2
Norway spruce	—	—	9.8	—	—	9.4	10.5
Sitka spruce	7.0	3.8	7.6	7½	Checked	15.7	12.0
Grand fir	—	—	11.3	10	—	11.1	10.3
Tsuga	15.4	7.0	22.7	—	With JL 13 With Bi. 14½	13.6	10.3
Thuja	—	Checked	7.2	—	Checked	9.9	—
Lawson Cypress....	—	3.4	8.6	2½	—	9.5	7.4
Beech	1.7	—	11.0	7	—	12.8	10.8
Grey alder	14.6	—	—	—	—	—	—
Assessment Method	(1)	(2)	(3)	(3)	(3)	(3)	(3)

Methods of Assessment:—
(1) Dominant heights for crops in canopy.
(2) Mean height, crops still open.
(3) Tallest per group planted, varying from 2–7 per group according to the experiment.
Figures for Wykeham 75/77 are approximations from the experiment means.

Notes: ‡ Includes results from Wykeham 41, 53, 58 and 59.
† The overcrop was removed gradually during the ten years after underplanting.

Abbreviations are: P.C.=lodgepole pine, S.P.=Scots pine, J.L.=Japanese larch; Bi.=birch.

importance of the various factors cannot be exactly gauged; several pointers are available however:

(1) Phosphate when applied to the trees in these experiments, for which point there were replicated controls, was of relatively little importance in the presence of broom, though the application to the broom itself is known from earlier work to be essential.
(2) The results were little different on shallow single-furrow ploughing with sub-soiling and on deep R.L.R. ploughing, even at Broxa where complete deep ploughing was employed.
(3) The Scots pine nurse can have had no effect as yet, being no more advanced than the other species.

All these observations point to the overwhelming importance of the broom as a nurse. Comparable results from plots planted some years later with tree nurses, but without broom, will become available within a few years.

Discussion

The eight trials from which results have been collected in Table 40 may be compared with each other and with the pure plots at Wykeham only in the broadest terms. (It should be noted that the results are given at either ten or at fifteen years from planting). Nevertheless it is apparent that very great progress has been made in the technique of growing the species concerned, and that no straightforward species trial in pure plots can be accepted as indicating the ultimate possibilities of these species on the heaths.

Both the actual and relative growth rates have been so influenced by the manipulation of the factors of the environment by silvicultural means that it is necessary, in the descriptions of the behaviour of the individual species, to define carefully the conditions under which any species comparison was conducted. Clearly the use of broom as a nurse is the optimum treatment silviculturally, for at Broxa (11.P.43) six out of seven 'exacting' species when raised with broom have outgrown Scots pine, the "hardy pioneer"; the majority of species in the ten-year-old Wykeham trial with broom (70.P.44) are similarly level with those in the fifteen-year-old trial planted into Scots pine (74.P.42).

The broom technique is, however, expensive and the generally satisfactory though somewhat slower growth in the 1939 introductions, on ploughing, into lodgepole pine at Teindland (41.P.39), and from the group introductions into Scots pine at Wykeham (74.P.42), have led to further trials under what were considered to be the optimum conditions short of the use of broom. These were that the introduced species should have side shade, be planted on fresh ploughing and receive phosphate, but that they should not be rapidly outgrown by the nurse crop. To achieve this end, lanes were cut in young Scots pine crops by removing two rows of trees out of six, a single furrow was ploughed down the centre of each lane, and the new species introduced at close spacing on the furrow. This was not visualised as a system to be applied in practice, but as a method of anticipating the more favourable conditions that will exist for tender species in the second rotation on these upland heaths. Trials of this type, involving about twenty-five species, were laid out at Newtyle, Morayshire (1.P.50); Devilla, Fife (1.P.50) and at Wykeham (84.P.50).

The most recent phase in the species trials at Broxa is that a series of quarter-acre plots have been laid out to demonstrate crops which might be grown, using as nurses Scots pine and Japanese larch planted in bands at the same time as the species under test (80.P.51). More recently similar work has begun at Teindland and Clashindarroch, where information on the behaviour of different species is much more limited. The pilot plots described in Chapter 11 also contain a proportion of less common species, notably at Cleveland, Yorks. (1.P.52).

CONIFEROUS TREES
ABIES—SILVER FIRS

Abies concolor Lindl. & Gord. This species has been used only in the three large introduction experiments of the 1950 series and after five years, is green and growing slowly at Wykeham and Newtyle, but has failed at Devilla.

Abies grandis Lindl. Grand fir has been used more extensively than other species of this genus, particularly in experiments at Allerston, where it was first used, on triple-furrow shallow ploughing; after heavy early losses, survivors range up to twenty-four feet, but are rather behind the plots of *A. nobilis*. The stocking of both species is, however, too patchy to give a full crop (Wykeham 9.P.29). Another early trial was at Drumtochty (1 & 2.P.34), where grand fir failed when used to beat up European and Japanese larch plantations on a grass heath site.

The results from a series of experiments at Wykeham and Broxa, planted from 1942-44, have been presented in Table 40 (p. 91), and show that with intensive methods *Abies grandis* may be established quickly in this area, and may attain a height of ten feet after ten years. In later plantings at Broxa, with deep ploughing and phosphate, it has made a good start without broom, and will later be nursed by Scots pine and Japanese larch (Broxa 76.P.50 & 80.P.51). Of other recent plantings *A. grandis* has made a slow start in the 1950 series of introduction experiments, is relatively poorer than *A. nobilis* in a species trial at Teindland (82.P.52), while at Cleveland (1.P.52) the two are equally promising.

Apart from the experiments, there are a number of blocks of this species on the grass-heath fringes of the upland heaths, as for instance in Clashindarroch and Drumtochty forests. While the timber of this species is not at present held in high regard, it is possible that slower-grown timber from the upland heaths would be of better quality than that grown on more fertile sites. Having shown that it can be established fairly easily, the next stage should be its employment in pilot scale plantings or in limited numbers in the second crop.

Abies nordmanniana Spach. has been used only in the 1950 introduction trials, and is the poorest of the five silver firs included, having failed at Devilla and lost half its number at Newtyle, mainly owing to frost; survivors at the latter site and at Wykeham are in complete check.

Abies nobilis Lindl. (=*A. procera* Rehd.) Noble fir was first used at Wykeham in 1929 where it is now healthy and rather taller than *A. grandis*, ranging from eight to thirty-six feet in height, twenty-seven years after planting. Subsequently this species was neglected as compared with *A. grandis*, and it was not planted again until 1950 when it was used in the introduction experiments and also in the series of pilot plots described in Chapter 11 (p. 132). This latter development followed an account by Redmond (1950) of the success of *A. nobilis* on exposed heathy sites in Northern Ireland. Early reports on the new trials confirm in several instances the resistance of this species to exposure, and particularly notable is its retention of green foliage under circumstances in which every other species has been browned or defoliated. The early growth of this species is however notoriously slow, and these trials are no exception, so that the mean height will rarely exceed two feet after the first six years. The Cleveland and Teindland species trials are on rather less exposed sites, and early growth has been stronger, with shoots up to a foot long in the third year.

It appears possible that there may be a use for this species in exposed areas, but the trials are too young for any extension to be recommended at the present time.

Abies veitchii Lindl. is a third species planted in only two of the introduction trials. At Wykeham it is the tallest of the five *Abies*, averaging almost four feet after six years, while at Newtyle it is promising though considerably slower in growth.

Summary for Abies

Of this genus only *A. grandis* can be considered to be worth more widespread trials at the present time. In the last few years the first plantings of *Abies lasiocarpa* have been made and these are to be followed by trials of *A. amabilis*, as these two alpine firs might be useful in exposed areas.

CHAMAECYPARIS—CYPRESSES

Chamaecyparis lawsoniana Parl. The first trials of Lawson cypress were at Allerston in 1939, where it was "pit and mound" planted with slag in a failed plot at Harwood Dale (1.P.32), and also on fresh double-furrow ploughing with subsoiling at Wykeham (58.P.39). In both plots the cypress checked severely and at Harwood Dale it has never emerged from the heather. At Wykeham the experiment was used for a mulching test in which cut heather was used to kill and rot down the heather around the checked trees, with the remarkable results described by Weatherell (1953) and attributed by Leyton (1955b) largely to improved moisture conditions associated with increased availability of nitrogen and phosphorus. The sequence of events following the stage described there is of some interest. When the heights in the mulched plot were approaching double that of the control, five years after mulching, the adjoining control trees started to turn from yellow to green and then began to grow. Examination showed that their roots had extended into the mulched area, and a trench was accordingly cut to isolate the plots, whereupon the trees have gradually returned to the checked state. Fifteen years after planting, and eight years after the mulch was applied, the mean height was ten feet in the mulched plot, where the trees were green and vigorous and starting to close canopy, but only three feet in the control with the prospect of an indefinite period of check.

The development of subsequent Allerston trials is shown in Table 40 (p. 91); Lawson cypress is clearly one of the slower-growing of the species tried, but nevertheless shows some promise, and the species has been planted in further trials in recent years. In the 1950 introduction experiments, it is promising only at Wykeham; but in a further trial at Broxa (88.P.52), when planted among ten-year-old Scots pine, the early growth is noteworthy for the good form and open nature of the crown, which suggests the advisability of raising this species in partial shade.

It is apparent that Lawson cypress may have a limited role on the heaths in the later rotations, and that the development of these experiments will be of interest.

Chamaecyparis pisifera Endl. has only been planted once, in the collection at Clashindarroch, and hand-planted, it failed even on the best part of this area, where Douglas fir has grown quite well under comparable conditions.

CRYPTOMERIA—JAPANESE CEDAR

Cryptomeria japonica Don. Japanese cedar was tried in two of the 1950 introduction experiments and it remains alive but in check at Newtyle, but is making slow progress at Wykeham.

CUPRESSUS—CYPRESSES

Cupressus macrocarpa Hart. was planted in two of the 1950 introduction trials and in the pilot plot at Forss, Caithness, but failed at all three sites within two years of planting.

PICEA—SPRUCES

Picea abies Karst. Norway spruce has been used to a limited extent in the experiments, but it is not a tree which has any place in the initial afforestation of the heaths. It is notorious for the severe and prolonged check which occurs when it is brought into competition with heather, and most of the experiments either demonstrate this point, or are concerned with attempts to alleviate it. The small use made of this species on the British heaths may surprise those familiar with the Continental heaths, particularly in Denmark, where the necessity to free this species from competition from heather, and nurse it into growth with mountain pine, dominates afforestation technique. Basically it would appear that Norway spruce is not used in this country because there is a wider choice of species available. There is little doubt that it could be used on the less exposed heaths, but the costs of establishment would soar, and thus in fact it is hardly found outside the twenty experiments described below, except in flush hollows in the heath forests, where the typical heath conditions are absent.

The prolonged checking of Norway spruce in the earlier Teindland species trial has already been noted; the gradual improvement in colour and commencement of growth, now taking place after twenty years in check, is a phenomenon well known abroad.

Other examples of prolonged check occurred in early trial plantations at Monaughty (4.P.22 & 5.P.23), the Staindale species trials, and early trials at Wykeham, but in most of these the plants died or were suppressed by the pines in mixture. An exception is in a Wykeham trial (12.P.31) where the perimeters of pure Norway spruce plots, in severe check for ten years, were nursed into growth by adjacent Scots pine. At a later date failures were replaced by Japanese larch, and once these were established and began to suppress the heather, the Norway spruce in the centre of the plots also improved, so that now after twenty-five years they range from eight to twenty feet under the Japanese larch, which varies from fourteen to twenty-four feet in height. The spruce will now be favoured in thinning to provide some information on the later development of this species, since these are now the most advanced plots on the Allerston heaths.

A small mulching experiment bears out this evidence that heather competition is the main adverse factor. Spruce planted in 1936 had checked severely and was first given a top dressing of phosphate, and later mulched, with the results shown in Table 41. Growth has been stimulated by the mulching to four times that of the controls during the twelve years since treatment, while the phosphate has had a much more limited effect.

TABLE 41: NORWAY SPRUCE

Development of Norway spruce after attempts at stimulation first by a phosphate top dressing and later by mulching with cut heather. Wykeham 79.

Mean Heights in Feet

Treatment	*Initial Aged* 8 *yrs.* 1944	15 *yrs.* 1950	20 *yrs.* 1955
Control	1.0	2.0	2.9
+2 oz. slag in 1938	1.5	2.9	3.9
Mulched in 1944	1.2	4.4	7.8
+2 oz. slag in 1938	1.5	5.3	9.5
Main effects Phosphate	+0.4	+0.9	+1.4
Mulch	—	+2.4	+5.2

Note: The experiment consists of 4 plots, each of about 25 trees, so that mutual interference is probably now taking place.

The experiments already described and summarised in Table 40 (p. 91) show what can be done to eliminate this severe check in Norway spruce. Though its growth has not been quite as spectacular as some of the other species, it has reached ten feet in ten years in both the trials with broom, and is better than Sitka spruce in the interplanting trial at Wykeham (74.P.42). It is clear that in several cases the early attempts at enriching pine crops with spruce might have been more successful had Norway replaced Sitka spruce as the species to be introduced, since the former is much more tolerant of shade.

There is one instance at Hamsterley of the successful use of Norway spruce in a straightforward mixture with alternate plants of Scots pine on single-furrow ploughed and subsoiled ground (10.P.40). Both the spruces have grown remarkably well here, and have every sign of forming satisfactory mixtures with Scots pine. The heather in this experiment developed, after the ploughing and manuring, until it is now almost two feet tall, but its suppression in the pine/spruce plots is now starting. This experiment confirms the belief that it is only where the heather itself is poor on infertile sites, that the checking of spruce by competition results; more fertile sites such as this can support the growth of both heather and spruce at the same time. Although Sitka spruce is growing well in heather in a number of experiments, this is the only one in which Norway spruce is doing so.

In recent years Norway spruce has been used in a small number of trials with Japanese larch as a nurse crop; thus it has been planted over a wide range of methods of ground preparation in the 1952-54 series of ploughing experiments, and is closely compared there with Sitka and Serbian spruces.

Finally it may be suggested that theoretically Norway spruce is more suited to the upland heaths than Sitka spruce, since it would appear simpler to match the climate within its natural range to that of the heaths. There are however at present no provenance trials of this species established on the heaths, and in view of the variation in results according to seed origin found on other ground types, it is obviously a matter that would need to be followed up, were its use to be extended. It appears that Norway spruce may have a far greater role to play in the second rotation in these forests, when the heather will have been eliminated to a great extent. The tendency of this species to degrade acid soils still further, would suggest, however, that its use should be limited to small areas and to mixed crops.

Picea asperata Mast. This species failed in the Wykeham collection where planted without phosphate, but of the small number which received basic slag, the majority survive, and after twenty years their heights range from three to twelve feet; they are of good colour, and making steady growth.

Picea engelmanni Engel. This species has been used only in the collection at Clashindarroch, where it failed when planted under severe conditions of elevation and exposure.

Picea glauca Voss (=*P. alba* Link) was used in a long belt at Clashindarroch, that was intended to shelter the Mytice experimental area and ran from 800 up to 1,400 feet in elevation. It appears likely that Danish practice in the use of this tree for shelterbelts was responsible for its employment, but on this steeply sloping site it was not possible to give the intensive ground preparation which is normal in Denmark. The greater part of the belt failed, the lowest part averaged two and a half feet after twenty years of semi-check.

Picea jezoensis Carr. This species also has been used only once, in the Wykeham collection, and the majority of the plants have died. The losses have occurred more slowly where slag was applied, but even there the survivors are in complete check after twenty years. Frost appeared to be one of the factors responsible for this failure.

Picea omorika Bolle. Serbian spruce had been used in three trials prior to 1950, in two of which it has grown, but one is of such an exceptional nature that it has led to wider trial of the species in recent years. Planted with hand preparation at Clashindarroch (9.P.33) it has grown very slowly, averaging six down to two feet after twenty years as the altitude of the plots increases from 770 to 1,080 feet, but is now very healthy and growing well in the lower plots. At Harwood Dale (8.P.33), it was again planted by hand, but although it received phosphate, the method of planting used, the inverted replaced turf, is now known to be one of the poorest. The spruce was in mixture with mountain pine, and both species checked badly; but the pine recovered after some years and has now completely outgrown the spruce, being eleven feet high after twenty years, compared to the one to three feet of the spruce. However, owing to the fastigiate nature of the pine, and its wide spacing, the ultimate fate of the spruce is still not certain; a proportion may even yet be nursed into growth.

The third early plot of Serbian spruce was planted in the Wykeham collection on two-year-old ploughing, half the plot receiving two ounces of slag (41.P.34). An early check occurred in the control, but there were no appreciable losses after the first year, and by 1942 both control and manured plots were of healthy appearance and growing, even though standing in dense heather. After twenty years the controls average five to six, and the manured plots twelve to fourteen feet. Though this may not seem over-rapid growth it is the contrast with the other spruces nearby that is remarkable. Under similar circumstances of old ploughing and in pure plots, Norway spruce has checked severely and Sitka almost as badly, neither having formed canopy without special measures for their stimulation. On the basis of this one trial on the heath, and of a not dissimilar plot history in a species trial on deep peat (Zehetmayr, 1954), Serbian spruce was selected for use in comparison with Sitka spruce on all sites where checking of the latter by heather was likely to occur.

Since 1950 therefore Serbian spruce has been incorporated into all the species comparisons, mixture plots, and trial plantations, on the heaths. Only the oldest of these are worth noting at the present stage. In the 1950 introduction experiments, this spruce is of good colour and making steady growth, but evidence is accumulating that while resistant to heather competition it is not so tolerant of exposure, and certainly it is not so fitted for exposed sites as Sitka spruce. Thus in the pilot plots at Forss, Caithness; Drumtochty, Kincardine; and Cleveland, Yorks., though neither species is very satisfactory, Serbian is certainly the poorer. In rather less extreme conditions of exposure at Teindland, but where soil conditions are poorer, than any of these sites, Serbian spruce has started well (82.P.52).

Picea orientalis Carr. was planted in the 1950 introduction trials and is quite promising though slower in early growth than *P. omorika*.

Summary for Picea

Of the species of spruce mentioned above, it would appear that only *Picea abies* and possibly *P. omorika* can be expected to play any part in the heath forests, and the use of the former species will certainly be confined to the second rotation or successor crops. In *P. omorika* it appears that a spruce less liable to check by heather has been discovered, though this finding is based largely on the evidence of two plantings. For the present therefore its use is confined to pilot scale plantings under a variety of conditions.

PINUS—PINES

There are three small collections of pines planted adjacent to large Scots pine provenance collections, at Inchnacardoch (92.P.31), Teindland (32.P.28), and Findon (4.P.36). In all three, the plants were directly notched without ploughing or phosphate. A number of species, *Pinus banksiana*, *P. densiflora*, *P. radiata*, *P. resinosa* and *P. sabiniana*, have checked or failed in one or other of these trials, and as they have not been planted since, are not mentioned further. None of the species in these collections can be said to have received fair trial, but the state of surviving species is noted below.

Pinus koraiensis Sieb. and Zuc. This pine has been planted only in the Teindland collection, where about half survive; after twenty-five years of semi-check they range in height from three to seventeen feet, are of good form, and now appear fairly healthy.

Pinus mugo Turra (=*P. montana* Mill.) Mountain pine is an extremely hardy species but slow in establishing itself and in subsequent growth. Nevertheless at the time the Forestry Commission started work on the heaths it was the only species known to grow on sites too poor for Scots pine, and it had been successfully used as a pioneer on the continent, especially in Denmark. Hence mountain pine was used to a limited extent in the early plantings, and as one of the main species in the early experiments. But with successive improvements in technique, and with the introduction of lodgepole pine for planting on difficult sites, the possible openings for its employment have dwindled, until its only use today is as a component of shelter belts. While mountain pine has long been suggested as a suitable nurse for spruce on the Danish pattern, in only one or two of the trials has it as yet succeeded in nursing the spruce into canopy.

There are a small number of old plantations on heath, the most notable being now included in Kilcoy Forest, Ross-shire, for which the growth figures given in Table 42 show that the crop is approximately equivalent to Quality Class IV Scots pine, the height being rather less, but the volume greater. The growth rate is approximately the same in the species trial at Staindale, and on a podzolised morainic slope at Inchnacardoch. On poorer ground at Harwood Dale, mountain pine is approaching Scots pine in rate of growth. Finally, figures are given from extreme conditions on or near high ridge tops at Clashindarroch. With a minimum of treatment the two forms of mountain pine employed are now both making canopy, but Scots pine and certain inland provenances of lodgepole pine have succumbed to the rigours of the sites, though one high elevation provenance of the latter species survives; unfortunately there is no comparison with the shore form of lodgepole pine.

Some of the early experiments demonstrated, however, that even this hardy species is not entirely unresponsive to ground conditions, for in a trial plantation at Monaughty (5.P.23), mountain pine failed when hand-planted without phosphate, while the results given in Table 3 (p. 31) show a good response to soil preparation and phosphate at Teindland. It may be noted that in the notched controls in the latter experiment, mountain pine showed better growth than Scots pine; but once hand digging was undertaken and phosphate applied, the Scots pine responded to a greater extent and outgrew the mountain pine; lodgepole pine, however, was superior to mountain pine under all conditions.

Varieties of Pinus mugo. In the various experiments, at least three forms of this pine may be distinguished, a prostrate form without definite leader (var. *mughus* Zen. or var. *pumilio* Zen.); an upright form with a definite single stem (var. *rostrata* Hoopes=*uncinata* Ram.) and an intermediate form with several ascending stems (var. *rotundata* Hoopes). The crops have not been examined for form of cone,

TABLE 42: MOUNTAIN PINE

Growth of mountain pine, *Pinus mugo*, under various conditions of soil and exposure compared to that of other pines.
Corresponding Quality Classes of Scots pine shown for all species.

Height in feet

Forest, Experiment and site type	*Age*	*Mountain pine*		*Scots pine*	*Lodgepole pine*	*Notes*
		Prostrate	*Erect*			
Good heath sites:						
Kilcoy plantations	45	—	33 (IV)	—	—	B.A. 133 sq. ft. q.g. Vol. 2,300 H.ft.
Staindale 1.P.31	25	—	18 (IV)	24 (III)	26 (III)	Shallow ploughing
Inchnacardoch 16.P.26	30	—	26 (III–IV)	42 (I–II)	53 (Super I)	Notched on moraine
Poorer heath:						
Harwood Dale	25	—	16 (IV)	—	20½ (III–IV)	Pit and mound, or hand dug groups, with phosphate
Exposed sites:						
Clashindarroch‡ .... 1,250–1,400 ft.	20	5½	9½	Failed	6†	Notch planted without phosphate

Notes: ‡ Combined results from experiments 9, 11, 12 and 14.P.31–34.
† One plot only, several others failed.

but fall quite clearly into these three stem classes, most of the experimental plantations being of the upright or intermediate forms. Using stock raised from seed from the older experimental plantations, an attempt has been made in recent years to rank two or even three forms in ascending order in shelterbelts, or in the shelter strip which surrounds all the newer trial plantations. The dense foliage mass of the prostrate type would appear ideal for edging belts or plantations, to prevent wind getting into the crop as the trees age and the canopy lifts at the edges.

Mixture of Pinus mugo with Spruce. Mountain pine has been used to nurse spruce in three ways, as an advance crop, as a nurse planted simultaneously, and as a repair species planted among checked spruce in order to try to nurse them into growth. None of the experiments show conclusively either which is the better method, or which form of mountain pine should be used; but certain examples may be given as to what has occurred in individual cases. In several experiments with Sitka spruce where the two species were planted together, conditions have been such that the spruce has failed or checked very severely before the pine had grown sufficiently to aid it. This was in some cases due to poor planting methods, or absence of phosphate, and where the erect variety of mountain pine was used it seems unlikely that the spruce will recover quickly enough to avoid suppression (Harwood Dale 8.P.33, Clashindarroch 12.P.33, Millbuie 4.P.46). Part of a second experiment at Clashindarroch (11.P.33) was given phosphate, and here a few Sitka spruce may grow, but at twenty years they were only four feet high when the mountain pine were over nine. In contrast, successful nursing of both the common spruces has been attained on ploughed ground with a heavy phosphate dose at Teindland (Figure 9, p. 88).

There is a very successful instance of the planting of spruce into established mountain pine at Drumtochty Forest, Kincardineshire, where a seventeen-year-old belt of pine at 1,000 feet elevation was interplanted with Sitka spruce in 1930. The pine here is of intermediate form and this has no doubt helped the spruce to overtake it, so that after twenty-five years they are emergent and average over twenty feet, while the pine, now forty-two years old, are about fourteen feet. Several other areas of mountain pine at this forest are now in canopy and these crops, totalling about fifty acres, will in due course be underplanted. In an attempt to repeat this success at Clashindarroch, the Sitka spruce which had failed when planted along with mountain pine in 1933, were replaced in 1950; but after six years they are in check, and give little hope of recovery before they are suppressed (12.P.33).

Finally two attempts have been made to aid checked spruce by interplanting them with mountain pine. At Inchnacardoch, Macdonald and Macdonald (1953) have shown how, on the poorest of three vegetation types, all three pines used, mountain, Scots and lodgepole, outgrew and suppressed the spruce, though on better—non-heath—vegetation, the Scots pine has nursed the spruce into good growth. Another trial was made recently in Drumtochty (6.P.51) where with direct planting the growth of the mountain pine has been extremely slow and after five years they have not emerged from the heather, while the spruce remain in check.

In conclusion it may be seen that while mountain pine has a possible role in shelterbelts or plantation edges on heaths, the trials made suggest that there is a fine balance between conditions in which it nurses or suppresses spruce. In the future some trial will undoubtedly be made of underplanting the existing crops, which are, however, small in extent. Chapter 2 (p. 8) gives further information on this species and suggests reasons why so much greater use has been made of it in Denmark.

Pinus nigra var. **austriaca** Asch. and Graeb. Austrian pine. The one possible use of this species is as a shelter tree in place of, or complementary to, mountain pine, but there are only two plantings of any age. The first is in a shelter strip at Harwood Dale (Table 64, p. 136) where it was placed behind mountain pine and in front of lodgepole pine; here it is healthy and vigorous, just exceeding the montain pine in growth, but falling rather short of the lodgepole. A second plot, in the pine collection at Inchnacardoch, is unhealthy and of poor form, while growth is irregular. In 1952 two further plantings were made in shelter strips at Teindland, and Skiall, Caithness. At the former the survival was good and plants are healthy, but at the latter, in the most severe conditions of exposure of any of the heath plantings, the Austrian pine is only just established.

P. nigra var. **caramanica** Rehder was included in the collections at Findon and Inchnacardoch; in the former collection one tree has reached four feet, but the majority have succumbed to damage by frost and deer; while in the latter collection the trees are unhealthy, though ranging up to nine feet.

Pinus peuce Gris., was included in the same two trials and is the most promising of the less common pines. At Inchnacardoch, after a slow start, it is now healthy, of good form, and growing steadily after a long check. Heights range from three to eleven feet after twenty years, with double this growth on a small section with better soil. At Findon, a plot of almost half-an-acre was planted, and in spite of slow growth in the difficult conditions, only five per cent have died and the remainder are two to three feet high after seventeen years. The plants look fairly healthy and have now received a phosphatic top dressing; in addition they appear to be unattractive to deer, which have ravaged several of the other pines in the vicinity. It is apparent that this species is worth further trial under more favourable conditions.

Pinus pinaster Ait. Maritime pine was sown in an early species trial on ploughed ground at Wykeham (9.P.29), where it has developed slowly to form a rough, heavily-branched crop, ten to eighteen feet tall after twenty-five years. Parts have been severely attacked by *Brunchorstia* fungus. Subsequently this species has failed in the very exposed trial plantation near the sea at Forss, Caithness (1.P.50).

Pinus ponderosa Doug. Western yellow pine was included in the first heath experiment, the species trial on shallow ploughing at Staindale, where the majority died, in common with the rest of the species used. One small group of plants survived, however, and are healthy, have formed canopy, and range up to twenty feet at thirty years of age. An early experiment at Findon (2.P.29) compared six provenance lots of this species from the south centre of British Columbia. The site includes typical heath, but is traversed by a grass flush, and site differences have proved more important than any possible differences in racial type. After twenty-five years the height ranges up to ten feet on the true heath; the trees are unhealthy and carry poor crowns. In contrast, on the grass flush the growth is much better, individual trees being thirty-five feet high. Subsequently this species failed in the Findon pine collection. In recent years it has been planted only in the 1950 introductions, where it has in two cases started rather slowly but appears to be healthy. At Newtyle, generally the least successful of these sites, this species is surprisingly vigorous, having reached four feet in six years, partly because it appears to be unpalatable to deer. This may be a species worth further small-scale trial in dry areas with higher than average sunshine. It is doing well at Culbin on sand within twenty miles of the plantings at Findon and Newtyle, which suggests that the species is more suited to the sandy areas near the heaths in the Moray Firth region, than to the heaths themselves.

P. thunbergii Parl., has been planted only in the Findon and Teindland pine collections. At the former it checked, and was later destroyed by deer, while at the latter the few survivors are of poor form, unhealthy, and have a maximum height of fourteen feet after twenty-five years.

Summary for Pinus

Of the pines discussed above, none would appear to be likely to play any great part in the heath forests. *Pinus mugo* has a use for shelterbelts or edging for exposed plantations, *P. peuce* is worth further limited trial, *P. nigra* var. *austriaca* may be useful in shelterbelts, and *P. ponderosa* on sandy dry heaths, but no large-scale use of any of these species is probable.

PSEUDOTSUGA—DOUGLAS FIRS

Pseudotsuga taxifolia Britt. Douglas fir is one of the species which may well become important on the heaths, though it is not well suited for the rigours of the first rotation. As with many other successor species, failures took place in the early plantings through inadequate technique, e.g. with ground preparation by hand at Inchnacardoch (78.P.31), and shallow ploughing in the first Staindale species trial. When the latter area was reploughed with better tackle and replanted, the Douglas fir survived, but has grown slowly, being the poorest species in the experiment (Table 39, p. 89). Growth of the same order has been obtained in pure plots with complete ploughing and phosphate at Wykeham, where in the species collection it averaged thirteen feet after twenty years.

On better soil and in shelter at Clashindarroch, results are far superior, good crops having been grown at the foot of the Mytice area; after hand preparation and without phosphate, the height is equal to that of Scots pine, twenty-three feet at twenty years (24 & 25.P.37), while nearby on ploughed ground it has reached nine feet in ten years (33.P.45).

The blasting and dieback shown by this species in exposure is well known, and it was one of the first species tried in the introductions into pioneer crops or with a rapidly-growing nurse crop. Table 40 (p. 91) contrasts results in shelter with those from pure plantings at Wykeham. Under the wide variety of conditions covered, Douglas fir becomes one of the fastest-growing species, so much so that it is in several cases emerging from the shelter of the nurse, with the prospect that it will suffer blasting. At Teindland it started very well, but was later attacked by the insect *Adelges cooleyi*, which has slowed down the rate of growth considerably. For the first six years the Douglas fir led the hemlock in growth, but after ten they were level, and after fifteen the latter is 50 per cent taller.

The pure plots at Wykeham are similarly affected by *Adelges* and show poor growth and signs of exposure. The general appearance and health in the remaining trials is excellent. It should be noted that the plants in these experiments come from seed of a wide range of origins, mainly from the Pacific coast of North America, but in some cases are of British origin. The degree to which this has influenced these results is unknown, though this species is known to vary widely in behaviour according to provenance.

Since deep ploughing was introduced, further trials have been made of planting Douglas fir as the first crop, and it has shown remarkable ability to survive and grow. Thus in Millbuie Forest various areas of very open scrub Scots pine were replanted with Douglas from 1942 onwards, and the fir was three to fifteen feet tall after fourteen years and had good shoots, even though its colour was poor. Similar results have been obtained in experiments at Millbuie on the open moor (5 & 6.P.47), where growth is surprisingly good although the appearance is very poor; only this species seems likely to make canopy with the Scots pine nurse, while Sitka spruce and hemlock remain in complete check ten years after planting.

Since 1950, Douglas fir has been used in a dozen further trials, including the introduction trials made in that year, but results so far obtained add nothing to the above. Care has been taken to include var. *caesia*, as being from a drier region it may prove less unsuitable for the heaths than for other sites. One of a recent series of comprehensive provenance trials has been planted on a marginal heath site, *Pteridium* with some *Calluna*, at Laiken Forest, Nairnshire (1.P.53).

The future use of this species thus remains open to question and the trials already established should help to determine its role.

THUJA—WESTERN RED CEDAR

Thuja plicata D. Don. Of nine plantings of western red cedar on the heaths only two are at all advanced; the earliest was on ploughed ground in the Teindland species trial, where there was an initial response to phosphate, but subsequently all the plants first checked, and then slowly died out. A second turf-planted trial at Teindland (59.P.35), and another on ploughing at Wykeham (59.P.39) both checked very severely even with phosphate. The former was burnt in 1942 before any ameliatory treatments could be tried; while in the latter mulching, nitrogenous manuring, and interplanting with Scots pine was tried in 1945-1951, but without appreciable results so far, except that four years after mulching the colour has improved, so that renewed growth may follow.

The two successful trials are those at Wykeham recorded in Table 40 (p. 91). In one case *Thuja* was introduced into young Scots pine, while in the other it was grown with broom. In both experiments it is among the slowest-growing species, but since it is fairly tolerant of shade it may be brought into the crop. That this species is not so shade-tolerant, or at least as suitable for underplanting, as sometimes imagined, is shown by the third trial where it checked when underplanted in young lodgepole pine, Japanese larch and birch crops. Root competition with the overcrop may have played some part.

The only recent plantings of *Thuja* are in the three 1950 introduction trials, in which it has failed at Devilla but shows some promise at Wykeham and Newtyle. It appears that the inability of this species to compete with heather precludes its use in the afforestation phase. The few small trials established by special intensive methods should suffice to indicate whether it can play any part in later rotations.

TSUGA—HEMLOCK

Tsuga heterophylla Sarg. Western hemlock is a species which may well come to occupy a much more important position on the heaths than it does today. The experimental and other plantings already made have shown the ability of this species to grow in mixture and in half-shade on the poorer heaths, and it is already recognised as a most useful species for enrichment or repair of damaged or defective plantations. Drawbacks to its wider use are the difficulty of obtaining seed and the likelihood of damage by deer where planted in closed forests. Until the existing plantations on the heaths are rather older it will not be possible to gauge how far they are likely to be attacked by heart rot, a disease to which this species appears prone on richer sites.

The earliest planting was in the main Teindland species trial, where it has grown well on ploughing with basic slag and alongside lodgepole pine (Fig. 9, p. 88). These small plots now form a most striking example of growth on a poor exposed site. In the Wykeham species trial, without phosphate and in mixture with birch, an open crop has been obtained with a height range of four to twenty feet after twenty-five years. A third early planting was in the collection at Clashindarroch where, hand-planted and without phosphate, the majority failed, though a small number of survivors are now growing quite well. Hemlock also failed at Teindland when planted by notching, without phosphate, as a beat-up species for Scots pine plantations (54 & 55.P.34); so it is apparent that adequate ground preparation and/or phosphate are required when this species is planted in direct competition with the heather.

A comprehensive experiment with good ploughing as the basic treatment, was planted at Wykeham in 1941, and results are given in Figure 11; a comparable experiment at Teindland was lost by fire. It is apparent from the diagram that a successful mixture has been obtained with Scots pine, so far as height growth is concerned. The mixtures are in fact

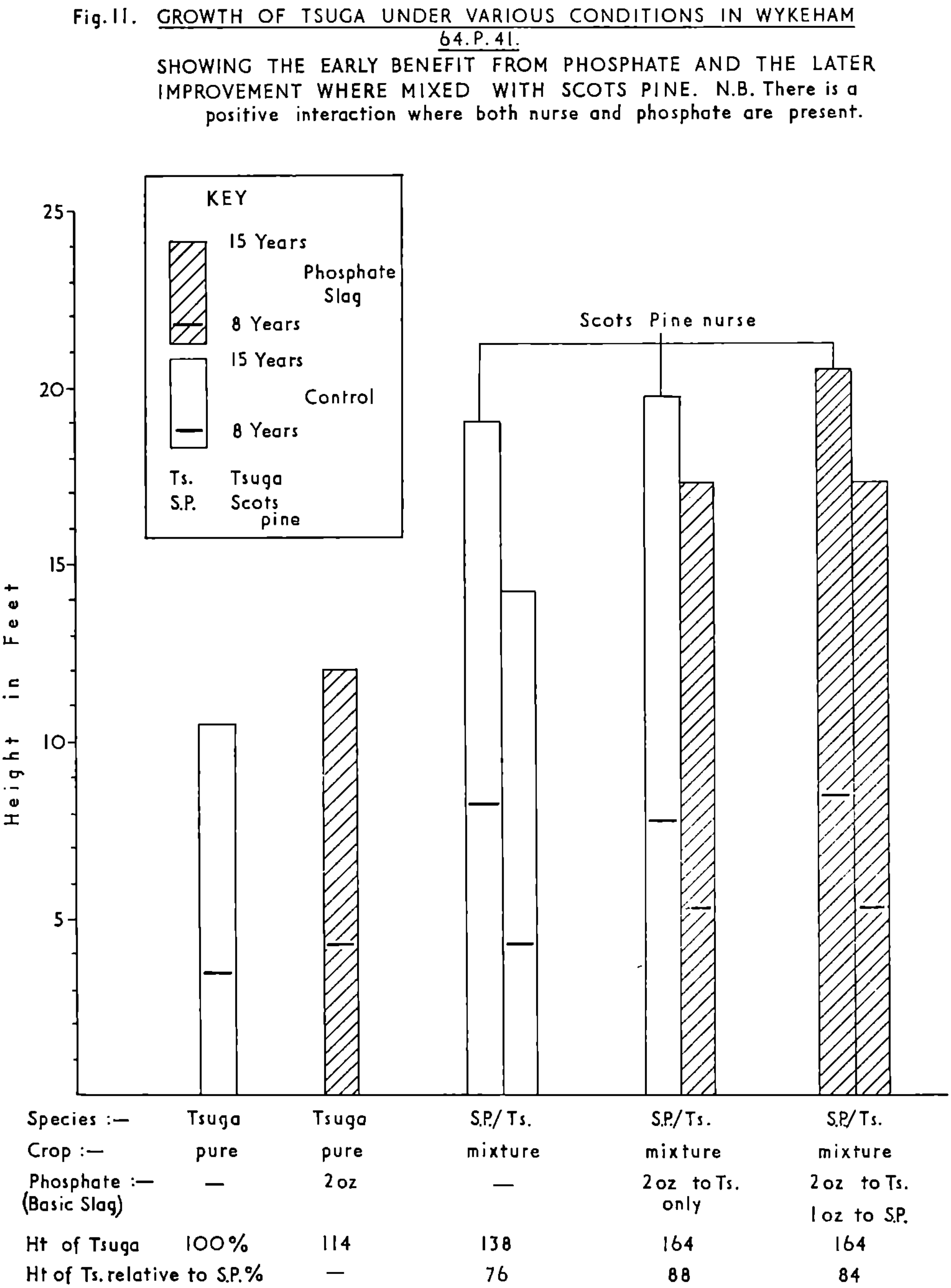

Fig. 11. Growth of Tsuga at Wykeham under various Conditions. (61.P.41.)

pleasing in appearance, the hemlock is of good form after the removal of double stems due to early frosting, and has green foliage to the ground, while the pine has been brashed and has obviously nursed the hemlock into better growth. It is apparent on the ground that had the pure controls been larger, their growth would have been poorer, since they have been to some extent nursed by the adjacent mixed plots. It may also be noted that differential manuring, with phosphate applied only to the hemlock, has given more even growth of the two species in the mixture. In spite of the poorer growth in the pure plots of hemlock in this last experiment, it is apparent that it is more tolerant of heather competition than are many other species, including Norway and Sitka spruce, Lawson cypress and *Thuja*, all of which check more severely under comparable conditions. Generally the height growth of hemlock is more comparable to that of Douglas fir, as shown in Table 40 (p. 91), though this is not so at Millbuie where the latter is growing where *Tsuga* is in complete check, ten years after planting on ploughed ground without phosphate (Millbuie 6.P.47).

Table 40 indicates also the remarkable growth achieved when introductions were made into closed crops, or when broom was used as a nurse. In the former cases hemlock was the fastest species; in the latter, though growth was even faster, the hemlock was not quite as fast as the Douglas fir or Sitka spruce.

Use was made of hemlock on a rather larger scale, from about 1925 onwards, for under-planting rough Scots pine crops in various forests, notably at Teindland, Monaughty, Culloden and Findon; all with considerable success. One difficulty is that in a patchy crop such as is obtained by underplanting in irregular crops, heavy side branches are formed by a high proportion of the hemlock. Interplanting in regularly-shaped groups after removal of the worst of the overcrop, would appear preferable, as likely to give finer-branched trees in the centre of the groups. If the overcrop is more even and shade greater, as in certain old Scots pine woods at Millbuie, then growth is slower but less coarse lower branches are obtained, and when released cleaner trees should result. Trees in some of these under-plantings are now twenty to thirty feet tall, and should provide the first produce of the species from heath sites.

There are examples of successful introductions of hemlock into young crops at Allerston. A few trees were planted into three-year-old Sitka spruce which has itself been planted into broom, and the two species are now in canopy together, and over twenty feet high after fifteen years (Wykeham 32). In 1950 hemlock was used to enrich an irregular crop of Scots pine four to eleven feet high, which had been planted in 1929 without ploughing (Wykeham 85.P.50). Lanes were cut through the crop, ploughed, and the hemlock planted with phosphate; the interplants now average twelve feet after ten years and seem likely to form canopy with the pine, even though the latter have also improved after the treatment; Douglas and grand firs, also used in this trial, are not so promising. In a repetition at Newtyle (2.P.50) hemlock again has made a better start than the other species, though growing more slowly than at Wykeham.

In a rather similar trial at Broxa, hemlock was used to replace failed Sitka spruce in a ten-year-old alternate-line mixture with Scots pine (88.P.52). The one-plus-one plants used were only four to five inches high, yet, when set on new ploughing and manured, they reached almost six feet in six years, and are of notably better form and growth than occurs on the open moor. It is apparent from these results that this species can be used to repair losses or failures in a mixture at a stage when most other species stand little chance of entering the canopy, and that shade enhances the quality and, if not too heavy, may also increase the rate of growth.

Besides this wide variety of trials in partial shade, hemlock has been used in all the recent species trials and pilot plots, generally in mixture with lodgepole or Scots pines. Early growth has been quite good, but in exposed areas much dieback of leaders has occurred, giving a bushy form to the trees within a few years of planting. The early trial at Teindland showed that the bushes may develop good leaders at a later stage, but this will obviously reduce the quality of the butt, and increase the tending required.

It is apparent that enough is known of this relatively inexacting species to encourage its use on a larger scale, particularly in the regeneration of old stands, and for the repair of storm-damaged or defective crops. It should be noted that nothing is known of provenance differences, nor as to how far variation in form depends on site or provenance, and these are questions which will arise if it is to be more widely employed.

BROADLEAVED TREES

A great number of species of broadleaved trees and also some shrubs have been tested by planting on a limited scale in the experimental areas, or have been sown in recent years at Broxa by Dr. Dimbleby of the Imperial Forestry Institute, Oxford, in his experiments to find and raise soil-improving species (Broxa 79, Dimbleby, 1958). In view of the small scale of the former, and the few years which have elapsed since the latter were started, the following section is not exhaustive and does not list single failures, nor does it attempt to anticipate Dimbleby's findings, except that cases of promising early growth in his experiments are noted.

These sowings were made after more intensive ground preparation than has normally been carried out, viz., complete ploughing followed by roto-hoeing. Seven hundredweight of basic slag and 1½ hundredweight of sulphate of potash, per acre, were applied before planting, while nitrochalk top dressings were applied to chlorotic seedlings as required. After a sowing technique using heavy grit cover had been developed, plantings were made in 1955 of selected species on single-furrow ploughing as a rough control.

ALNUS—ALDERS

Alnus glutinosa Gaert. Common alder was planted in seven of the early experiments at Allerston, but has failed wherever used on typical heath sites. In the first experiments at Harwood Dale, alder started to grow very rapidly where planted with phosphate after intensive hand preparation—pit and mound or dug-over patches—although it soon failed where notched, or planted on replaced turfs (1, 3, 7.P.32 & 8.P.33). With the most intensive treatment, it averaged four feet within five years of planting, almost double the height of lodgepole pine alongside, but then slowed down, checked, died back and after fifteen years had failed completely. Attempts to stimulate regrowth by coppicing were not successful. During the early promising phase further plantings were made, but these also failed, apart from a small area where flush vegetation is found beside a small stream at Harwood Dale (13.P.35).

More recently, excellent early growth has been obtained by Dimbleby at Broxa using relatively intensive cultivation and manuring and by raising the trees by direct sowing. After six years they remain healthy and vigorous, the best sustained growth achieved to date.

Alnus incana Moench. Grey alder has been tried under a wider variety of conditions than common alder, without as yet providing one example of satisfactory growth over a period, though in several cases there is some indication that it may grow if suitably treated. There were early failures in the collection at Clashindarroch, and on replaced turfs at Harwood Dale (8.P.33). Three plantings on ploughed ground at Teindland grew well for the first few years, reaching average heights of four to eight feet, but then checked and began to die back (47 & 48.P.32, 62.P.38). One of these experiments was burnt in 1942, and coppice growth has occurred from the stumps, while in a second case growth of suckers is occurring up to ten feet away from the plants. Both these plots are being preserved to see if some form of cover crop can be produced.

The plantings in 1938 and 1939 into lodgepole pine at Teindland (41.P.29) both included grey alder. In the first, planted by hand methods, it has not been so successful as the Oregon alder which is described below; though where planted on dug-over patches and given phosphate it had reached fifteen feet in as many years; it is now being suppressed by the pine. In the second trial in ploughed lanes, about the same rate of growth has been obtained, but with the more open situation it is possible that the grey alder may come into canopy with the hemlock and lodgepole pine, though at present the alder is not very healthy.

Later introductions in the 1950 series have started quite well at Wykeham and Newtyle, but clearly their testing time is still to come. In a recent trial at Broxa it is already apparent that this species is more healthy, and growing faster, in plots which were manured with lime and receive side-shelter from pines, than in the open or without lime. In the former more intensive treatment, the alder has reached up to nine feet in four years (86.P.52).

Dimbleby has recently secured vigorous crops, grown by direct sowing after intensive ground preparation and manuring.

Alnus rubra Bong. (=*A. oregona* Nutt.). The history of Oregon alder is very similar to that of the others, except that two small patches at Teindland and Dornoch have grown well under true heath conditions. Planting began in 1932, at a time when earlier plantings in the peat experiments were making very rapid growth. In the second species trial at Teindland (48.P.32), the usual history of rapid early growth and subsequent check occurred, but the plots were then burnt and subsequently there has been regrowth from coppice. In an adjacent trial, results of which have been given in Table 20 (p. 58), Oregon alder grew very fast where planted with phosphate on intensively cultivated ground, and after eight years reached fifteen feet, while Japanese larch was still only four feet tall; but once again die-back followed, and at twenty years the plants were at best bushes alive to only ten feet.

Oregon alder was, in 1935, the most promising broadleaved tree in the experiments, and was employed as an indicator in the draining experiments summarised in Chapter 4. Results have been given in Tables 8 and 9 (pp. 37 and 38), and show that at Dornoch there has been excellent growth where intensive draining or soil working was undertaken. Results were not so good at the other two sites where there has been dieback, though there are good individual in the most intensive treatments. Clearly, Oregon alder requires intensive ground preparation, but even so failure may occur, as in an experiment at Harwood Dale where mock ploughing was carried out and phosphatic manure applied (24.P.39).

While the plots in the earlier experiments were still growing rapidly, the first introduction was made into lodgepole pine at Teindland on dug-over patches manured with phosphate (41.P.29). This small plot has been most successful, and apart from the Dornoch plot contains the only broadleaved trees of any size in the Scottish experiments. Within eight years the alder was level with the pine planted nine years earlier, and since then the dominants have kept pace, the pine being thinned to give them room. After seventeen years, the alder ranged from eighteen to twenty-three feet, with a girth of ten inches. The form is not good and some die-back has occurred in the crown; but the trees are fairly vigorous, and it is apparent that their leaf-fall is influencing the nature of the humus on the forest floor. As has been noted, it was here that grey alder failed to get through the pine and was suppressed. In addition, six other species, including birch, beech and *Sorbus intermedia* made little or no growth and slowly died out under comparable conditions.

At about this time use was made of Oregon alder to fill gaps in certain of the obsolescent Wykeham experiments; most of the plants failed, but a few have reached comparable dimensions to those at Teindland, but nowhere in such numbers as to form a significant proportion of the crop. One exceptional tree is thirty feet tall and has a good crown, and may be used for propagation, though possibly the existence nearby of a large soil pit has influenced the growth.

The only subsequent plantings have been in the 1950 introduction trials, and in recent sowings and plantings at Broxa, where as usual rapid early growth has been obtained.

In an attempt to improve Oregon alder in a debilitated condition, various treatments were applied in 1950 to an eleven-year-old plot in the Wykeham collection. Removal of heather, liming, and mulching with bracken, were tried with remarkable results in the last case, so that canopy has formed and growth been renewed within four years of application, the first response being an increase of leaf size and improved vigour of branchlets. The effect of lime, though positive, was much less marked, while screefing was harmful, presumably through damage being done to the roots.

Clearly this species remains a problem, growth in certain cases is promising enough to encourage further trials, while die-back apparently may occur at any stage. The addition of an alder to the list of plantable species on the heath would be of enormous importance on account of its ability to fix nitrogen and thus to assist in maintaining or improving the soil fertility, which may be the major problem in the perpetuation of the heath forests.

Other Alnus Species. *Alnus sinuata* Rydb. (=*A. sitchensis* Sarg.) has been planted once at Teindland, where it has been in check for some years after reaching five feet within a few seasons (61.P.37). *A. cordata* Desf. and *A. viridis* DC. have made good early growth in the Broxa sowings, though they are not quite so tall as the common and Oregon alder plots.

BETULA—BIRCHES

Betula pubescens Ehrh., and **B. pendula** Roth. (=*B. verrucosa* Ehrh.). Birch is a natural component of the original and planted pinewoods of the heath regions, and has received considerable attention on the Continent, and latterly in Britain, on account of its possible soil-improving qualities. From an early date, attempts were made to raise it in pure or mixed crops in the experimental areas. The seed used was sometimes of one particular species, but more often mixed, and very rarely were the parents of good growth or form, which may account in part for the very moderate success of the plantings. Birch of good type is in fact rare in Britain, and for that reason seed has in recent years been imported from stands of high quality.

The majority of the early trials have produced open crops of birch scrub rarely attaining ten feet in height after twenty to twenty-five years. Examples of such crops exist in several experimental areas, and are being retained for future study, though in some cases failures were so numerous that the blanks were filled with conifers. These trials include hand-prepared and shallow-ploughed areas; in certain cases phosphate was applied, apparently without effect; in none of them has the heather yet been suppressed. (Hamsterley 5, Harwood Dale 1 & 8, Staindale 39, Teindland 47, 48 & 49, all planted between 1930 and 1934).

There are a few cases in which growth has been rather better, and which are worth more detailed examination. In the Harwood Dale shelterbelt, intensive hand-preparation by dug patches with phosphate has given better growth than pit-and-mound planting (Table 64, p. 136). On fresh ploughing at Wykeham fair crops have been raised in three cases (9, 11, 23.P.29-32), whereas growth on four-year-old ploughing was much slower (45.P.36). Figure 6, (p. 46), which shows the results from the most successful of these experiments, indicates that both ploughing intensity and phosphate affect the birch; it is notable that birch showed the strongest response to subsoiling among the five species, which is of interest in view of the fact that it is considered a deep-rooting species.

Birch seed was sown either broadcast or in patches on ploughed ground in several trials at Teindland, and although some of them were burnt over some years later, birch is now growing in mixture with the pine and spruce planted after the fire; earlier it was observed that germination was best in the plough furrows (62, 63 & 66.P.38-39).

In recent years Weatherell at Allerston has obtained better results from birch planting by lifting natural seedlings from birch stands and lining them out for one year before planting. Stock raised by this method has done well in recent trials, often reaching four to five feet in six years. Excellent growth has also been obtained in the 1950 introductions, where side-shelter may well be a factor.

In another trial at Harwood Dale (3.P.32) an interesting mixture is developing where Scots pine was interplanted in 1943 among ten-year-old spaced groups of birch. The birch was in check when the conifers were planted, but after twelve years in mixture both species range up to fifteen feet.

It may well be therefore that birch is easier to raise in mixture with conifers than as a pure crop, as was the plan in the earlier trials. The best results in those have been obtained in small plots which, though classed as 'pure', are in fact affected by taller adjacent conifers.

A further recent result is that the early growth of birch appears to have been depressed by lime, in an experiment where phosphate has had a positive effect. (Broxa 86.P.52).

The work carried out by Dimbleby on the function of birch as a soil-improver is summarised in Chapter 12, and it is apparent that the experiments described above provide no information as yet on this subject. Nevertheless they will give ample opportunity for investigation in the future, since those birch areas established are surrounded by pure coniferous plantations, and it will be possible to carry through analyses on a sound basis of sampling and replication, which has been lacking so long as natural birch stands were all that was available for investigation.

In recent seasons birch has been raised successfully in heathland nurseries in the east of Scotland and in many areas a small proportion is being mixed into predominantly coniferous plantations.

Other Species of Betula. A number of other species of birch, together with plants of *Betula pubescens* and *B. pendula* of selected origins, have been included in recent plantings at Broxa (85.P.52) and Devilla (2.P.54). *Betula lutea* Michx. has made a good start in the 1950 introductions at Wykeham, reaching four feet in six years, and results are almost as good at Devilla. In contrast *B. lenta* L. is only half this height at Wykeham, and has failed at Devilla. *Betula populifolia* Marsh. has grown vigorously from sowings at Broxa, but suffered slightly from dying-back in 1955.

B. japonica and *B. papyrifera* are also established in Dimbleby's sowings at Broxa, but are growing more slowly than the common species.

FAGUS—BEECH

Fagus sylvatica L. Beech was used on some scale in the earlier years since it was known to grow on somewhat acid soils, and was widely believed on the Continent to act as a soil improver. Early failures occurred at Teindland (7.P.26), Wykeham (8.P.29), and Hamsterley (7.P.30), in spite of the use of intensive hand methods or ploughing, phosphate, and on the third site, caging against vermin. Even on much more fertile sites, where beech was used to beat-up Scots pine and Japanese larch plantations at Inglismaldie, Kincardineshire, (1 & 2.P.34), Drumtochty (1 & 2.P.34), and Inchnacardoch (110 & 111.P.34), there was practically a complete failure; only three trees at the last site have reached pole-size under the Japanese larch.

The next series of trials was that for which results have been given in Table 40 (p. 91). Even under the improved conditions, beech failed again at Teindland, but remarkably rapid early growth has been obtained at Allerston, particularly using broom, so that there is little doubt the beech will come into canopy with the other species. In another case beech was introduced into Sitka spruce which had itself been planted into broom; here the beech has not formed canopy with the spruce, but is twelve feet tall after fifteen years, about half the height of the spruce, so that its development will be of interest (Wykeham 32).

In the 1950 introduction trials, beech has made a slow start at Wykeham, but failed at Newtyle and Devilla. Other recent trials are in certain of the pilot plots which are on more fertile land but in exposure, as at Cleveland (1.P.52) where it is promising, and Forss (1.P.50) where it is checked. These sites are more fully described in Chapter 11, page 132.

Beech has been successfully established by sowing in Dimbleby's trials at Broxa.

Clearly beech has little place in the afforestation of the heaths but it may be possible to grow it by intensive methods on the English heaths, even if not on the Scottish. The soil-improving qualities once attributed to this species are not so generally accepted today, at least for sites of the type found on the heaths, and there would thus appear little point in growing this species in heathland surroundings.

QUERCUS—OAKS

Quercus petraea Lieb. Sessile oak was tried for the first time in the 1950 introduction experiments, where it is growing slowly at Wykeham. It has also been used as an indicator in a major trial of the effects of cultivation and lime by Rennie (1953), which is however too young as yet to provide results. Natural seedlings of oak are making their appearance in the experiments at Wykeham and their development will be watched, though so far growth is poor.

Quercus borealis Michx. Red oak has been used in a few small-scale trials in the past six years, and has made a slow start. No older crops exist on heaths in Britain, though on the Continent it has been used on some scale. In Holland, where good growth has been obtained and the leaf-fall was found to improve soil conditions, this species has caused difficulty in mixed plantations, as its vigorous crown has crushed all other species. The vigour of the regrowth when coppiced make it difficult to handle as an underplant, another role in which it has been tried on the Dutch heaths.

OTHER BROADLEAVED TREES

There remain a few cases where isolated broadleaved trees have grown which are worth record. Rowan, *Sorbus aucuparia*, has reached heights of nine feet at Hamsterley, where other species, alders, beech, and chestnut, failed when planted by hand methods (3 & 6.P.29-30). Fair growth has been obtained in recent sowings at Broxa.

A small number of sweet chestnut, *Castanea sativa*, survive at Wykeham (9.P.29), where planted on shallow ploughing to form twenty per cent of a mixture with conifers. After a long check, the survivors now form an understorey to Corsican pine and range in height from four to sixteen feet after twenty-five years. This species might possibly be employed for soil improvement and is being retried at Broxa where good early growth has been obtained in both sowings and plantings.

Sowings made by Dimbleby at Broxa from 1950 onwards include, in addition to those already mentioned, promising patches of the following species:—

Caragana arborescens	*Quercus borealis*
Carpinus betulus	,, *petraea*
Crataegus monogyna	,, *robur*
Frangula alnus	*Robinia pseudacacia*
Laburnum anagyroides	*Sorbus aria*
Prunus padus	,, *intermedia*

For further details, see Dimbleby (1958).

Chapter 8

MANURING AT PLANTING

Manuring was one of the first lines of approach to the problem of improving tree growth on the upland heaths, and it has proved to be rewarding, though of less importance than cultivation. Early work pointed to the importance of phosphates, on which research was concentrated for fifteen years from 1930. This resulted in the development of a satisfactory technique, and to the use of phosphate in practice on a limited scale. Early trials of other artificials having proved abortive, they were hardly used during this period. As an alternative, the use of legumes to provide nitrogen and act as nurses was developed and is considered in Chapter 9.

Meanwhile the late Dr. M. C. Rayner was investigating the effect of organic manures and composting, mainly at Wareham Forest, Dorset, but a few experiments were carried out on her behalf on the upland heaths. Though no practical results emerged for application in the forest, this work led to the development of the heathland and woodland nurseries which produce so much of the planting stock used today.

Another approach to the subject of forest manuring was made under the aegis of the Commission's Advisory Committee on Forest Research, which instigated an inquiry into the production of nursery stock, under the direction of the late Dr. E. M. Crowther of Rothamsted. Crowther's work led him to investigate the conditions under which the stock were to be planted in the forests and thus, to investigate forest manuring on the more difficult sites. A series of "nursery-extension" experiments, planted at Broxa from 1947 to 1949, were used as a basis for re-investigating the accepted phosphate technique, and for trying balanced NPK fertilizers.

During the same period, Leyton (1954) conducted an enquiry into the nutrient status of plants on the heaths, with particular reference to the manuring of spruce in semi-check, and this work is considered in Chapter 10, p. 127, on the stimulation of checked plantations.

The sections which follow deal fully with the Research Branch experiments, make a provisional summary of the results from Crowther's experiments, and refer briefly to the forest manuring aspect of Rayner's work. Manuring for direct sowing is covered in Chapter 12, while manuring in order to stimulate checked or slow-growing plantations is included in Chapter 10.

EARLY EXPERIMENTS

The first manuring experiment was carried out at Teindland in 1926, when one-quarter ounce of Kainit, or else one-half ounce of basic slag, was applied to pit-planted Scots pine (11.P.26). The Kainit increased the death rate, but there were no early losses among the plants which had received basic slag, and their appearance and growth was better. The unit in this trial was a single plant, and as soon as the early result was apparent this experiment was superseded by tests of basic slag on a larger scale.

Early results from these experiments, carried out in 1928-29 at Teindland, Hamsterley and Wykeham, are given in Table 43. By 1931, it was clear that phosphate was beneficial in the major experimental areas and that the effect varied with species, being most marked with larches, while with mountain pine it was apparently negligible.

Meanwhile early trials of other fertilizers were not so promising. The use of ammonium sulphate at Wykeham resulted in heavy losses; and an attempt to grow perennial lupin as a source of nitrogen failed (8 & 9.P.29). The plots which had received phosphate were often of strikingly good appearance, and thus it is that for over fifteen years research on manures was devoted almost exclusively to the technique of using phosphate, while at the same time phosphates were applied in practical large-scale planting on the poorer heath types.

PHOSPHATIC FERTILIZERS

The Technique of Applying Phosphates

As soon as the beneficial effect of phosphate had been observed in the earliest trials, an application of basic slag became a basal treatment in much of the experimental work, while further experiments were designed specifically to develop a technique for its employment. The series of experiments described

TABLE 43: BASIC SLAG

Results available, in 1931, from early experiments in manuring with basic slag, measured after 3–4 years growth.

Heights in Feet

Forest Experiment Treatment	*Scots pine*	*Other pines*		*Larches*		*Sitka spruce*
				European	*Japanese*	
Wykeham 6.P.28		Corsican:				
3 furrow ploughing	1.0	0.6		—	0.7	1.2
+2 ozs. slag	1.1	0.8		—	1.0	1.4
Hamsterley 1.P.29						
Prepared patches	Game	—	—	0.9	0.4	—
+1 oz. slag	damaged	—	—	1.5	1.1	—
Teindland 36.P.29		Mountain	Lodgepole			
Dug-over groups	0.8	0.65	0.55	—	—	—
+2 ozs. slag	1.1	0.65	1.05	—	—	—

on the peatlands by Zehetmayr (1954) were however duplicated on the heaths to only a limited extent. Most of the results agree with those obtained on peatlands, and the technique in use at present is identical, namely the application of about two ounces of ground mineral phosphate or high-grade basic slag as a top dressing, spread round the plant stem soon after planting.

Form of Phosphate

Basic slag was used exclusively until 1933, but from 1933 to 1935, following excellent results obtained on the peatlands, Semsol, a proprietary fertiliser consisting of a mixture in equal proportions of superphosphate and mineral phosphate, was employed in many experiments. The year 1933, the first in which it was employed on the heaths, proved to be a drought year and serious losses occurred in many places where it had been used. Thus, at Clashindarroch, European larch losses were two-thirds in the first year, though Sitka spruce showed no ill-effects (PT. 33/2). At Wykeham in the same year both Japanese larch and Sitka spruce lost very heavily where Semsol had been used, whereas losses where basic slag had been applied were less than in controls, as shown in Table 44. This experiment was repeated, with an additional treatment, in the following year, and the results given in Table 44 show that delay in the application of Semsol may alleviate its ill-effects.

Semsol was used again in a series of experiments at Teindland in 1935, particularly to try different methods of application. In one, where Semsol *or* basic slag was applied at the roots, losses of hybrid larch were greatly increased, being fifty and eighteen per cent respectively, as compared with two per cent in unmanured controls (57.P.35). With these object lessons, the use of Semsol on the heaths was never

TABLE 44: FORM OF PHOSPHATE: WYKEHAM

First year losses and mean heights 8–9 years after planting in two experiments at Wykeham.

Treatment	*Japanese larch*				*Sitka spruce*			
	27. P.33		33. P.34		27. P.33		33. P.34	
	%	*ft.*	%	*ft.*	%	*ft.*	%	*ft.*
Control	18	7.0	7	5.5	17	0.9	Nil	1.4
2 oz. slag	14	10.5	6	10.4	8	2.4	Nil	3.2
Semsol‡	88	—	40	8.9	56	2.4	3	3.4
Semsol after one year†	—	—	6	8.6	—	—	3	2.6

Notes: Manure was in all cases spread round the plants as a top dressing.
‡ 1¼ oz. in 1933 experiment, 2 ozs. in 1934.
† Losses given for year after application.

TABLE 45: FORM OF PHOSPHATE: TEINDLAND

Mean heights and losses of Japanese larch and Sitka spruce four years after planting in Teindland PTs. 35/1 and 35/2.

Phosphate 3 *ozs.*:—	*Japanese larch*		*Sitka spruce*	
	% loss	*Feet*	*% loss*	*Feet*
Control	18	1.1	Nil	0.5
Basic slag	35	1.6	10	0.6
Ground mineral phosphate	15	1.7	Nil	0.8
2 Ground mineral phosphate : 1 superphosphate....	98	—	40	0.6
Four mixtures with over 50% superphosphate	80–100	—	70–100	—

Notes: All manures applied under the turf in contact with the roots.
Area burnt 1942 so that later records are not available.

continued on the same scale as on the peatlands, while pure superphosphate was tried only once until recent years.

Ground mineral phosphate was tried for the first time in this 1935 series of manuring trials at Teindland. Losses, as shown in Table 45, were lower than for basic slag, even under conditions where losses with superphosphate were disastrous. From this time, ground mineral phosphate came gradually to take the place of basic slag, although there was only one more comparative experiment until recent years, and in that particular instance the increased growth with phosphate, though significantly greater, was not worthwhile; after eight years, growth in the controls was eighty per cent of that with basic slag or mineral phosphate (Wykeham 56 & 57.P.39).

More recently new trials have been made, using triple superphosphate in comparison with ground mineral phosphate, as only one-third the weight of the latter is required for a given dose of P_2O_5. Though the cost of this fertilizer would be higher, it would be more than offset by the great reduction in transport and distribution charges which form the major part of the cost of manuring. Results from trials made on the heaths in 1954-55 show that early losses have not been excessive, particularly where care has been taken in placement, by notching or spreading the manure a few inches away from the plant. (Edwards 1959).

Quantity of Phosphate

Very little work has been done on this subject. The small dose of half-an-ounce used in the first experiment at Teindland was followed by heavy broadcast doses applied to existing experiments, but by about 1930 the practice became to use about two ounces per plant, with limits of one ounce to three ounces, according to the estimated requirements of the site. Thus at Allerston one ounce was generally used, whereas at Teindland three ounces was common.

TABLE 46: QUANTITY OF PHOSPHATE

Mean heights and losses seven years after planting in Harwood Dale 4 & 5.P.32 and Wykeham 23.P.32.
Height in feet: losses per cent.

Quantity of slag	*Scots pine*			*European larch*	*Japanese larch*	*Sitka spruce*	*Birch*
	Harwood Dale		*Wykeham Ploughed*	—	*Wykeham*	*ploughed*	—
	Notched	*Pit & Mound*					
0	1.1	1.6	3.2	3.4 (14)	1.6 (45)	0.7 (34)	4.2 (16)
1 oz.	1.3	2.0	4.0	4.5 (5)	3.7 (12)	1.5 (13)	4.3 (6)
2 oz.	1.5	1.9	4.0	5.0 (2)	3.7 (19)	1.7 (18)	4.9 (12)
3 oz.	1.5	2.1	4.3	5.3 (6)	4.0 (8)	1.6 (10)	4.9 (17)

Notes: Losses of Scots pine were negligible.
Use of a bad planting position at Wykeham may have influenced the results.

TABLE 47: METHOD OF APPLICATION OF PHOSPHATE

Puddling of plants in mixtures of ground mineral phosphate and water. Mean heights and losses eleven years after planting in Teindland PT. 37/2.

Treatment		*Scots pine*			*Japanese larch*		
Puddle Water/G.M.P.	*Applied to*	*Ozs.‡ G.M.P.*	*Losses %*	*Height feet*	*Ozs.‡ G.M.P.*	*Losses %*	*Height feet*
1 : 1	Roots	0.007	7	2.8	0.003	14	2.2
3 : 1	Roots and shoots	None†	6	2.7	0.005	13	2.3
1 : 1	" " "	0.05	17	3.5	0.1	19	2.9
1 : 3	" " "	2.0	36	3.6	0.8	77	4.6
Control: No phosphate		Nil	35	2.1	Nil	47	1.1
2 ounces G.M.P. at roots		—	3	4.2	—	8	4.9
Standard error		—	—	±0.16**	—	—	±0.28**
Diff. for sign. at 5% level		—	—	0.5	—	—	0.9

Notes: ‡ The quantity of phosphate adhering to the plants was determined by analysis of sample plants from the puddling treatments; in the case marked † none could be determined on the sample, though presumably this was not representative.
G.M.P.=Ground Mineral Phosphate.
**Significant at the 1 per cent level.

Two experiments on quantity were invalidated by the use of Semsol, with consequent heavy losses which increased with the quantity of fertiliser. (Teindland PT. 35/3 and Clashindarroch 33/2).

The results of experiments with basic slag are given in Table 46. Two trials were made at Harwood Dale, using from one to three ounces of basic slag, in one case on notched Scots pine, and in the second on Scots pine planted on pit-and-mound; whereas at Wykeham the same quantities of slag were used for several species planted on moderately deep double-furrow ploughing. The trials were all made with single line plots, and only the short-term results are valid. In all cases the phosphate gave considerable beneficial results, improving growth and often reducing losses, though in the Scots pine deaths in the controls were negligible.

It is, however, possible that the position of planting has affected the result in this Wykeham trial. At this time, heavy losses on fresh ploughing had led to the use of the unploughed strip as the planting site. The correlation of high losses with poor growth is very marked in this experiment, particularly for Japanese larch and Sitka spruce. It is possible that phosphate stimulated the plants sufficiently for their roots to reach the ploughed soil, after which growth became rapid. Had all the plants been set into broken ground at the start, the result would perhaps have been much less marked. This suggestion is borne out by the 1939 experiments already mentioned, where phosphate had much less effect on the growth of larches, since by this date planting was carried out in the furrow (Wykeham 56 & 57.P.39).

The efficacy of very small doses of phosphate, if well placed relative to the roots, is shown by the results of the puddling experiment given in Table 47, where significant height increases of Scots pine and Sitka spruce were obtained by one-tenth of an ounce of fertilizer. The dose producing the greatest height increment was however lethal if closely placed, and it is apparent that there is interaction between the quantity and its placement.

The acceptance of one-and-a-half to two ounces of high-grade fertilizer as the normal dose is thus based on fairly tenuous evidence. That there is more evidence that this is the correct dosage *on the peatlands* is not necessarily convincing; far more so is the very substantial increase in increment obtained in a number of the trials where this dose was in fact used, the main results are set out in Tables 49 and 50 (pp. 111 and 113).

Placement and Method of Application

In the earliest trials the phosphate was dug in during the preparation of the planting positions. Then, during the phase of top dressing those experiments already planted, basic slag was broadcast, sometimes in rather heavy quantities. With the adoption of phosphate manuring as a basal treatment for much of the experimental planting, small quantities were placed near the roots, either in the planting notch or under a turf or mound. When the heavy losses occurred in 1933 the placement was questioned, as much as was the form of phosphate. Experiments planted in 1935 again suffered from drought, and the failures with superphosphates when placed under the turf have been recorded. Several placement experiments had been planted in these years 1933 and 1935, but unfortunately the interaction between form of manure, quantity and placement was not realised, and the evidence is scattered in a number of overlapping experiments.

Table 48 brings together the first-year losses of several of these experiments, from which a number of points emerge. Though Semsol was usually lethal in these dry years, there were exceptions, particularly with Sitka spruce or with *Thuja* where the manure was spread above the turf. On the other hand Japanese larch proved particularly sensitive. Basic slag was clearly much safer than Semsol, but even with this fertilizer, losses could be higher than controls, particularly if it was applied at the roots. These results led to the abandoning of Semsol; the adoption of surface spreading as the normal method of application; and to the expansion of the use of ground mineral phosphate, which was not included in the placement experiments at all, but gave even lower losses than slag when placed at roots in one trial (Table 45, p. 108).

An important practical point is that top dressing can be done after the planting is completed, and in the relatively slack period of the forester's year before weeding begins. A possible alternative would have been to use superphosphates a year or two after planting, but this has not been adopted in practice, though Tables 44 and 48 (pp. 107 and 110) each contain an example of the successful use of this method, (Wykeham 33.P.34 and Teindland 56.P.35).

One further experiment concerns the method of applying ground mineral phosphate. Plants were loosened in their bundles at the planting site, and either the roots or the whole plants were puddled in mixtures of manure and water. The amounts of phosphate adhering was estimated and results, already given in Table 47 (p. 109), show not only that mineral phosphate can be effective in very small quantities, but also that even it may be harmful if directly applied to the tissues in larger amounts. The ordinary "at roots" application, so deadly with Semsol, was innocuous in this case. These results however illustrate the interactions set up, and the difficulties of interpretation in experiments where only one or two factors were varied.

Results from Use of Phosphatic Fertilizers

All the results given above are short-term, showing how phosphate increases the early growth rate; and how with the less hardy species, such as Jap-

TABLE 48: PLACEMENT OF PHOSPHATE

First year losses in experiments planted from 1933–35.

Losses per cent.

Species / *Forest and Experiment*	*Method of planting*	*Control No phosphate*	*Semsol*		*Basic Slag*	
			Under turf or in notch	*Spread on surface*	*Under turf or in notch*	*Spread on surface*
Japanese larch						
Teindland 56.P.35	Turf planted	—	58	14‡	—	—
„ PT. 35/5	Notched/turfed	15	100	45	45	30
Harwood Dale 10.P.33	Lifted turf	1	—	51	—	2
„ „ 11.P.34	„ „	1	3†	17	Nil	Nil
European larch	Notched PT.33/2	28	55	—	—	—
Clashindarroch ø	„ PT.33/1	—	—	—	Nil	Nil
Sitka spruce	Notched PT.33/2	11	Nil	—	—	—
Clashindarroch	„ PT.33/1	—	—	—	Nil	Nil
Harwood Dale 10.P.33	Lifted turf	1	—	6	—	Nil
„ „ 11.P.34	„ „	Nil	1	1	Nil	1
Teindland 56.P.35	Turf planted	—	16	3‡	—	—
„ PT.35/5	Notched/turfed	Nil	10	Nil	Nil	Nil
Thuja plicata						
Teindland 59.P.35	Turf planted	2	60	8	—	—

Notes: Only the figures from a single experiment are directly comparable, but the relative losses in the different experiments are important.

‡ Losses shown are those after the Semsol was spread as a top dressing in the third year.

† This low figure is anomalous, possibly the lifted turf method resulted in the phosphate being isolated from the roots.

ø The European larch in the two trials was of different ages and origins, and only the comparison of the pairs of figures is valid.

TABLE 49: PHOSPHATIC MANURING. SUMMARY

Summary from all the available experiments to show the effect of a dose of 1–2 oz. of phosphate at planting on the height attained at 8–10 years.

Forest Ground Preparation Dates of experiments Ozs. of phosphate	*Species*	*Number of comparisons*	*Mean Age, Years*	*Heights in feet*		*Percentage increase with phosphate*	*Standard Error Feet*	*Diff. for sign. in feet*	
				Control	*Phosphate*			*5%*	*1%*
Teindland Hand or Shallow ploughing 1928–37 2 ozs.	Scots pine	5	9.8	2.8	4.3	54%	±0.16**	—	1.1
	Lodgepole pine	6	9.5	3.1	4.9	58%	±0.27**	—	1.5
	Japanese larch	2	10.5	2.4	5.0	108%	—	—	—
	Sitka spruce	2	10.5	1.4	2.8	100%	—	—	—
Hamsterley Hand or Moderately deep ploughing 1929–40 1 oz.	Scots, Corsican, Lodgepole pines, Japanese larch, Sitka spruce†	10	8.6	4.1	4.4	7%	±0.11	0.36	—
Wykeham Moderately deep ploughing 1928–41 1–2 ozs.	Scots pine	5	8.0	4.2	5.1	21%	±0.06**	—	0.4
	Corsican and Lodgepole pines†	6	8.3	3.9	5.0	28%	±0.08**	—	0.4
	Japanese larch	9	8.4	5.2	7.9	51%	±0.38**	—	1.8
	Sitka spruce	7	8.4	1.35	2.55	88%	±0.11**	—	0.6
Broxa Deep ploughing 1943–44 1 oz.	Scots pine	4	10	7.3	8.5	16%	±0.01**	—	0.8
	Corsican pine	2	10	5.4	7.1	32%	—	—	—
	Japanese larch	1	10	8.9	11.1	25%	—	—	—
	Sitka spruce	4	10	3.8	5.0	32%	±0.15**	0.7	1.2
Harwood Dale Hand preparation 1932–41 2 ozs.	Scots, Corsican, and Lodgepole pines†	6	9.8	3.3	3.8	15%	±0.09*	0.3	—

Notes: Results of all the experiments using basic slag or ground mineral phosphate, for the given species, at a particular site, have been included, regardless of the magnitude of the effect. Experiments using superphosphate have been excluded, owing to the high losses often resulting. Notch-planted experiments are also excluded, as controls often failed.

† In these cases only from one to three comparisons were available for any species, and the results have been analysed as one.

** Highly significant. * Significant.

anese larch, it improves survival on the poorer sites, although on any site it may reduce survival if it is not carefully applied. During the period from about 1930-45 while the present technique was being developed, a large number of experiments were planted using phosphate as an aid to growth, but with unmanured controls as a check on its effect. This was particularly necessary during the phase when adverse results were being obtained following the use of superphosphate. From the time of the development of a safe technique, it has become common to apply phosphate as a basal treatment without controls on the poorer heaths, and this has been the practice in experimental work since about 1945.

A number of the interim results of phosphate application have already been given, notably in Tables 3, 11 and 20 (pp. 31, 45 and 58), covering experiments at Teindland, Wykeham and Broxa, representing the poorest and relatively more fertile land types. Figures 5, 6 and 9 (pages 43, 46 and 88) give results at a rather later stage in the Wykeham experiments and for a further experiment at Teindland. These experiments show that the effect of phosphate is to increase growth rates in all cases, but the proportional increase is much greater at Teindland than at the other sites. In addition at Teindland it appears that phosphate is essential to ensure good stocking of all species other than pines. Nowhere in these trials however, does phosphate mean the difference between complete failure and growth, nor is there the spectacular two to three-hundred per cent improvement in growth rates found on deep *Trichophorum* peats. Under these circumstances the use of phosphate is by no means always justified, and the decision on when it should be used on silvicultural grounds is not easy, while to decide on economic grounds is almost impossible at the present time, as very little evidence is available as to the long-term effects.

To obtain a better picture of the effect on early growth rates, the short-term results to about ten years of all the trials available have been examined. Wherever there are enough examples of plots with and without phosphate, at a given site, the data has been analysed and the results are summarised in Table 49. With one exception the increase in growth due to phosphate is significant, generally at the one per cent level. At Hamsterley, however, this is not the case, while the scanty data available at Clashindarroch also suggests a lack of response, at least on the slopes.

The response of the various species at one site, or of the same species at different sites, varies enormously when considered as a percentage increase over controls. Thus the importance of phosphate is clearly greatest at Teindland, even though the absolute response is no greater than at other sites. A further complication is introduced here, however, in that the average level of intensity of ground preparation varies between the sites according to the period when the experiments were started, being low at Teindland and Harwood Dale, but particularly high at Broxa. It is apparent that improved ground preparation may reduce the importance of phosphate; thus Wykeham and Broxa are considered to be closely comparable sites, yet the relative response of Sitka spruce is only 32 per cent at Broxa where deep ploughing was used throughout, as compared to 88 per cent at Wykeham where less intensive ploughing methods were employed. In contrast, the response of Scots pine has fallen only from 21 to 16 per cent. Though ground preparation is the major difference, improvements in the quality of the planting stock and in planting methods may also have played a part.

It is clear however that at Broxa the optimum conditions for the early growth of Sitka spruce have been far more nearly approached than at Wykeham; and although the absolute effect of phosphate was approximately the same (1.2 feet), the effect relative to the controls is so different that applications of phosphate would be important for Sitka spruce with the technique used at Wykeham, but unnecessary with the improved methods used at Broxa. Japanese larch appears to react in a similar manner, for the single case at Broxa shows a great reduction in the relative effect of phosphate with deep single-furrow ploughing. Results at Harwood Dale are rather anomalous, in that the effect of phosphate is small as compared to those at Wykeham. The level of cultivation was low, and possibly this was the limiting factor here; on the other hand the soil at Harwood Dale is intrinsically more fertile than at Broxa or Allerston, although the surface conditions are more difficult, and this may account for the small response.

It is not possible at the present time to pursue this subject to the logical conclusion, a balancing of ground preparation against use of fertilizer on an economic basis, for much of the data is lacking. Thus at Teindland, after the excellent response in early trials, phosphate was used on the majority of subsequent trials as a basal treatment, so that it is not possible to determine at present whether the improved ground preparation would have reduced the response of pines to phosphate.

It is difficult to determine the long-term effect of phosphate on the growth and production of the pines and larches, which will grow fairly well without manuring, as few plots of sufficient size are old enough to yield results in terms of produce. Many of the experiments used to compile Table 49 contained plots of less than one hundred plants, and in these cases the initial differences in height have tended to disappear as canopy closed, an example being shown in Figure 6, p. 46, where apparently the effect of phosphate on the fastest-growing lodgepole pine and Japanese larch is much less at sixteen years than at twelve years; at a subsequent assessment this reduction has occurred with the European larch and Sitka spruce also. It is however certain that these experiments are on too small a scale to enable the true long-term value of phosphate to be ascertained. Interaction may have taken place by the taller plots physically sheltering the shorter; by the leaf-fall from phosphate plots contaminating controls; or by roots from the controls invading the manured plots. A similar sequence of striking early response to basic slag, followed by the controls apparently drawing level in the pole stage, has occurred in other cases with Japanese larch at Wykeham (14.P.31, 33.P.34).

Unfortunately in very few experiments were the plots large enough to give results over a longer period; the oldest example is at Teindland where there are one-acre plots of lodgepole pine planted with two ounces of basic slag, and comparable controls, all planted on shallow triple-furrow ploughing. The results from this experiment after twenty-seven years are given in Table 50, and show a striking increase in production with phosphate, the basal area having been increased by 45 per cent as compared to a 16 per cent increase in height. This

TABLE 50: USE OF PHOSPHATE

Stand data for plots which received basic slag at planting and for controls which did not.
Basal areas in quarter girth measure, and Volumes in Hoppus measure, both over bark

Experiment, Species and Treatment	Age	Top Ht., feet 100 largest trees per acre	Main Crop				Total crop		Notes
			Stems per acre	Mean Girth in.	Basal area, sq. ft., q.g.	Est. Volume hop. ft.	Basal area, sq. ft., q.g.	Est. Volume hop. ft.	
Teindland 41.P.29	27								
Lodgepole pine		25½	2,260	10	100	—	100	—	Not yet thinned } 3 pairs
+2 oz. basic slag....		29½	2,070	12	128	—	145	—	One thinning } of plots
Wykeham 26.P.33	25								
Lodgepole pine		31	1,230	13	87	—	126	—	4 pairs of plots, 2 of 2+0
+ 1 oz. basic slag....		31½	1,130	13½	91	—	132	—	and 2 of 2+1 originally
Wykeham 26.P.33	25								
Scots pine		28	1,290	13	91	900	104	980	2 out of 3 pairs of plots
+1 oz. basic slag....		29½	1,080	14	94	1,000	116	1,180	were of 1+0 seedlings
Wykeham 26.P.33	25								
Corsican pine		27	1,300	14	110	1,200	125	1,360	2 pairs of plots, originally
+1 oz. slag		30	1.050	17	129	1,600	160	1,850	of 1+0 seedlings
Wykeham 26.P.33	25								
Japanese larch		30	710	14	66	650	78	760	2 pairs of plots, originally
+1 oz. slag		38	580	17	78	1,200	121	1,750	of 1+0 seedlings

Note: Standing crop volumes have been derived from alignment charts based on top height and basal area.

type of lodgepole pine, of far inland form, short-growing and with very narrow crown, does not fit either of the existing pine yield tables owing to the high number of stems per acre; nevertheless the difference in height corresponds to a difference of just over half a quality class for Scots pine or Corsican pine of this age; this difference, if continued through the rotation, will bring a great increase in production.

Somewhat similar plots exist for four species at Wykeham but are unfortunately only one-tenth-acre in area. The figures in Table 50 have been obtained by measuring from one-twentieth-acre circular areas in the centre of these square plots, and averaging results from the two-to-four replications. Here a smaller dose of one ounce of basic slag has again produced a considerable effect, which is again more marked by an increase in basal area than by that in height growth.

Owing to the need for the plots to be of some age, the results quoted come inevitably from experiments where the intensity of ground preparations was low. Possibly the use of one-year seedlings for so many of the plots has influenced the results at Wykeham, and the question arises as to whether these results can be reproduced. A particular point is that the greater improvement in basal area, as compared to that in top height, suggests that the dominants have been little affected by the phosphate, while the smaller trees have been stimulated to grow; and it has been suggested that with improved technique this may no longer occur. On the other hand it may be that the productive capacity of the site has been increased, but that the effect on height is masked by the small plots and generally exposed position of the experiments.

For this reason, from about 1950 a series of experiments has been laid out on the heaths, comparing half-acre plots with and without ground mineral phosphate. These have not been sited on the poorest types of *Calluna-Trichophorum* where phosphate is in any case valuable for speeding establishment, but on the rather better ground, mainly with pure *Calluna*, where phosphate is not in general use, since quite satisfactory growth is obtained without it; the intention is to compare the production in these plots rather than the early growth rates.

Galoux (1954) has recently summarised comparable results obtained from fertilization experiments laid out on heaths in Belgium from 1903-24. They suffer in some respects from defects in design consequent on the early period at which they were planted. Galoux concludes that while the relative effect of phosphate diminishes after the thirtieth year; the absolute effect remains constant at two to three years increment which is obtained by faster earlier growth and is the benefit obtained over the rotation.

The general conclusions to be drawn from all the work on phosphate is that it has a more limited part to play in establishment on the heaths than on the peatlands, and in particular that it can be used to compensate to some extent for less intensive ground preparation or for planting stock below normal size or quality.

It is *essential* to establishment only for species other than pines on the poorer sites, typified by the *Calluna-Trichophorum* of Teindland. Here it has made possible the employment of Japanese larch on some scale, while the use of other species such as hemlock is under test; on these sites the growth of all species including pines is considerably increased.

On heaths of intermediate quality, such as those of Allerston, phosphate is nowhere essential but is very useful where rapid early growth is desired, and it is here that the long-term effect on production particularly needs investigation, to determine whether use of phosphate on a large scale is justified. Finally on the best heaths typified by Clashindarroch and Hamsterley, phosphate has given no response once adequate ground preparation was undertaken.

Cost of Phosphate Manuring

The application of a single dose of 1½ or 2 ounces of ground mineral phosphate to about 2,000 plants per acre requires about two cwt. (or 224 lb.) per acre. Material costs 24/- at the present time (1958), while labour for spreading, inclusive of overheads, costs about twenty-five shillings. The total cost of £2 to £3 represents only 3 to 5 per cent of the total cost of establishment on the heaths, and it is clear that where benefits of the order cited for Teindland are obtained, it is likely to be a most rewarding operation.

BALANCED FERTILIZERS

After the heavy losses already recorded in the earliest manuring trials with Kainit and ammonium sulphate, nitrogenous and potassic fertilizers were not employed for ten years. In one of these trials (Wykeham 9.P.29) there was, however, an appreciable improvement in the early growth of several species where ammonium sulphate had been applied in addition to basic slag. In 1939 an experiment on complete fertilizers was laid down at Teindland, but was burnt after three years. Crushed granite and "Keronikon", a proprietary hoof and horn manure, were used as sources of potassium and nitrogen; they did not increase the early losses, but neither was the early growth appreciably better.

The next investigation on balanced manuring was that made by Crowther at Broxa, using plants produced in his extensive programme of nursery manuring experiments. Samples of these plants were set out at Broxa from 1947-49 in order to check their performance against the results in the nursery. Forest manuring trials were in many cases superimposed on the blocks of these nursery extension trials, which in all cases consisted of Scots pine and Sitka spruce in equal proportions. Either one-year seedlings or one-plus-one transplants were used throughout, and many experiments were duplicated on both ages. The data available for these experiments is both complete and complex, and the figures relevant to forest manuring have been extracted and condensed in the tables below, from summaries produced by Crowther and Benzian (1950-54) and Benzian (1955); the conclusions drawn from the tables must, however, remain the responsibility of the present author, pending the full summary which is in preparation by Benzian at Rothamsted.

In the first year a factorial nitrogen-phosphate-potash experiment was started, including also a comparison of mineral phosphate with high grade basic slag, but no difference was found between these two. It was, however, discovered on analysis that the formalised casein used to supply nitrogen contained appreciable quantities of phosphate, so that the effect of nitrogen alone cannot be estimated. Condensed results are given in Table 51 and show a marked response to phosphate, with a smaller response to nitrogen, or nitrogen and potash, in the presence of phosphate. These results are conveniently compared with others obtained from planting in 1948, when three sources of phosphate and a nitrogen-phosphate fertilizer were compared with very similar results; the various phosphate treatments have again been averaged.

In both 1948 and 1949 factorial NPK trials were planted, and the mean growth with main effects are shown in Table 52. After the first two years, the response to nitrogen generally equalled or exceeded that to phosphate, but the position has changed since then, to that shown in Table 52. The response to phosphate after six years is almost three times as great as that to nitrogen in seven cases out of eight; in the exception the responses are equal, that to phosphate being unusually low. Potassium has had no appreciable effect throughout.

A further trial in 1949 compared three sources of nitrogen applied in the presence of phosphate and potash. The average dose was 0.1 ounces of nitrogen per tree, this dose only being applied with urea formaldehyde, while with formalised casein and nitrochalk larger and smaller quantities were also used. The nitrochalk was in each case applied in three equal parts, yearly from 1949 to 1951. The differences between the treatments after six years were small and generally insignificant, while the

TABLE 51: BALANCED FERTILIZERS

Heights after six years in experiments at Broxa planted in 1947–48.

Heights in feet

	Scots pine				*Sitka spruce*			
Fertilizer	1+1 1947	1+1 1948	1+0 1948	*Mean*	1+1 1947	1+1 1948	1+0 1948	*Mean*
Control	(3.5)	4.1	4.1	3.9	(2.6)	3.9	4.1	3.5
P.	4.7	4.3	4.2	4.4	4.6	4.6	4.6	4.5
NP.	4.9	4.6	4.6	4.7	4.8	5.1	4.9	4.9
NPK.	5.0	—	—	—	5.3	—	—	—
S.E.	±0.11**			—	±0.13**			

Notes: The Standard Errors shown for the 1947 experiments do not apply to the controls; there is no single S.E. applicable to the later experiments.
In the 1948 trials manures were applied notched or broadcast but differences were negligible.
** = Highly significant.

Fertilizers used were:—

1947	*ozs. per tree*	1948	*ozs. per tree*
N. Formalised casein (contains phosphate)	0.15 N (0.001 P_2O_5)	P. Basic slag/Gafsa or superphosphate	0.25 P_2O_5
P. Bessemer basic slag/Gafsa rock phosphate	0.3 P_2O_5	NP. Combined fertilizer	0.07 N; 0.24 P_2O_5
K. Muriate of potash mixed with fine glauconite	0.2 K_2O		

Data from Crowther and Benzian.

gain in height over trees which received no nitrogen was only a few inches.

The final set of trials was laid out in 1948 and 1949 to find the effect of an N.P. or N.P.K. fertilizer on a longer-term basis, plots of larger size being used. Results are shown in Table 53, and overall show a moderate benefit to Scots pine and an improvement of almost fifty per cent with Sitka spruce. In view of the evidence already discussed from Tables 51 and 52, the major part of this improvement must be attributed to the phosphate.

Certain of these trials also investigated various methods of placement, including the application of manures by spreading on the surface or in notches made with a spade, and also the use of granulated and pelleted manures. The conclusions drawn were that none of the methods tried showed any appreciable advantage over spreading, which was the cheapest method. In these trials the fertilizers were spread in two bands, six inches on either side of the tree. This spatial separation of manure from the tree may account for the successful use of superphosphates in these experiments.

It is satisfactory that this work, undertaken only as a side line in the major project of producing high-quality plants, confirms with great precision the technique based on the use of phosphate only, built up on the earlier less comprehensive trials already described. It is also noteworthy that the quality of the plants used in these experiments was considerably higher than that of those in general use, this being evident from the very low losses in the forest throughout the whole series of trials; it is possible that this may have reduced the relative, if not the absolute, benefit from manuring. Partly for this reason, many of the recent series of trials of phosphate on a large scale, and the intensive experiments on the use of triple superphosphate, have been superimposed on plantations newly planted during large-scale work on the heaths, and not on specially laid out areas.

OTHER MANURING TRIALS

Boron

Boronated slag was tested on Japanese larch and Sitka spruce at Teindland, in comparison with basic

TABLE 52: BALANCED FERTILIZERS

Mean heights and main effects of treatment after six years in factorial manuring experiments at Broxa planted in 1948–49.

Heights in feet

	Scots pine					*Sitka spruce*				
	1+0		1+1			1+0		1+1		
	1948	1949	1948	1949	*Mean*	1948	1949	1948	1949	*Mean*
Mean of Expt.	4.00	3.88	4.42	4.24	4.14	4.25	3.23	4.51	4.52	4.13
Main effects:										
Nitrogen	0.16	0.20	0.21	0.21	0.20	0.18	0.20	0.29	0.00	0.17
Phosphate....	0.51	0.92	0.22	0.63	0.57	1.27	1.46	0.71	0.92	1.09
Potash	0.09	0.04	0.12	0.17	0.11	–0.08	–0.07	0.07	0.21	0.03
Standard Error	±0.15	±0.13	±0.10	±0.08	—	±0.19	±0.17	±0.13	±0.15	—

Fertilizers were broadcast at the following rates in ounces per tree:—

N	Nitrochalk	0.1 N
P	Superphosphate	0.25 P_2O_5
K	Muriate of potash	0.1 K_2O

None of the interactions were significant and half were negative.

Data from Crowther and Benzian.

slag and ground mineral phosphate. The majority of the plants receiving the boronated slag died in the first year, while losses in the controls were negligible. In the absence of detailed analysis, however, the boron cannot be definitely held responsible, as other elements may have been present which were not in the slag used as control. (Teindland P.T.37/3).

Copper

Trials of this element followed reports of success following its application to agricultural crops on acid soils in the United States. One gram of copper sulphate, either alone or in combination with ground mineral phosphate, had no effect on the growth or losses of Japanese larch or Sitka spruce (Teindland P.T. 37/1).

Humus and Compost

There have been only three trials of the use of organic manuring for planted trees, apart from its use for direct sowings (Chapter 12), and the results of these are shown in Table 54. In an early trial at Wykeham, humus from a thriving European larch plantation was applied to a new plantation; the dose was defined as "a cube of three-inch side per tree"; this is approximately two ounces weight. This

TABLE 53: BALANCED FERTILIZERS

Heights after six years in extensive plots planted at Broxa in 1948–49 using either no fertilizer, or NP, or NPK.

Heights in feet

	1+0			1+1		*Means*	*Percent-age Increase*
	1948	1949	1949†	1948	1949		
Scots pine							
Control	3.6	3.2	3.7	4.0	4.4	3.8	—
+NP(K)	4.2	4.5	4.3	4.9	5.2	4.6	21%
Sitka spruce							
Control	4.0	2.2	3.0	3.9	3.1	3.2	—
+NP(K)	4.9	4.1	4.3	5.3	4.9	4.7	47%

Notes: † The second seedling trial in 1949 included 3 placements; pellets notched, and granulated fertilizer notched or broadcast. Differences were small and in favour of broadcasting.

Fertilizers used were

		1948	1949
N	Ammonium Sulphate	0.07 N	0.1 N
P	Superphosphate	0.24 P_2O_5	0.24 P_2O_5
K	Potassium Sulphate	—	0.1 K_2O

Data from Crowther and Benzian.

TABLE 54: HUMUS AND COMPOST

Mean heights and losses 10–12 years after planting in three experiments at Allerston.

Treatment	*European larch* Wykeham 8.P.29 11 *years*			*Corsican pine* Harwood Dale 28.P.41 12 *years*			*Sitka spruce*† Harwood Dale 39.P.45 10 *years*		
	Dose	*Feet*	%	*Dose*	*Feet*	%	*Dose*	*Feet*	%
Control	—	Failed	100	—	4.4	5	—	3.2	25
Basic slag	1 oz.	4.2	13	2 oz.	4.8	4	2 oz.	4.8	8
Humus	2 oz.	3.5	24	—	—	—	—	—	—
Compost	—	—	—	1 lb.	5.1	7	5 lb.	6.2	1
Standard Error					±0.22			±0.3**	
Differences for 5%		—			0.76			0.9	
significance 1%					—			1.3	

Notes: † Interplanted into six-year-old Corsican pine.
** Highly significant.

inoculation proved successful in maintaining the majority of the trees alive, whereas the controls died; subsequent growth has been not far behind that in plots which received basic slag, although the losses were double. Dr. M. C. Rayner's "C5" compost, made from spent hops, was used in the other experiments at Harwood Dale, and while proving unnecessary for the Corsican pine, it has been most successful with Sitka spruce. The dose of five pounds per tree employed in this case is however quite beyond the bounds of practical application.

The use of composts in the forest has not been pursued, as only very special circumstances would justify the transport of such a bulk of manure. The supply of one pound of compost to trees planted at normal spacings would require one ton of material per acre, occupying about eighty cubic feet.

Lime

An early small-scale trial on Inchnacardoch moor compared the effect of slaked lime, calcium hydroxide, with that of phosphate, on Japanese larch and Sitka spruce (P.T. 33/4). Unfortunately the experiment was planted by notching, a method quite unsuited for these species on this site, and deaths were numerous in all treatments. Nevertheless the effect of ten ounces of slaked lime on the growth of the survivors was rather greater than that of two ounces of phosphate. This result was not however followed up until recently, when liming trials were laid out at Broxa (86 & 87.P.52) and Teindland (86.P.53). Early results after six years' growth show some improvements in growth of conifers, particularly Japanese larch, at both forests, and of certain hardwoods, notably grey alder, at Broxa.

Chapter 9

NURSE CROPS AND THE ESTABLISHMENT OF MIXTURES

As recorded in Chapters 4 and 5, pines were almost the only species successfully established in the early heath plantations. When ploughing was introduced it became possible to plant larches, and for a time it appeared that other species, notably spruces, might grow with this treatment also, particularly when combined with the application of phosphatic manures. By about 1933 however this hope appeared lost, for after several years' good growth in the big species trials laid out in 1927-30, the spruces went into a state of check there also. Several of these trials included spruces in mixture with pines or larch, as well as in pure plots. For a time these mixtures looked no more likely to succeed, and in the period 1933-43 a research programme was followed at Allerston, employing broom, *Saraothamnus scoparius*, as a nurse to raise Sitka spruce. About 1938 however the spruce in the mixed plots were seen to be drawing away from those planted pure, and as a result the planting of experimental mixtures was greatly increased; the results from these mixture experiments are now becoming available.

The present chapter deals with these two lines of approach to the problem of growing more exacting species. For ease of reference it is confined to cases where the two tree crops were planted simultaneously; cases where spruces were planted into pine are regarded as inter- or under-planting (page 89); while cases where pine was planted into checked spruce are regarded as salvage operations and are dealt with in Chapter 10 (p. 127). Virtually all the work on nurse crops was, until recently, carried out with Sitka spruce, so that almost the whole of what follows applies directly to that species only. There are however a few trials which indicate that many of the results may apply equally to other species.

THE USE OF BROOM AS A NURSE

This line of investigation stemmed from the long-established Continental practice of raising tree crops with leguminous nurses. The first trials were at Teindland, where in 1928-9 five legumes were sown or planted on ploughed (27.P.28), or hand-dug ground (37.P.29). Tree lupin—*Lupinus arboreus*, Spanish broom—*Spartium junceum*, gorse—*Ulex europaeus*, common broom—*Sarothamnus scoparius*, and the common laburnum—*Laburnum anagyroides* were tested. In the first trial where no manures were employed, only a patchy crop of gorse was raised, but in the second trial common broom and gorse were raised in manured plots, the former being the more successful. Interplanting with Sitka spruce was carried out six years later, but the plants checked severely, whereas control plots planted at the start had grown slowly, being five feet high when burnt in 1942. Later trials which were carried out at Allerston suggest that it was the long delay between broom sowing and interplanting with spruce, which caused the poor showing of the plots with leguminous nurses.

There were two early failures with perennial lupin (*Lupinus polyphyllus*) at Wykeham (8.P.29 and 15.P.31). In the second trial however a very good crop of broom was raised, using fifteen pounds of seed and ten hundredweight of basic slag; both seed and manure were raked into cultivated strips on ploughed ground. Unmanured parts of this broom crop failed, and cultivation and manuring in patches or strips now became the practice for raising broom; in addition the seed was scalded immediately before sowing; germination tests showed this to be most important. This broom crop, and two others sown by similar methods in 1933 and 1934 (Wykeham 32 and 40), were interplanted with Sitka spruce two to four years later. All these experiments suffered however from defects in the lay-out of the controls, so that although the spruce among the broom grew better than normal at Allerston, it is not possible to assess exactly the role of the broom.

The most spectacular result was in Wykeham 32; there the Sitka spruce were planted in 1937, four years after the broom was sown, and reached five feet in six years, or four times the height of the controls. The main difficulty in interpretation was due to the control spruce being planted at the same time as the introduced spruce, while the ground preparation for all plots had been carried out prior to the broom sowing. Thus the controls were planted on old ploughing among regenerating heather, and

TABLE 55: USE OF BROOM

Development of Sitka spruce in three experiments at Allerston, to show the effect of broom and Scots pine nurses.
Mean heights in feet, those of Scots pine in brackets

Experiment	*Langdale* 3.P.40 *Shallow s.f.+ subsoiling*			*Harwood Dale* 27.P.41 *Shallow single furrow ploughed+subsoiling*					*Broxa* 8 *and* 9.P.43 *Mean of 5 types intensive, mainly deep, ploughing*				
Years from planting		15 *yrs.*			8 *yrs.*		14 *yrs.*			6 *yrs.*		13 *yrs.*	
	**Details*	*Sitka spruce*	*Scots pine*	**Details*	*Sitka spruce*	*Scots pine*	*Sitka spruce*	*Scots pine*	**Details*	*Sitka spruce*	*Scots pine*	*Sitka spruce*	*Scots pine*
Crop:— Sitka spruce: Control	—	—	—	—	—	—	—	—	—	3.2	—	6.3	—
Sitka spruce with broom	10 lb.+4 cwt. sown 1939	13.4	—	15 lb.+5 cwt. sown 1940	4.4	—	5.3	—	9 lb.+2 cwt. sown at planting	4.1	—	12.8	—
Sitka spruce with broom and Scots pine	—	—	—	7½ lb.+2½ cwt. sown 1940	3.8	(6.3)	6.9	(14.1)	9 lb.+2 cwt. sown at planting	3.8	(4.9)	14.2	(13.4)
Sitka spruce with Scots pine	—	6.8	(13.4)	†2½ cwt. slag	2.6	(6.6)	6.2	(14.3)	—	3.4	(4.4)	10.7	(12.8)

Notes: * Weight of broom seed and basic slag per acre applied to prepared patches or furrows. In addition each tree plant received 1 oz. of basic slag amounting to about an additional hundredweight per acre.
† The same number of furrows were cultivated and manured as in the previous treatment in order to remove the bias consequent on the heavier rate of manuring necessary to raise the broom.

were much less successful than plantings made on fresh ploughing. In addition the broom had received a heavy dose of phosphate with consequent improvement in soil conditions. Clearly either the controls should have been planted at the start, as at Teindland, or ground preparation for the controls should have been undertaken immediately before their planting.

These difficulties were overcome in later experiments. The broom had required cutting back at least every two years in the early trials in order to free the interplanted spruce; in the later experiments planting was delayed at most a year after sowing of the broom, thus incidently eliminating the experimental difficulty of staggering the ground preparation. In one experiment, as a final check, the cultivation and manuring necessary for raising the broom was carried out in the control plots also (Harwood Dale 27.P.41). The result of this and other comparable experiments are given in Table 55. As by this time the alternative method of using tree nurses was well established, the comparison of broom and Scots pine nurses was a main object of the experiments.

The three experiments tabled show an interesting contrast in results. The plots of spruce for which broom was the sole nurse, made in each case the best start, but, in the two cases where this treatment exists, plots with broom and Scots pine are now taller. In contrast, plots with Scots pine alone have started more slowly, and only at Broxa is spruce likely to form canopy with the nurse pine; while at Harwood Dale and Langdale the spruce was only half the height of the pine after fifteen years. Thus at present it appears that the spruce will be successful in all treatments in Broxa except the absolute control; with broom, but not with Scots pine at Langdale; while the outcome at Harwood Dale is doubtful. The deeper ploughing at Broxa was probably the deciding factor in this difference, and this is confirmed by a second experiment at Broxa, similar in many ways but on shallower ploughing; here results with broom are comparable, but without it growth is very much poorer than in the experiment in Table 55 (Broxa 6.P.42 and 9.P.43).

At this time the broom technique was extended for the first time to raise other species. The results were most successful in experiments at Broxa and Wykeham as indicated in Table 40 (p. 91).

During the period when the results of these experiments were becoming clear, evidence was accumulating of the effective nursing of spruce by other conifers, and particularly by Japanese larch. The relative cost of the two methods was one deciding factor in the virtual abandonment of broom. The costs of a mixed plantation including a nurse tree is no greater than that of a pure planting, whereas the costs of using broom are considerable. The collection, cleaning and scalding of the seed, the cultivation and manuring of patches or strips, and the cutting back necessary when growth is excessive, all contribute to make its use much more expensive than normal plantation work.

It must also be recorded that in the most recent trial with broom, sown in 1946, and intended as a demonstration of the method, there was a partial failure of the nurse crop, possibly due to the severe winter 1946-7 (Broxa 18.P.46). The technique used here, regarded as the best from consideration of previous trials, was to sow the broom in patches at six-foot spacing, with one spruce planted between. The broom/spruce mixture was in bands of four rows with alternating double rows of pine. This mixture required seven pounds of broom seed and one hundredweight of slag per acre. The work on sowing, which involves patch preparation, sowing and manuring and raking in the seed, was estimated to require twenty man-hours per acre in addition to the normal plantation cost. When the collection of the seed and the possibility of two or even three weedings were added, it is estimated that the cost of adding broom, in 1956, would not be less than £12—£15 per acre.

Thus it is that experiments on the use of broom have been abandoned in the last decade. It should be remembered however that the first Wykeham trials, notably experiment 32, provided the earliest example of rapid establishment of Sitka spruce on the heaths. The occurrence of a check period was taken for granted at the time, but in this experiment it was completely eliminated, by planting into well-established broom. The early rate of growth of the Sitka spruce here has probably not been equalled elsewhere in the experiments, though the subsequent development of the pure crop when it emerged from the broom was not so striking.

USE OF NURSE TREES

Early Mixture Trials

When the programme of broom sowing was undertaken, the possibility of the growth of spruce in the existing plantations appeared poor, and it was not in fact until some years later that the spruce began to improve in certain of the earlier plantings where mixed with pine. Table 56, compiled from Guillebaud (1938), gives the evidence available at that date. The spruce in the mixed plots exceeded the pure spruce by more than a foot in only one experiment, but the difference in colour, vigour, and shoot growth made it quite apparent that the environment and potential growth had been radically improved. Nevertheless it may also be noted that in only one case had the spruce drawn level with the nurse, namely in the Sitka spruce/mountain pine plots at Teindland.

These results set in motion a considerable programme of experimentation, but first the later results from these experiments may be considered. Soon after the improved growth was observed, a policy of tending the spruce was initiated, since in every case the mixture was intimate, generally by single plants. Interfering branches were cut back, or the nurses high pruned or cut out wherever they threatened to suppress the spruce. The results however were not encouraging. Individual spruce grew rapidly and came into canopy with the pine, but the pine formed canopy over the majority which had not responded, and indeed their growth rate started to fall. The cutting out of nurses did not help as expected, because in many cases their removal prolonged the life of the heather which, though almost suppressed after the closure of the pine canopy, was rejuvenated when that canopy was opened again to free the spruce. After almost a decade of such attempts to free the spruce from the pine nurses, they were abandoned except for a limited number of the most

TABLE 56: NURSING

Summary of the evidence available in 1938 of the improved growth of spruces when grown in mixture with pines (after Guillebaud, 1938).

Heights in feet

	Teindland 23.P.28 *Shallow ploughing and phosphate* 10 *years*				*Wykeham* 6.P.28 *Shallow ploughing* 10 *years*	*Inchnacardoch* 16.P.23 *spruce interplanted with pine in* 1927 *Sitka spruce* 13 *years* *Scots pine* 9 *years*	
	Norway spruce		*Sitka spruce*		*Sitka spruce*	*Calluna-Erica vegetation*	*Calluna Pteridium vegetation*
Spruce heights:						Sitka spruce	
Pure crop	1.5		2.9		2.0	1.7	4.2
In mixture with nurse stated below	2.3	1.9	3.2	3.8	2.4	2.9	8.8
Nurse crop	M.P.	P.C.	M.P.	P.C.	Scots pine	Scots pine	
Height of nurse	3.2	6.2	3.2	7.2	4.8	9.3	13.0

M.P. = Mountain pine; P.C. = Lodgepole pine;

Note: Differences in the general appearance, especially colour, vigour and length of leading shoot were also recorded, the plants of spruce in mixture being superior in each respect.

promising groups, for in the meanwhile a new factor had emerged.

The controls to Table 56, called there 'pure' crops, were in fact small experimental plots adjacent to similar plots of other species. About 1942, when the plantations were about twelve to fifteen years old, improved growth was noticed in these spruce plots along the edges adjacent to vigorous plantations of pine or larch. The improvement in growth occurred successively in each line of the plot, until the effect was apparent throughout the plot, giving a "lean-to roof-like" or "U-shaped" appearance to the canopy, according to whether there were vigorous crops on one or both sides. This effect also appeared in other species trials where small plots had been used, notably in Wykeham 11.P.31 and Clashindarroch 5.P.31. These provide the best documented evidence for this phenomenon, but before describing them the end-point of the first trials may be summarised. In general the 'pure' plots of Table 56 now form vigorously growing sizable groups or strips of spruce in among similar groups of other species, whereas the spruce of the mixed plots survive only in small groups or as individuals among the nurse pine. The only exception to this last is that the Sitka spruce at Teindland now dominates the "nurse" mountain pine, and will form the crop over the whole of these plots (Figure 9, page 88). It will be noted that this was the crop in which the spruce had already drawn level with the pine nurse by the tenth year, as shown in Table 56.

Nursing by Adjacent Crops

After the growth of the edge trees of the pure spruce plots had improved markedly, the inner rows gradually followed. Figure 12 shows the progressive nature of this development across the plots. Here at Clashindarroch the plots were twenty yards across, and the stages of development clearer than in other experiments with narrow bands. In this experiment at Clashindarroch and also at Wykeham (11.P.31, Table 57, p. 123), it was possible to observe from an early date that the greatest response occurred adjacent to Japanese larch, rather than to Scots or lodgepole pines. Root investigations at Wykeham showed that the spruce emerging from check were rooting vigorously in the litter of the nurse species, particularly under Japanese larch, where extensive superficial root systems extended many feet under the larch canopy from the most vigorous spruce; root development among the spruce crop itself was, in contrast, sparse and with little branching. No direct experiments with trenches have been made to check that the phenomenon is mainly attributable to the rooting of the nursed species under the nurse, but the following observations are pertinent:

(a) On deep peat at Inchnacardoch, where exactly comparable nursing has been observed between Japanese larch and Sitka spruce, nursing is absent where a drain runs between the species.

(b) There is a close parallel with the experiment at Wykeham where a trench was cut to isolate the "control" of Lawson cypress, in which the edge trees adjacent to a mulched plot were rapidly coming out of check. After the trench had cut their roots, these trees steadily deteriorated into check again.

(c) In a checked Sitka spruce plantation seen by the author in Holland, a few vigorous trees were found to have roots running under a very deep ditch into an adjoining larch plantation. No such roots could be found near the checked trees.

It may be concluded that under the conditions observed, shelter plays a relatively small part in the phenomenon of nursing, as compared with the provision of an improved rooting substratum.

Layout of Nursing Mixtures

It is apparent from the history of the experiments set out above, and the knowledge built up of the different responses of the various species to ploughing and phosphatic manuring, that a great variety of planting prescriptions are available for the raising of nursing mixtures, in which the choice of intensity of ploughing, method of manuring and spatial arrangement will all play a part, as well as the choice of species both as "nurse" and "nursed". A number of experiments ring the possible changes in almost bewildering variety. All are too young to give any final result, though in certain cases the ultimate pattern can be guessed at; others give results for only a proportion of the treatments under test. All have the object of finding the best balance between the species, by manipulation of the planting prescription to favour the nursed species.

As an early example of this, there was an attempt at Inchnacardoch to equalise the growth in mixture by planting Sitka spruce with intensive hand preparation, while alternating lines of Scots pine were notch planted. This has been only moderately successful, but even though the spruces checked badly, selected groups have been relieved by thinning, and now at seventeen feet are half the height of the Scots pine nurses. (Inchnacardoch 57.P.28). In some of the first nursing experiments on ploughed ground there was insufficient cultivation to give rapid growth, and later experiments on deep ploughing have overtaken them (Broxa 4.P.41 and Millbuie 2.P.42).

The main results from these later nursing experiments are set out in Tables 57 and 58 and Figure 13. The following paragraphs consider the results

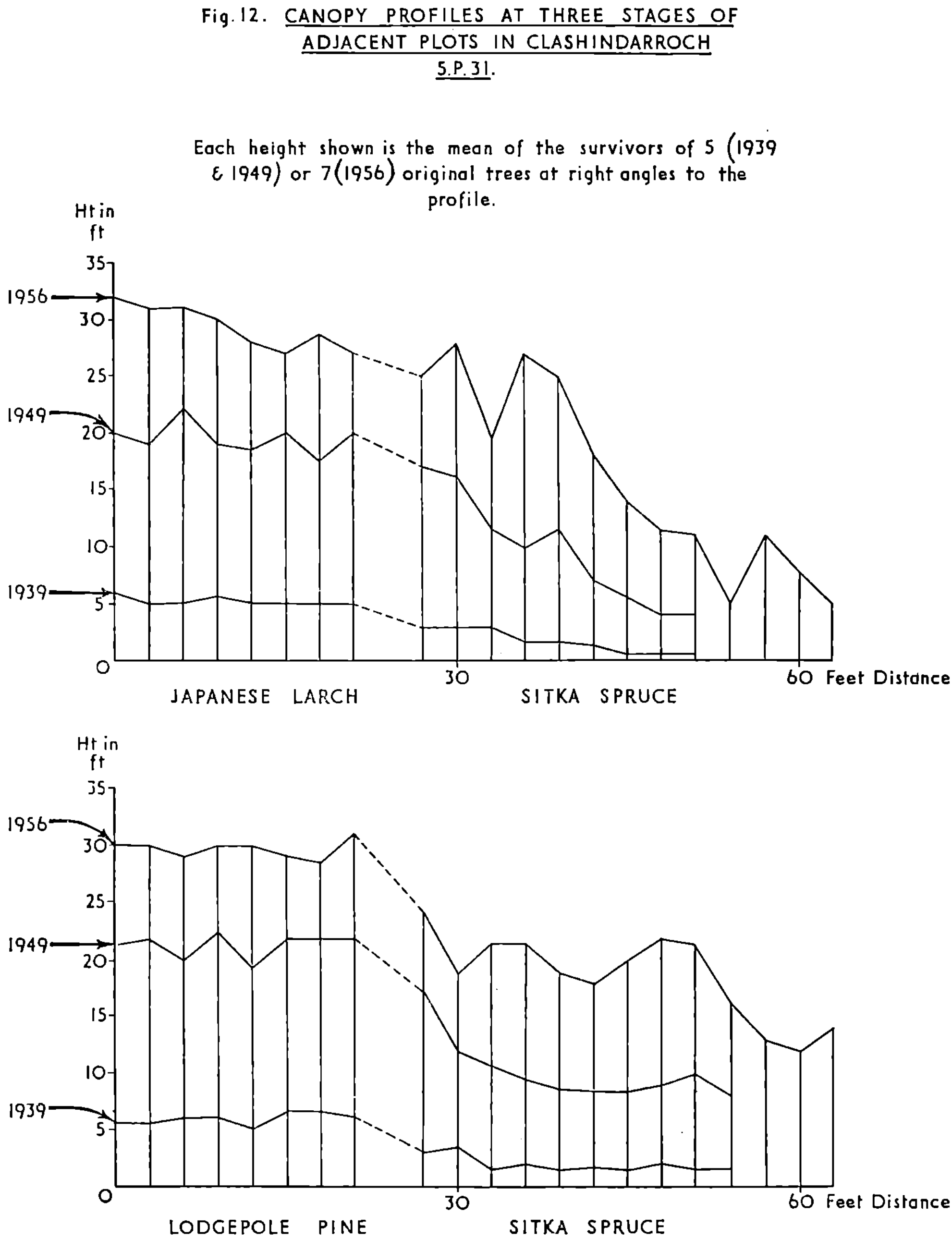

Fig. 12. Canopy Profiles at Clashindarroch. (5.P.31.)

TABLE 57: NURSING

Heights and relative growth of nursed species, with various nurses.

Experiment *Ploughing* *Method of Mixture* *Phosphate*	*Age*	*Height of pure Sitka spruce ft.*	*Heights in feet and relative growth (Height of nursed as % of nurse)*								
			Scots pine nurse	*Sitka spruce (nursed)*	*%*	*Pine nurse*	*Sitka spruce (nursed)*	*%*	*Jap. larch nurse*	*Sitka spruce (nursed)*	*%*
Wykeham 11.P.31 † Mod. Deep Ploughing .... Adjacent plots .... ±1 oz. slag	17	(10½)				*Lodgepole/Sitka* 20½	13	63	23	17	74
Broxa 8 & 9 P.43 5 Ploughing Treatments See Footnote ‡ .... 1 oz. slag	13	6.1	12.8	9.9	76	*Corsican/Sitka* 10.9	8.6	79	12.6	12.5	99
Broxa 10.P.43 S.f. ploughing .... 2 line. 2 line .... 1 oz. to S.S. and J.L.	13	6.0	10.8	8.6	80	8.8	7.9	90	15.4	11.8	77
Clashindarroch 33.P.46 S.f. ploughing .... Alternate plants .... 1 oz. to S.S.	10	4.1	7.9	4.0	51	*Lodgepole/Sitka* 11.2	4.1	37			
Complete ploughing .... Alternate plants .... 1 oz. to S.S.	10	6.0	8.8	7.9	90	12.2	6.7	55			
Clashindarroch 33.P.46 Mean of 2 Ploughings .... Alternate plants .... 1 oz. to D.F.	10	8.6	*Scots/Douglas fir* 8.5	8.7	102	*Lodgepole/Douglas fir* 12.4	9.7	78			

Notes: † Strips of species were 8 plants wide, and measurements were made in the four rows nearest the nurse species. Figures are means for 3 types of ploughing. (See Fig. 6, p. 00). The controls are not adequate.
‡ Figures are meaned over 5 ploughing treatments detailed in Fig. 7 (p. 00). Pine mixture figures are means for 3 types of mixture, detailed in Table 58. Japanese larch mixture was 2 row : 3 row, across the ploughing (contrast Broxa 10). S.f. = Single furrow.

according to type of treatment. In these trials particular importance is attached to the relative growth of the nursed species, and this is shown as a percentage of the growth of the nurse, since experience has shown how easily nurses can suppress the nursed, if once they draw too far ahead.

Selection of Nurse Species for Sitka Spruce

Table 57 shows that, of four species tested, not all on the same site, Japanese larch has nursed the spruce into faster growth than have any of the pines, although in one case the relative growth of the spruce was rather greater with the pine (Broxa 10). Lodgepole pine of coastal provenance at Clashindarroch has completely outgrown the spruce, and will suppress it. Between Corsican and Scots pine nurses there is little difference; the *absolute* growth of spruce is greater with Scots pine but the *relative* growth better with Corsican. This last species is itself however only under trial on the heaths, and has been used in practice far less than Scots pine.

In a further experiment at Wykeham three provenances of lodgepole pine were used to nurse Sitka spruce. One of the provenances was a heavily branched coastal form which has almost completely suppressed the spruce; with the other two there is more chance of the spruce reaching the canopy. The relative, but not the absolute, height of the spruce is greatest with the slowest growing provenance, and this seems likely to be the most successful nurse.

In general it remains to be seen, therefore, whether Sitka spruce can endure a larger degree of overtopping by deciduous Japanese larch, rather than a lesser amount of overtopping by evergreen Scots pine, these being the two most successful and widely used nurses. In the meanwhile, certain plots have

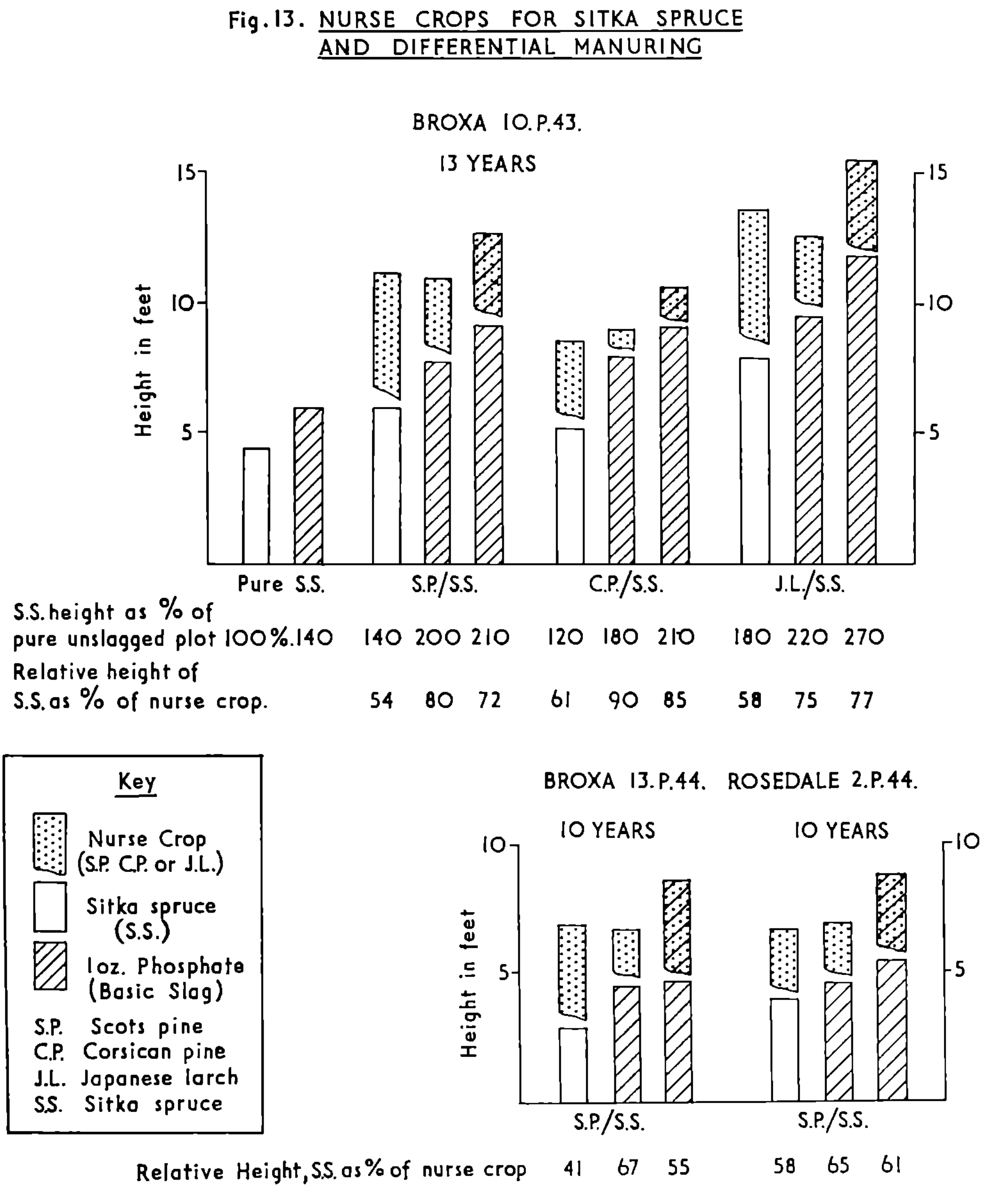

Fig. 13. Nurse Crops for Sitka spruce, and Differential Manuring. (Broxa 10.P.43; 13.P.44; and Rosedale 2.P.44.)

TABLE 58: ARRANGEMENT OF NURSES

Preliminary results from two experiments, showing the effect of different arrangements of species in nursing mixtures. (On ploughed ground with 1 oz. of basic slag).

Heights in feet. Percentages represent height of nursed spruce as per cent of pine nurse

Method of Mixture	*Wykeham* 54.P.38 *aged* 18 *yrs.*			*Broxa* 8.P.43 *aged* 13 *years*					
	Scots pine	*Sitka spruce*	%	*Scots pine*	*Sitka spruce*	%	*Corsican pine*	*Sitka spruce*	%
Alternate plants †	20.7	15.3	74	—	—	—	—	—	—
Alternate lines	21.2	17.7*	84	12.8	10.7	84	11.0	8.7	79
Line nurse/2 lines Sitka spruce	—	—	—	12.5	9.5	76	10.6	8.1	76
Alternate double lines	—	—	—	13.0	9.5	73	11.2	8.9	80
Sitka spruce groups in Scots pine matrix	21.4	17.8	84	—	—	—	—	—	—
Sitka spruce matrix with Scots pine groups ø	20.2	13.0	64	—	—	—	—	—	—

Notes: Wykeham 54. This experiment is unusual in having had double cultivation. A previous experiment planted in 1929 having failed, the ground was reploughed and this unusual history may have influenced the result.

† Regularly set out, this arrangement gives diagonal lines of each species.

* This treatment is significantly better than the two poorest, but the other treatment with a high average was too variable as between plots, to show significance.

ø This is virtually a control of pure spruce in the early stages.

Broxa 8. The experiment comprises many plots on the different ploughing treatments shown in Figure 7, p. 00, but systematic layout precludes analysis.

been planted using both nurses in alternating bands. The results of many more experiments will become available in the next decade.

Arrangement of Mixtures

The results of the early species trials demonstrated that the group or strip mixture was much more likely to produce a controllable crop than were the intimately mixed plots. The only experiments which compare different arrangements and are old enough to give results (Table 58), suggest an alternate-line mixture as giving the quickest response from the spruce; while a group method is also good, though this result is not significant. However, these results are, as indicated in the footnote to the table, only tentative, and mixtures with more than one line of a species are much easier to control, particularly if the height differences are rather greater. Thus it is that from about 1945 onwards the use of two-line mixtures, that is two lines of nurse species alternating with two of nursed, was widely adopted.

In recent years there has been a tendency to go even further and use three-line mixtures. On the grounds of amenity all broad strips should either be confined to flat areas or set out so that they do not, too obviously, run up and down hill. Alternating three-line mixtures have also been employed to a small extent, the species changing over after perhaps twenty rows, giving species groups of 3×20 rows. The main advantages of these strip mixtures are believed to lie in ease of thinning in the future, though nowhere has this thinning yet begun.

Experiments have been laid out to compare blocks of such mixtures with the species lines set along, or across, the ploughing. The last-named is more difficult to plant in practice, but it seems likely that the nursing effect will be obtained more quickly, since the roots of the nursed species spread more rapidly along the furrows than they do across them. In one such experiment at Rosedale, Yorks., a consistent slight positive effect has been observed after ten years (2.P.44), but in a comparable experiment at Broxa this was not so; the results here were, however, much more variable (13.P.44).

Differential Manuring

A further method of influencing the relative growth is to apply phosphatic manures to the nursed species but not the nurse. Results given in Figures 11 and 13 show conclusively how effective this can be in increasing the relative height of the nursed species with a very small reduction (if any) of the absolute height. Clearly this is the correct procedure provided that the growth of the nurse is certain on the chosen site. With Japanese larch there remains an element of doubt on many heaths, and hence it is common practice to manure it also when used as a nurse.

Species Other than Sitka Spruce

Apart from the example of Douglas fir given in Table 57, and western hemlock in Figure 11 (p. 100), there is virtually no evidence of the relative merits of different methods of nursing. The examples given in Table 40 (p. 91) show that the effects of broom were similar, on a range of species, to those produced on Sitka spruce. Several young experiments at Teindland, Broxa, and Clashindarroch, test the nursing of a wide variety of species by Scots pine, Japanese larch, or a combination of the two, but informative results will not be available for at least a decade.

It is concluded that the problem of raising a more tender or "nursed" species by use of a pioneer or "nurse" species lies in attaining the correct balance. The choice of species and treatment must be such that both will grow, and at not greatly dissimilar rates, under the planting prescription adopted. While rapid establishment of the nurse is important, it must not far outstrip the nursed species or it will suppress it. The check period of the nursed species must be reduced to a minimum by ground preparation and manuring. The layout must be such as to allow the nursed species to root freely under the canopy of the nurse, while giving freedom from overtopping. Clearly groups or strips of limited width, of both nurse and nursed species, give the best hope of fulfilment of these conditions.

Handling of Mixtures in Thinning Stage

It has become apparent that it would be unwise to regard the nurse crop in these mixtures as "expendable", to be opened up when the nursed spruce starts to grow, and to be finally removed as the spruce closes canopy. These nursing mixtures are very different from those used for instance with oak on ground where it is known oak has grown before. With Sitka spruce on the heaths there is little evidence that the species will grow as a pure crop, there are few crops older than the pole stage, and it is outside what might be considered as its normal range of soil and climate. Nevertheless, as already indicated, small promising groups of this species show signs of heavy production and great resistance to exposure. For these reasons the policy is to treat the older experiments as testing grounds for different thinning regimes, which are often applied to both nursing mixtures such as Scots pine/Sitka spruce, and to long-term mixtures such as lodgepole pine/Japanese larch. These may be broadly defined as:—

(a) Maintenance of a mixture, in roughly the original proportions, by selective thinning, often of a crown type.

(b) Silvicultural thinning to preserve the best trees regardless of species. This may be defined as a test of the relative ability of the species to compete, and to produce stems of good form on the particular site.

(c) Conversion to as complete a crop of the nursed species as possible, by steady removal of the nurse.

The third course is only followed where the nursed crop shows great promise, as for instance in the lodgepole pine/Sitka spruce mixtures at Hamsterley, in parts of which the nurse is being suppressed (Hamsterley 4 and 5.P.30). The other two regimes may be assessed in two ways, by production and composition, and this is being attempted by plots in which the standing crop is counted, volume estimated, and all thinnings are measured. To date these measures have only been applied to the older types of mixture, those formed by single trees or lines, or to spaced groups; the most important trials are at Clashindarroch (6 and 7.P.31) and Wykeham (4a.P.31). These treatments are only feasible in relatively successful mixtures; where one species has fallen far behind, little can be done except to relieve occasional promising groups. This is not considered a practical treatment on any scale, and it may involve considerable losses in increment; but is desirable to obtain information on the ultimate growth of the second or "nursed" species.

Chapter 10

THE STIMULATION OF CHECKED PLANTATIONS AND INVESTIGATIONS INTO THE "SPRUCE HEATHER" RELATIONSHIP

The checking of spruces, and of other conifers such as Lawson cypress and *Thuja plicata*, on heaths is a well known phenomenon, characterised by the cessation of growth and yellowing of foliage to a greater or lesser degree. Check usually occurs soon after planting, but stimulatory treatments such as ploughing and manuring may postpone its onset for some years, so that the trees only start to check when perhaps two to three feet tall. A number of experiments have been made to relieve this condition, and once again the majority of the work has been done with Sitka spruce.

The checking was, from an early date, associated with the presence of heather, *Calluna vulgaris*, and in 1928 an attempt was made to eliminate the heather by burning, cutting, pulling and suppression by canvas coverings (Inchnacardoch 64.P.28). New plants were notched into the cleared areas, but this treatment was insufficient to promote their growth, since the essential minimum of ground preparation was lacking. In the same year at Dalby, Allerston, checked spruce were interplanted with Scots pine but without effect; directly-planted spruce could not be nursed back to vigour on such land.

In contrast, at Inchnacardoch, on better ground with *Calluna-Erica cinerea* and *Calluna-Pteridium*, striking results were achieved by this method, and it provided some of the first evidence of the benefits of mixing (Inchnacardoch 16). Early results are shown in Table 56 (p. 120), while later results are given by Macdonald and Macdonald (1952).

From this time on, a succession of ameliorative treatments were applied to checked plantations, usually of Sitka spruce; these trials are dealt with in rough chronological order below, ending with the more comprehensive experiments laid out from about 1949, which attempt to assess the importance of the various factors involved.

Manurial Top Dressings with Phosphate

Once the beneficial effect of phosphate application at planting had been shown, top dressing was tried on certain of the older checked plantations, using manurial doses of up to four ounces of basic slag per plant. In general such trials have been unsuccessful, and there is not a single example of striking improvement, such as has been recorded in several cases in the peat plantations.

On the heaths the life of the spruce was prolonged, and small improvements in growth and colour occurred, but the improved growth was never sufficient to bring the spruce crop into canopy, (Monaughty 4 & 5.P.22-23, manured at ten years; Teindland 26.P.28, manured at five years; Wykeham 46.P.36, manured at two years). Special care was taken in one case with the placement of the top dressings; application in the planting notch, careful spreading, and forking around the plant were tested, but to little effect (Clashindarroch 20.P.31, manured at five years). A large experiment was laid down at Glenlivet Forest to plans prepared by the late Dr. E. M. Crowther for the Basic Slag Committee. Four types of phosphate were tested at four levels, on Sitka spruce which had checked badly, but once again the result was negative (Glenlivet 2.P.34 manured at two years). A single trial of basic slag on checked Japanese larch was equally unsuccessful (Dalby 28.P.30 manured at three years).

Recently, thirty-year-old crops of checked or slow-growing Scots and lodgepole pine have been top-dressed with triple superphosphate, but without visible result after the first two years (Teindland 87). This is in complete contrast to results at Inchnacardoch on deep peat, where checked Scots pine of comparable age and appearance responded rapidly to ground mineral phosphate, changing colour from yellow to green within three months and making more vigorous shoots the next year. It is thus apparent that phosphate is not the limiting factor on these heaths, while it often is so on the peatlands.

Heather Removal

Small plots of Sitka spruce, planted on complete ploughing seven years earlier in the species trial at Teindland, were treated in 1935 by digging between the lines to eliminate the heather. The results are shown in Figure 8 (p. 84). The one surviving plot now contains the tallest spruce in the experiment, and indeed in the Findlay's Seat area. Clearly the line between this treatment and the recultivations dealt with in Chapter 5 is fine, but later trials at Broxa set out to eliminate the heather with a minimum of soil disturbance. Three-year-old heather regeneration was eliminated, by hoeing and pulling, on parts of pure spruce plots on various ploughing treatments, and in subsequent years annual hoeings prevented regeneration (Broxa 20). The colour and growth of the trees improved in the hoed area, but not to such an extent as in the mulched areas described below. Part of this experiment was subsequently shaded with laths. Analyses made by Leyton (1955a), one year after the shading, showed improved growth and nutrient uptake by the spruce among the heather, while the uptake of nutrients by the heather itself was reduced. Results in terms of growth are given in Table 59, which includes also results from a further experiment where very shallow cultivation with a rotary hoe was used to destroy heather regeneration three years after complete deep ploughing. In spite of the intensive treatment already applied, this treatment gave a further increase in growth (Broxa 19.P.46).

As an alternative method of freeing spruce from competition, sodium chlorate was used at Clashindarroch to kill the heather round badly-checked Norway spruce, which had been notch-planted about

TABLE 59: ELIMINATION OF CALLUNA

Results from experiments in which the heather ground vegetation (*Calluna*) was destroyed, mainly in checked or semi-checked plantations.

Heights in feet

Experiment	*Species*	*Original treatment*	*Initial position*		*Additional treatments*	*Results*	
			Age, Yrs.	*Heights*		*Age, Yrs.*	*Heights*
Broxa 20	Sitka Spruce	Ploughed +phosphate 1943	3	1.6	Control	14	5.1
				1.5	Screefed		7.2
					†Lath shades		5.7
					†Screef+laths		8.0
Broxa 19	Scots pine	Complete ploughing 1946	3‡	—	Control	13	7.6
			—	—	Rotary hoed		8.0
	Sitka spruce			—	Control		4.7
				—	Rotary hoed		5.8
Clashindarroch 34....	Norway spruce	Notch planted 1934	14	ø1.8	Control	22	4.3
				1.6	Sodium Chlorate 50 lb. solution/ acre		5.0
Wykeham 60	Sitka spruce	Patch planted 1928	12	ø1.1	Control	25	2.2
				1.0	Mulched		4.2
Wykeham 71	Sitka spruce	Ploughed 1932	10	1.7	Control	20	3.6
				2.1	Mulched		8.2
Wykeham 72	Sitka spruce	Complete ploughed +phosphate 1933	10	2.4	Control	20	7
				2.2	Mulched		9½
Wykeham 58	Lawson cypress	Ploughed +phosphate 1939	7	ø2.6	Control	21	3.8
				2.7	Mulched		16.0
Broxa 78 .... and adjacent plot	Sitka spruce	Ploughed +phosphate 1945	6	3.0	Control	10	6.6
				3.2	'NP' application		9.2
				3.0	Branch mulch		12.6

Notes: † The additional treatment with lath shades was added in the 10th year and produced a further improvement which shows no interaction with the hoeing.

ø These three plantations were fully checked when treated.

‡ This was the only plantation showing no signs of ill health when treated.

TABLE 60: STIMULATION OF SITKA SPRUCE BY MANURING

Initial height and heights at intervals of three years following manuring of Broxa 78 in July, 1950.

Heights in feet

Treatment	*Initial*, 1950, *Aged* 6 *yrs.*	*After* 3 *years, Aged* 9 *yrs.*	*After* 6 *years, Aged* 12 *yrs.*
Control	3.0	3.8	6.6
2 ozs. Nitrogen (hoof and horn)	3.0	4.5	7.6
2 ozs. Phosphate (ground mineral)	3.1	4.0	7.2
'N+P'....	3.2	5.2	9.2
Standard error	±0.15	±0.21**	±0.34*
Diff. for significance at 5% level	0.49	0.68	1.08
Main effect Nitrogen	—	0.9	1.5
,, ,, Phosphate	—	0.45	1.0

Notes: * = Significant. ** = Highly significant.

fifteen years earlier. A variety of doses, and dry and wet application, were all tried. The result given in the table show that there was definite stimulation following the treatment, but the improvement relative to the control was small (Clashindarroch 35). The great improvement of the latter is difficult to explain; possibly the plots were too small and the controls have benefited from the removal of heather in adjacent plots.

Mulching

The publication of results by Fabricius (1938) on the beneficial effects of mulching Scots pine and Norway spruce on heaths, led to the first trial at Wykeham, where eleven-year-old directly-planted Sitka spruce were mulched with heather cut from the area (Wykeham 60, planted 1928, mulched 1939, '42 & '49; Table 59). The first two dressings were not heavy enough to suppress regrowth of heather, though there was a slight response in improved colour and growth of the spruce. The third mulching was much heavier, and by 1952 the mulched plants were twice the height of the controls, by then twenty-five years old and only two feet high.

In the next trial, with Sitka spruce on ploughed ground, a much heavier mulch was used, the heather applied being cut from three times as great an area as that mulched. The improved growth obtained is shown in Table 59, together with results from a comparable trial (Wykeham 72), wherein growth of the control itself was better. The very striking result, shown in Table 59, obtained with Lawson cypress, is discussed on page 93, and comparable results for Norway spruce are given in Table 41 (p. 94). At Broxa, birch branches were used to mulch a few Sitka spruce, comparable to those in a nearby manuring trial. This 'spot trial' gave better results than any of the main treatments, as indicated in Table 59 (Broxa 78).

The latest test in this series employs needle litter from various conifer species to mulch semi-checked spruce. After a preliminary one-plot trial had shown a quick response to applications of Japanese larch litter, an experiment was laid out in 1955 to compare the litter of the most important nurse species with that of Sitka spruce itself. The benefit of the litter is clear in the second year's growth, but it is too early to judge between species (Broxa 95, planted 1941, mulched 1955) (But see Leyton and Weatherell 1959—J. L. Best).

Nitrogen and 'NP' Applications

In June, 1950, semi-checked Sitka spruce at Broxa were treated with ground mineral phosphate and various nitrogenous fertilizers, mainly hoof meal. The manures were placed around each tree in four holes, eighteen inches from the stem and about six inches deep, this treatment being designed to permit the manure to reach the roots quickly. Within three months the colour of all trees which received nitrogen had greatly improved, and growth in each of the following two years was doubled. After a fall in the third year (1953), growth of all plots improved again, but the NP treatment now stood out. The results are given for three stages in Table 60, and show quite clearly the two distinct phases in development of the experiment, with nitrogen having a diminished effect, but phosphate an increased effect, in the second three-year period.

In the following year a further trial investigated the quantity of combined fertilizers needed, and methods of application, using flash as the source of nitrogen. The general result was much less striking and possibly flash was too slow-acting a form of N to be suitable (Broxa 78, 1951 Section).

Manuring as applied here, however, gave far less stimulus than did mulching, as shown by the single-plot trial using branches in the same crop. This has been confirmed by the earliest result from a later trial which directly compares mulching with application of nitrogen (Broxa 96, planted 1941, treated 1955).

Comprehensive Experiments

By 1949, evidence was accumulating, from the various trials described above, on the alterations in growth rate which could be produced by manipulating the heather vegetation. The effects of ploughing, manuring and nursing were also well known, and it became possible to lay out more comprehensive trials to investigate the inter-relationship of the various factors. These trials were stimulated by the fact that the growth and appearance of Sitka spruce was at that time particularly poor, probably due to a series of fine summers culminating in the drought of 1947.

Trials were laid out at Wykeham and Clashindarroch, to the design of Dr. L. Leyton, to investigate the effect of screefing and phosphatic top-dressing. Intensive analysis of foliage was carried on over several years (Leyton, 1954). In brief Leyton found that poor growth due to nitrogen deficiencies in the soil was aggravated by the presence of heather, and that screefing alleviated this, but only temporarily. He confirmed earlier results that phosphate is of little use as a stimulant for checked plantations, but showed that a response could be obtained if the amount of nitrogen available to the trees was increased by screefing. (Wykeham 83 and Clashindarroch 35). To a lesser extent screefing improved the growth of Corsican pine at Wykeham.

In the same year an extensive trial was designed by Rennie (1950 and '53), and laid out at Broxa to investigate the relation of the growth of Sitka spruce to ploughing, screefing and mulching. Preliminary results, purely in terms of growth, are shown in Table 61, which confirms the earlier results, given in Table 59, that neither superficial cultivation nor mulching is a satisfactory substitute for deep ploughing. This experiment also confirms the suggestion, apparent in the earlier results, that it is only where reasonable ground preparation has been carried out that the ameliorative treatments show sufficient effect to be worth while. Proportionally the effects may be greater on directly-planted areas, e.g. in Wykeham 60—Table 59, but the absolute effects are then hardly sufficient to make treatment worth while. The effect of mulching in these trials has been shown by Rennie (Leyton, 1955b) to be an increase of the water content of the soil, particularly in drought periods.

TABLE 61: HEATHER-SPRUCE RELATIONSHIP

Heights in feet, six years after planting Sitka spruce in Broxa 52.P.49.

	Initial Treatment		
	Screefed by shallow rotary hoeing	*Cultivated by deeper rotary hoeing*	*Deep single furrow ploughing*
Control	0.8	1.0	3.6
Subsequent Treatment:			
Hoed annually	1.2	1.0	3.4
Hoed and mulched	1.2	1.5	4.8

TABLE 62: STIMULATION OF SITKA SPRUCE

Effect after five years, of additional treatments applied five years after planting, in the 1946 ploughing experiments.

Heights in feet

Treatments Dosage per tree	*Fetteresso* 1.P.46	*Millbuie* 11.P.46
Control	4.3	1.9
2 oz. phosphate†	4.6	2.1
P at 24 oz.	4.2	2.1
N at 2 oz.	4.8	1.9
Screefed	5.8	2.5
Mulched	6.2	2.6
Standard Error	±0.73	±0.18*
Difference for significance at 5% level	2.3	0.56

Notes: For results of the main experiments see Table 12 (p. 49).

The results above are averaged over all ploughing treatments.

† At Fetteresso this treatment was applied at planting.

P = Ground mineral phosphate.

N = "Flash", applied in bore holes near the stem.

* = Significant.

Finally comparisons were made, within the large-scale ploughing experiments laid out in 1946-7, of the efficacy of phosphate and nitrogen applications, screefing and mulching. The results, set out in Table 62, indicate quite clearly that only mulching can be relied on. This confirms Leyton's conclusion that this is the surest method of stimulation.

From the practical viewpoint, these results suggest the great importance of the initial treatments of ground preparation, manuring, and planting of nurses. Once a crop checks it is difficult to prescribe any treatment which is certain to stimulate renewed growth. Experience has shown, however, a practical method for treating large checked areas, short of replanting.

In 1949-50 large areas of checked Sitka spruce were inter-ploughed and replanted with pine or larch at Clashindarroch and Broxa. The growth of surviving spruce has often been excellent, and it is clearly the ploughing that is responsible, since it is too early for them to have benefited from the nurse crop. The question arises as to how much reploughing would have sufficed rather than full replanting? An experiment at Clashindarroch seeks to answer this question (Experiment 38, planted 1938, inter-ploughed 1950). The method employed was to plough single lines or strips through the crop at intervals, and to plant Scots pine, lodgepole pine or Japanese larch. All Sitka spruce were manured with phosphate, since this has been proved to prolong their life, and will ensure that they survive until the nurses can assist them.

Order of Sensitivity to Heather Competition

At this point it is perhaps legitimate to make a tentative "order of sensitivity to heather competition" derived from the various trials on the raising of difficult species by nursing and of attempts to relieve check by treatment:

Most sensitive to heather competition and difficult to stimulate.

Thuja plicata	No success achieved in relieving check, only grown satisfactorily with broom.
Norway Spruce Lawson cypress	Isolated successes by mulching and nursing with broom.
Sitka spruce Douglas fir	Examples of successful stimulation by mulching, manuring, or nursing.
Picea omorika Western hemlock	Will grow when planted pure on the better heaths.

Least sensitive, check only on poorest heaths and no experiments on stimulation yet.

The species trials show that the first three species are unsuited for use in afforestation on the heaths, while Sitka spruce and Douglas fir should be used with discretion and given the benefit of ploughing, manuring and nurse crops.

Where checked crops exist on heaths, the most certain treatment is mulching, which is practical on small areas but too expensive for large-scale use. The reason for checking has been shown to be competition with the *Calluna* for water and nutrients, especially nitrogen and phosphate. Ploughing makes nitrogen available from the decay of the buried vegetation, and applications of phosphate at this time are effective. But when check occurs this is no longer true, and more drastic treatment than top dressing is necessary to alleviate check. Removal of heather by screefing or the use of sodium chlorate weedkiller is not adequate, since the bared ground surface leads to dessication.

Chapter 11

TRIAL PLANTATIONS

In effect, all afforestation experiments are trial plantations; but from time to time experiments are made for the specific purpose of testing a planting prescription on a particular site, and on a scale sufficient to give long-term results. In many cases experimental comparisons are included, but the major treatments, intensity of ground preparation, main species and manurial dosage, are generally either uniform or nearly so. Some of the earliest species trials however served also as trial plantations, in that they were planted far out on the more exposed areas of heath. Afforestation then proceeded from the more fertile lower slopes, and by the time the experimental plots were reached, they were old enough to give valuable evidence on the correct choice of species, and the results to be expected from the particular methods employed. The Findlay's Seat enclosure at Teindland, and the species trials at Staindale (1.P.24, replanted 1931), and Hamsterley (1.P.29, 4 & 5.P.30), are the most important blocks of this type; they were not reached in the general planting-up of the forests for about fifteen years.

A large-scale trial plantation was made in 1929 at Teindland to test and cost the horse-drawn plough on a practical scale. Normally spaced planting, and also "spaced groups", were tried in separate blocks, and the whole planted with lodgepole pine; the only replicated treatment was the use of basic slag (41.P.29). Certain results have been given in Tables 10 (p. 44) and 50 (p. 113), and the experiment provides the earliest example of a crop of lodgepole pine, though it is regrettably of the slow-growing far-inland provenance from Alberta which has been surpassed in growth by several younger small-scale experiments using other provenances.

Almost ten years passed before the next such trial, also at Teindland, when the single-furrow plough was used for the first time (62.P.38). Here the plantation was made up of nine-plant groups of four species, lodgepole pine comprising almost forty per cent, with smaller proportions of hybrid larch, Scots pine and grey alder, while in addition birch seed was broadcast along the furrows. The ploughing was so contrived that the groups could be planted at four-foot spacing, with eight feet between. They cannot however be termed true "spaced groups", in that there is only one central tree in each group, losing much of the advantage of the system. The alder failed and was replaced by mixed groups of pines and Sitka spruce. Growth of the other species has been slow; the relatively low intensity of ground preparation and the overall low stocking are probably responsible. An interesting mixed plantation will eventually be formed, in which there will be a few spruce, birch and alder, the main crop consisting of lodgepole pine with groups of hybrid larch and Scots pine.

The post-war years have seen a great expansion in trial plantation work of the type often termed 'pilot plots', since it is unlikely that short-term results will be of much use in determining the plantability of the sites, which are generally completely treeless and on land 'unplantable' by present standards. At least twenty years will probably be required to get the crops into the thicket stage and give confidence for future planting, for the sites are in most cases so severely exposed that early growth has been much slower than is expected on the older heath sites, given modern methods of establishment. The soils are not in fact always as poor as in the typical heathland forests, and in some cases similar plantations have been made nearby on peat, since these sites lie on the fringes of the heathlands where lower temperatures and higher rainfall may easily lead to peat formation. 'Heath' conditions arise on these sites where the subsoil allows of free drainage, whereas with impeded drainage peat is formed.

The main features of these new trial plantations are given in Table 63. In practically every case, the plantation is based on a matrix of coastal lodgepole pine, though the provenances most resistant to exposure have unfortunately not always been available. The proportion of lodgepole pine is rarely below seventy-five per cent of the total, all other species being kept to a low proportion, as their chances of establishment in the first rotation is considered to be small. A surrounding belt of mountain pine, with behind it lodgepole pine of coastal origin, has been provided in every case to

TABLE 63: TRIAL PLANTATIONS

Outline of the site factors, and the results to date, of the plantations laid out on marginal heathland sites, 1950–54.

Locality and Experiment	*Altitude Ft.*	*Exposure Aspect*	*Relative Exposure§*	*Rainfall ins.*	*Peat depth Soil Subsoil*	*Vegetation*	*Main species and heights after 6 yrs.*	*Notes*
Skiall, Caithness 3.P.51 (part) 4.P.52	300-350	Very Severe N	1.95	35-40	Peat 4–6 in. White/grey sandy clay Broken sandstone flags at 14 in.	*Calluna-Trichophorum*	P.C. Slow, 2 ft. S.S. Poor, 1 ft.	Lower on the hill, where the vegetation is dominated by *Agrostis & Holcus lanatus* and the Relative exposure is 1.5, the Sitka spruce averaged 3 ft. after six years (Skiall 1.P.49).
Forss, Caithness 1-3 P.50-51	250-300	Severe NW	1.7	35-40	No peat Compact clay loam 6-10 in. Shattered sandstone flags below	*Calluna-Trichophorum*	P.C. Fair, 3 ft. S.S. Slow, 2½ ft.	More a grass heath than typical upland heath.
Fetteresso, Kincardine 5.P.53	1,000	Severe N and S	1.8	35-40	Peat 8 in. Thin pan at 14 in. Sandy clay below	*Calluna* (burnt)	P.C. Good, 3 ft. S.P. Slow, 2 ft. S.S. Good, 3 ft.	The first plot to be tine ploughed.
Drumtochty, Kincardine 3.P.50	1,200	Severe NE and flat	1.75	35-40	Peat 3 in. Leached, peat stained drift to 9 in. Subsoil of O.R.S. till.	*Calluna-Vaccinium* spp	P.C. Poor S.P. Very Poor.	Shallow ploughing (Solotrac), planted on ridge top.
5.P.51	1,000	Moderately Severe SE	—	35-40	Peat 2 in. Faint pan at 6 in. O.R.S. till at 14 in.	*Calluna-Erica cinerea*	P.C. Slow, 1½ ft. S.P. Slow, 1¾ ft.	A little deeper ploughing, step planting.
Cleveland, Yorks. 1.P.52	900	Moderately Severe† N	—	35	Peat 2 in. Faint pan at 8 in. Rotten sandstone below	Patchwork vegetation, see Note‡	S.P. 4.4 ft. P.C. 4.7 ft. J.L. 6.2 ft. S.S. 4.6 ft.	R.L.R. ploughing. Excellent growth. The very unusual vegetation was one of the main reasons for this plantation.

Notes: § Relative exposure has been calculated from the amount of material which has tattered away from unhemmed linen flags exposed over period of 3 months. For this series 1.00 = Findlay's Seat, Teindland, Moray (750 feet).
† This area is also liable to smoke pollution.
‡ The area has a number of species each locally dominant over areas of a few square yards. *Calluna vulgaris, Juncus communis, J. squarrosus, Empetrum nigrum, Nardus stricta, Deschampsia flexuosa, Polytrichum commune.*
S.P. = Scots pine
P.C. = Lodgepole pine.
J.L. = Japanese larch.
S.S. = Sitka spruce.

form a windfirm edge. The exception to these general statements is that, where the soil is more fertile and podsolisation less advanced, Sitka spruce has been brought in as a main species in addition (or alternatively to) lodgepole pine, because the spruce is undoubtedly more resistant to exposure than the pine. These conditions obtain at Forss, Caithness and possibly at Cleveland, Yorks.; while at Skiall the area is mainly suitable for Sitka spruce, and here lodgepole pine is the principal species only on the higher podsolised ground.

Exposure is clearly one of the main limiting factors on these sites, and an effort has been made to calibrate the different areas by observing the rate of tattering of unhemmed flags. It was hoped that the action of the wind on the flags would parallel to some extent that to be expected on the trees, and thus indicate at least the order of exposure of the various sites. There is no evidence that this order is on a linear scale. The results given indicate that Findlay's Seat, Teindland, which was classified as severely exposed when the first plantings were made, is in fact far less exposed than the new pilot plots in the north and east of Scotland.

As indicated in the table, the outcome of these experiments will remain in doubt for some years. Several of the earlier ones suffered from the fact that they were planted just before the tine plough was produced, and before the overwhelming evidence for furrow planting accumulated; this has undoubtedly adversely affected critical plots such as the first at Drumtochty (3.P.50).

Of the species other than those shown in Table 63 little can be said at this early stage; small numbers of either hybrid or Japanese larch, Sitka and Serbian spruces, noble fir, and hemlock are included in all the plantations, but early growth has been slow, and improvement can be expected only as the pine matrix starts to give shelter.

As afforestation continues and the demands on hill-land increase, it is to be expected that this type of experimental plantation will become increasingly important.

Chapter 12

OTHER EXPERIMENTS

PLANTING IN 'SPACED GROUPS'

Anderson has described, in detail (1951) and in their wider implications (1953), the plantations established in Great Britain in 1929-32 by the "spaced group" method of which he is the originator. The principle of the system is that, instead of plantations being made at constant planting distances, with the individual tree as the unit, the same number of plants are re-arranged in closely spaced groups leaving unplanted interstices. This arrangement is intended primarily to produce cleaner stems in the final crop, and to enable the work of establishment and tending to be concentrated within the area of the groups. A number of the plantations set out by this method lie on the upland heaths; in almost every case the spacing within the group is two feet, and the groups are of thirteen plants arranged 1:3:5:3:1. The groups generally lie at fifteen to eighteen feet centre to centre, equivalent to 190-140 groups per acre; this is equivalent also to normal spacings of approximately four to five feet. The closer spacing of the groups was generally used for Scots pine or mixed groups, and the wider spacings for lodgepole pine and Japanese larch.

The method of ground preparation employed for these plantations on the heaths varied considerably. Direct notching in screefed patches at Inchnacardoch produced patchy crops of pines, even with phosphate at two pounds per group (79 & 81.P.31), while most of the Japanese larch areas failed (80 & 81.P.31). At Clashindarroch, slow-growing crops of European larch have been obtained at high elevation (1 & 4.P.31). In contrast, hand-digging was employed elsewhere; patches 7 × 7 feet contain a group, and required the cultivation of only one-fifth to one-sixth of the total surface area. Here good crops of pines have been obtained, mixed in some cases with fair larch, as at Harwood Dale (2 & 3.P.32), Wykeham (4a.P.32), and Teindland (44.P.31). With the exception of Harwood Dale, all these areas were ploughable even in 1930, and in certain cases groups were established on ploughed strips, as at Teindland (41.P.29) and Inchnacardoch (81 & 82.P.31). The spacing between groups and trees was in these cases adjusted so that the land was fully ploughed in alternate ten-foot-wide strips, the groups lying at short intervals along each ploughed strip, leaving blank lanes between. This system might well have been used on a larger scale, but complete ploughing is technically more difficult than single or double-furrow work, owing to the need either to run the tractor on the ground already broken, or to offset the plough, either of which makes ploughing more difficult on marginal sites. For this reason no further plantations have been made on complete ploughing. One plantation was made with smaller groups on single-furrow ploughing, but it has not been very successful (Teindland 62.P 38—p. 130). The grouped plantations on ploughed strips have been generally satisfactory. In two cases it will be possible to compare their stand structure on a long-term basis with adjacent plantations at normal spacing (Teindland 41.P.29 & Inchnacardoch 82.P.31).

Another feature of the spaced group system, of interest on the heaths, is its potential resistance to exposure, and possible use for windbreaks and forest borders. Anderson suggests that the advantage possessed by the groups under these conditions is that they provide mutual support and filter the wind, rather than providing a solid obstruction, as does an equally-spaced plantation; though this latter statement would not hold until the canopy closed. The results given in Table 64 (p. 136) for the normally-spaced and grouped sections of a belt at Harwood Dale, show little difference in growth, but again it is the long-term results which are important here. Further comparisons of grouped and normal plantations were made at Clashindarroch, where the main species, European larch, was planted pure, and also mixed with Scots pine in normal plantations, in alternating groups, and also in mixed groups with Scots pine. It appears that the larch may have benefited from both nursing and grouping. These results are tentative, since the plantations were notched on a steep high slope, and after twenty-five years the larch is only 8–11 feet tall at the foot (1,150 ft.), and 5–7 feet at the top (1,350 ft.), and it still remains to be seen if an economic crop will be obtained (Clashindarroch 4.P.31).

The more advanced "spaced group" plantations are now being used to test the theory that the groups can stand for a long time without thinning, and that at most they require the removal of dominants competing with the cleanest stems. Pine and larch plantations, some with mixed or alternating groups at Inchnacardoch (79-82.P.31), Teindland (41.P.29), and Wykeham (4a.P.32), are being subjected to these two treatments; the last experiment as a further treatment seeks to retain the Scots pine/European larch mixture (p. 77). Once again the long-term results will decide on the value of this feature; these plantations were planned at a time when thinnings could not be sold in remote areas, and a plantation of a type that did not require thinning might thus be more profitable.

Clearly this project is one on which no definite conclusions can be reached until the final form of the crops can be seen more accurately. Much work remains to be done on the relative dominance of inside and outside trees in the groups, and on comparisons with ordinary stands, but unfortunately few of the plantations have adequate normally spaced controls. Anderson (1953), in the light of results so far, advocates larger groups with wider spacing inside than on the margin and need for this is borne out by observation on the heath plantations, where outside trees are clearly dominant in many groups. The major objection today would appear to be that the use of groups, combined with single-furrow ploughing, is more complicated than with hand preparation, and this type of ploughing is the basis of all the present heath afforestation.

SOIL AMELIORATION

Advance Crops

From time to time attempts have been made to improve heathland sites by the use of a pioneer crop, which would be accepted as uneconomic and later replaced by a commercial crop. The early trials consisted simply of plantings of species such as mountain pine, birch, and alders with the then current methods of ground preparation and planting (Teindland 47.P.32 and Harwood Dale 3.P.32). A control pine/larch mixture in the second place grew well enough for introductions some ten years later to be made with Sitka spruce, rather than pine and larch as intended, but as is now well known, Sitka spruce does not grow well when introduced in this manner.

Later trials included a wide range of hardwoods and shrubs, particularly *Leguminosae* and *Alnus* spp., few of which thrived. (Teindland 52 & 58.P.34-39). The early trials of broom and gorse belong to this series and they were the most successful of the species tried, but the interval between the advance sowing and the introduction of the tree crop was rapidly reduced with experience until it became simultaneous, so that these experiments were described under the heading of "nurses" in Chapter 9, page 118.

A new approach to this problem was made by Dimbleby, when in 1949 he started an experiment at Broxa to investigate the effect of birch litter on heath, following his investigations at Allerston on the role of birch as a soil improver (Dimbleby 1952c). The object was to convert the poor soil of the heath back into the mull that Dimbleby showed had existed prior to denudation and burning. Birch litter was applied annually at a rate equivalent to the leaf fall of a stand. The earliest effect was a marked increase in the vigour and flowering of the heather; subsequently changes in the soil fauna occurred; these latter changes were accelerated if the heather was eliminated by screefing (Broxa 51.P.49). From this work developed the extensive sowings of hardwoods after intensive cultivation and manuring, planned by Dimbleby and carried out at Broxa, briefly referred to in Chapter 7 (Broxa 79.P.52—Dimbleby 1958).

Maintenance of Fertility

That the poorest heaths have been upgraded, is shown by the fact that old pine trees of low stature have developed new leaders after soil working nearby. How far this process can be carried, and the possibility and desirability of converting mor humus into mull, are open questions. It is widely believed today that a proportion of broadleaved trees should be introduced into the crop. But the fact remains that planting of broadleaved species in the first rotation, so freely advocated by critics of the Forestry Commission, has been shown to be both difficult and expensive. On the other hand the natural associate of pine on the heaths, *Betula pubescens*, although not easy to establish by planting, readily invades pine plantations in conditions not yet defined; while invasion by other species, oaks, rowan, willows, and sycamore is not unknown. The present trend is to introduce, where possible, a small proportion of broadleaved trees, and to trust that they will form a higher proportion in the next crop. This attitude might be condemned as too optimistic, but may be justified in that considerable research is being done, both fundamental and applied, so that more will be known when the time comes to establish the second rotation. Meanwhile the heaths are producing a crop of softwood where previously they produced very little. It seems improbable that the soil improvement effected by afforestation: cultivation, manuring, and elimination of the heather, will be effaced by a single rotation of pure conifers.

SHELTERBELTS

A small number of experiments seek to compare various methods of producing effective shelterbelts or shelter strips for the edges of exposed plantations. The most important of these trials on the heaths is at Harwood Dale, where five species were used with two methods of planting, namely close spacing and spaced groups, the latter employing only half as many plants per acre as the former. The results are given in Table 64, and show that while alder has failed, the other species are all growing steadily, apart from the patchiness of the birch in the close spacing. The belt consists of alternate lengths of the two systems, and will thus produce an interesting contrast between the "dense wall" and the "filtering" type of belt; much Danish work has shown the latter to be preferable for certain types of shelter.

The next belts were very small blocks of various species and mixtures, planted at Clashindarroch in 1933-34 at elevations of 1,250–1,400 feet. Results for the pines have been summarised in Table 42 (p. 96); mountain and lodgepole pines were the only survivors under difficult conditions where a minimum of preparation was employed; Scots pine, Japanese larch and Sitka spruce all failed.

In recent years two further belts have been laid out, one to protect new experiments at Teindland (83.P.52), and the other on a very severely exposed site at Skiall, Caithness (4.P.51). Mountain and lodgepole pines are the main species, Austrian pine is used in both plots, while close spacing, and the use of wire netting as a temporary windbreak in front of the belt, are also being tested at Skiall. This last shelterbelt is growing slowly in very severe exposure, and for several years heavy beating-up was required. This is in contrast to most recent experiments, where one year's replacement of losses has sufficed. The use of complete ploughing here, in an endeavour to give maximum stimulation, was probably a mistake; the plants would have benefited more from the shelter provided by single-furrow ploughing. The figures for relative exposure given in Table 63 (p. 133) show that this is in fact the most severely exposed of all the heathland areas.

This work is again clearly of a long-term nature. It seems probable that the best species are now known; the difficulty of obtaining the correct provenances, particularly of lodgepole pine, remains; as does the question of the best arrangement.

DIRECT SOWING EXPERIMENTS

Sowing as an alternative to planting has certain advantages. At less cost than is involved in raising and planting large numbers of transplants or seedlings, it may be possible to get much higher stocking than normal, thus producing cleaner stems and allowing greater choice in the selection of the final crop. The possible effect of the root breakages due to transplanting on the incidence of root rot and windthrow has never been determined, but this possible source of damage in the later years is entirely avoided by sowing. Thus it is that direct

TABLE 64: SHELTERBELTS

Results after twenty-five years in Harwood Dale 7.P.32, using five species and two methods of planting. Dominant heights in feet

Species	*A* *Equal spacing at 3 x 3 ft, planted pit and mound*	*B* *Staggered dug-over groups at 21 x 15 ft. 13 plants per group*	*Notes*
Outside edge			
Mountain pine	16.0	15.8	General heavy branching. Little difference in appearance.
Birch	13.9	14.9	Poor form; patchy crops in *A*; *B* definitely superior.
Austrian pine	18.2	17.4	Heavier branching in *B*.
Common alder	Failed	Failed	—
Lodgepole pine	21.2	19.5	Greater variation in heights in *B*, and heavier branching.
Inside edge			
Remarks:	Heather suppressed under conifers	Heather vigorous between groups.	

Note: Both treatments received basic slag, *A* at 2 oz. per plant and *B* at 1½ lb. per group. *A* requires more than twice as many plants as *B* for a given length of belt. With the dominant height method of assessment (p.27) this difference in numbers will tend to give a higher figure in *A*, which in fact occurs with 3 out of 4 species.

TABLE 65: DIRECT SOWING

Comparison of sown and planted crops and of manuring for sowings in Wykeham 7.P.29.

Crop and Manure per patch	*Losses, %, in 1st year‡*	*Additional Losses, %, to 12th year†*	*Total losses*	*Heights, Ft., at 12 years*
Sown:—				
Control	30	37	(67)	2.5
2 oz. basic slag	24	13	(37)	4.5
2 oz. Amm. sulphate	48	34	(82)	1.7
Slag+Amm. sulphate	37	19	(56)	4.3
Planted:—				
1+0 Seedlings	48	25	(73)	2.8
2+1 Transplants	33	4	(37)	6.3

Notes: ‡ In the case of sown crops, losses represent the numbers of blank patches.
† These losses are additional after re-sowing and beating up in 1930.

sowing may appear an attractive alternative to planting, and trials have been made periodically from the start of the heathland experiments.

The early trials were all at Teindland and Wykeham. A group of experiments at the former forest tested various forms of patch and mound preparation for pines and spruces, but the greater part failed in the absence of phosphate (Teindland 3–5.P.26 & 18–21.P.27). An exception was that Scots pine sown on mounds in Expt. 18.P.27 grew slowly until burnt in 1942; one-year seedlings used as a control for the sowing did little better.

The first manurial trial was at Wykeham, as part of an age-and-type experiment on Scots pine, sowing being compared directly with planting. Results given in Table 65 show the great importance of phosphate in direct sowing; after twelve years, sowings with slag were markedly superior to one-year seedlings, though inferior to 2+1 transplants. Within the next few years there were two failures with Scots pine, in the first case through poor germination (10.P.31), and in the second through smothering by rank grasses, *Holcus* sp. and *Agrostis* sp. (29.P.33). In the first of these trials, however, lodgepole pine was successfully sown, reaching almost three feet in seven years where treated with slag. At Staindale, Allerston, a sowing of Corsican pine on ploughed ground failed despite careful patch preparation and an application of basic slag (31.P.33).

The only other pre-war experiment was the establishment of birch by sowing at Teindland, where the seed was broadcast with basic slag on ploughed ground. The best germination occurred in the furrows; much of the seed remained dormant for a year before germinating. The major part of these sowings was burnt in 1942, but the birch persists in the replanted crop (Teindland 62 & 63.P.38). Thus, of some twelve trials, from 1926 to 1938, only two produced a crop with reasonable stocking, one of Scots pine and one of lodgepole pine, both at Wykeham.

After the development of the R.L.R. plough a new approach was made to the problem of establishment by direct sowing, since it was felt that the conditions at the sowing spot had been radically altered. A detailed account of these experiments has been given by Edwards, Zehetmayr and Jeffries (1959). The main series of experiments was carried out from 1947-51 at Broxa, with comparable tests from 1947-9 in the Black Isle, while some field-scale trials were made in East Scotland in 1951, using the technique worked out at Broxa.

The intensive trials were made with Scots pine and Sitka spruce and the findings were as follows:

(1) Nitrogen and phosphate were beneficial to growth and survival, but potash was of doubtful value.

(2) Flash, a waste plastic, proved a better form of nitrogen than hoof-and-horn or nitro-chalk. Hoof and horn caused the death of the germinating seedlings, particularly in seasons when the germinating period was dry, as in 1949.

(3) The preparation of sowing patches in the furrow bottom, and the working up of a tilth on the patch, both increased germination.

(4) Quartzite grit cover to the patches increased the germination of Sitka spruce in a dry season, but not in a wet one.

While the same conclusions were true both at Broxa and in the Black Isle (Millbuie and Kilcoy Forests) the actual rate of growth was very different, for at Broxa both species were successfully established in several seasons, whereas in the Black Isle Sitka spruce checked and slowly died off, while the growth of Scots pine was extremely poor. For this reason the Black Isle trials were abandoned after three years; the Scots pine will in two cases form a ragged crop (Millbuie 7.P.47, 9.P.48 and Kilcoy 1.P.49).

In contrast the trials at Broxa continued for five years and were in general successful; Table 66 gives a selection of results from the more detailed experiments to illustrate most of the conclusions outlined above. The results in the intervening year, 1948, were similar as far as the benefit from nitrogen and phosphate are concerned, but the effects of tilth and grit cover were not significant and it appears that the beneficial effect might only appear in a dry season as in 1949. Table 67 lists the results, over the five years, from the treatment which most nearly approached the optimum, deduced from the intensive trials, together with results from the planting of one-year seedlings of Sitka spruce, which proved a more reliable method.

The trials at Broxa were extended to other species after the early successes, and semi-field-scale trials of up to one acre were sown in 1949-51. Lodgepole pine was sown successfully in 1949 and 1950, and Japanese larch in 1950, the stocking being 65–70 per cent, but the stocking of larch from the 1949 sowing was only 40 per cent; both species failed in 1951, when there was vole damage. In the successful sowings the lodgepole pine averaged three feet and the Japanese larch six feet, both after six years. Further species, Norway spruce, Douglas fir, and western hemlock were tried in 1949, but the stocking that resulted was very low. The complete failure of four species in the last year, 1951, was regrettably not followed up by a further trial; but by then it had become clear that sowing could be considered even remotely feasible only at Allerston; especially in view of the poor results from the extensive trials in East Scotland carried out in 1951. In that year three species were sown at four sites. (Speymouth, Moray; Monaughty, Moray; Clashindarroch, Aberdeenshire; and Fetteresso, Kincardine-shire), using the optimum treatment as developed at Broxa. After four years, stocking averaged only 50 per cent for the pines—Scots, and lodgepole, with Corsican pine in one case. The best growth was obtained with lodgepole pine, but it was much poorer than at Broxa. Japanese larch was equally poor in these trials.

Thus it is that the sowing trials were dropped. Though considerable successes were obtained with

TABLE 66: DIRECT SOWING

Selected results after 6 years from the 1947-51 series of sowing experiments with Scots pine and Sitka spruce at Broxa.

Heights in feet: stocking per cent.

29.P.47	*Scots pine*		*Sitka spruce*		*Dosage per sowing patch*
	Stocking	*Height*	*Stocking*	*Height*	
Control	79	1.2	14	0.8	
P	98	3.5	94	3.9	P = 0.6 oz. ground mineral phosphate
PK	99	3.5	80	3.5	K = 0.15 oz. muriate of potash
NPK	95	4.1	64	4.1	N = 0.75 oz. hoof and horn
1 lb. compost	100	3.8	95	4.2	
Standard Error	—	±0.11**	—	±0.23**	
Diff. for sign. 5%		0.31		0.65	
1%		0.42		0.87	
55.P.49	*Phosphate to all treatments*				
N as Hoof and horn	56	2.6	50	3.1	Hoof and horn at 0.75 oz. and Flash at 0.4 oz. to give equal dosage of N.
N as Flash	79**	2.7	73**	3.1	
Control	72	2.8	61	3.0	This experiment was factorial in design, and results are averaged over all other treatments.
K	64	2.6	62	3.2	
Control	59	2.2	48	2.8	
Tilth on patch	76**	3.1**	75**	3.4**	
Control	70	2.7	58	2.9	
Grit cover....	70	2.6	68*	3.2	

Note: These two experiments which gave the largest number of significant results in the series were sown in the unusually good summers of 1947 and 1949.
*=Significant at 5% level. **=Significant at 1% level.

TABLE 67: DIRECT SOWING

Results six years after sowing in the 1947-51 series at Broxa, taken from the treatment most closely approximating to the optimum deduced from the experiments. Results from planting experiments using one year seedlings are given for comparison.

The Optimum prescription is considered to be:
N = 0.4 oz. Flash (waste plastic).
P = 0.6 oz. ground mineral phosphate.
Tilth worked up on sowing spots.
Grit cover for Sitka spruce patches only.

Height in feet; stocking and survival per cent.

Experiment	*Differences from prescription*	*Scots pine*		*Sitka spruce*		*Planted as one year Seedling Sitka spruce‡*	
		Stocking	*Height*	*Stocking*	*Height*	*Survival*	*Height*
29.P.47	No cover; N=hoof and horn	100%	4.0	71%	3.8	—	—
30.P.48	N=hoof and horn; Potash also applied	100%	3.7†	97%	4.0†	92%	4.7
55.P.49	—	86%	3.1	75%	3.2	84%	4.3
74.P.50	Potash also applied	Failed to germinate ø		73%	3.8	100%	4.5
82.P.51	—	Complete failure of both species believed due to voles (*Microtus* spp.)				—	—

Notes: † These results were obtained after seven years.
ø Comparable results with lodgepole pine were 63% – 3.8 ft.; poor quality seed was thought to be the cause of the failure of the Scots pine.
‡ Furrow side position from "position of planting" experiments nearby, with 1 oz. of ground mineral phosphate.

the more usual species at Broxa, it is clear that the main deterrent to direct sowing is the variation in results in different seasons, these fluctuations being more pronounced than in sowing in the nursery. The increased use of one-year seedling stock for lining out, and even for planting, is another reason why sowing was dropped. The semi-field scale trials at Broxa were costed and showed that the sowing technique evolved would be more expensive than the use of cheap planting stock.

BLACK GAME DAMAGE

The main damage to the heath plantations, apart from fire, has been caused by the attacks of black game or black grouse (*Lyrurus tetrix*) sometimes coupled with capercailzie (*Tetrao urogallus*). These birds feed on the buds and young shoots of pines, and are particularly injurious to young plantations, where the removal of leaders for several years in succession may seriously prejudice the form, if not the survival, of the trees. The early years of the planting on heaths by the Forestry Commission coincided with one of the periodic increases of the population of black game, and attacks in certain forests were severe. In some of the experimental areas height assessments of the pines were suspended about 1930, since the removal of shoots had 'ironed out' any height differences which might have resulted from the various treatments.

An attempt was made to assess the amount of the damage being caused, by protecting parts of two experiments with wire cages, including overhead cover. Three years after caging at Teindland, the death rate was four per cent in the cage, as against twelve per cent outside, while the percentages of damaged leaders were five and thirty respectively (Teindland 17.P.27). This cage was low and was soon dismantled, but a taller cage at Hamsterley was maintained for eight years 1930-1938. At the end of this period Scots pine in the cage, which had received slag, were three times the size of the controls outside, which had made little effective height growth, even where slagged. Results with Corsican and lodgepole pine were less striking, but there was still a marked improvement inside the cage (Hamsterley 7.P.30).

With the fall in the numbers of black game from about 1935, this matter ceased to be of importance, but there is no doubt that the retardation of the early growth in some forests was serious, a considerable amount of additional beating-up was required, while the crops are today still of poor form in the butt-length, over twenty years after the severe attacks ceased.

SUMMARY

This bulletin has attempted to describe the methods used for the afforestation of a particular land type which provides an important proportion of the present afforestation programme in Great Britain. In addition the experimental data built up over thirty years have been summarised, and related both to the various papers which have from time to time appeared covering limited aspects of this subject, and to the major investigations made by Dimbleby (1952-1958) and Yeatman (1955).

The upland heaths have been defined as a section of the Callunetum of Western Europe, limited to upland areas over 500 feet (150 metres) in altitude, and generally eastern in Britain; the forests described all lie in north-east England and the eastern half of Scotland. On the predominantly gentle slopes and compacted siliceous soils of these regions, shallow podsols have arisen, typified by two more or less impermeable layers, a thin surface peat and an iron pan, which lead to waterlogging and anaerobic soil conditions. This degraded condition has resulted mainly from human action in destroying forests by felling and burning and from uncontrolled grazing which promoted the dominance of heather, *Calluna vulgaris*. On the least fertile areas even this undershrub exists only in a depauperated form.

Periodically in the recent past, parts of the upland heaths have been planted, but considerable areas of these plantations, almost exclusively of the native Scots pine, *Pinus sylvestris*, have been of low production, while on the poorest ground a satisfactory crop was not obtained.

A renewed attempt was made to afforest these heaths by the newly constituted Forestry Commission, starting about 1920. Within a few years the difficulties were apparent and a large research programme was begun, which ran concurrently with the extension of afforestation on to poorer land. A brief descriptive note is given of the majority of the heathland forests and the research work is then considered by subjects. The successive stages in the research projects are related to the technique in general use, which has developed rapidly over the thirty years. The interlocking of research work and general practice has been a marked feature on the heaths, so that a description of either separately would be inadequate. The results are briefly summarised below.

Mechanical Cultivation

The importance of cultivation on the heaths has been evident from the start, for old plantations bore witness to its beneficial effects. The main task has been to obtain machines capable of withstanding the very rough usage to which they are subjected on the wet, compact and stony soils, and to determine the most economical method of employing them. Thus it is that, while it has been shown that every increase in soil disturbance by increased coverage, depth and repetition, increases growth, the economic method chosen is much less intensive than that adopted in Continental Europe.

The method employed in practice is of a single cultivation made by a heavy plough for each line of plants. Disturbance of the surface peat to promote its aeration and breakdown is the vital factor in this cultivation. Breaking of the pan is of great importance where it is near the surface, as in the typical iron or peaty podsols. While deep single-mouldboard ploughs have been used more widely than any other type, they have been largely replaced since 1950 by a plough with a shallower-going mouldboard mounted on a deep-subsoiling tine. Both types penetrate to a depth of 12 to 15 inches (30 to 40 cm.).

Ploughing of these types solved the problem of establishment for pines and larches over a wide range of heaths. The increased growth may be attributed to improvements in aeration, drainage, nitrogen supply, freedom from competition, and in some cases early shelter. The relative importance of these factors has not been determined, nor have the long-term effects with any precision. But it is clear that on the poorest heaths ploughing has extended the area on which planting is economically possible; while on the moderately fertile areas early growth has been radically improved.

Planting Methods

Planting on ploughed ground presents little difficulty, and for the drier areas furrow-planting has been shown to be best, while on wetter areas, or where the rainfall exceeds thirty-five inches, planting on the side of the plough ridge is advisable.

There remains the problem of unploughable slopes; often these are more fertile and better drained, so that traditional hand methods using mattock

or spade are adequate. At the time of first planting, the heather on such areas is often short or can be burnt off. More difficulty arises when the heather is tall and vigorous, as may happen if the area is fenced well before planting, or if the first planting fails. Here no real solution has been found, and such problem areas exist in several heath forests.

Species

Scots pine, *Pinus sylvestris*, has always been the most important species, and would appear likely to remain so. The rapid early growth and the greater volume increment of Corsican pine on the more southerly upland heaths seemed at one time likely to lead to this species displacing Scots pine in these areas, but that is improbable today. In the early years, with the very poor Scots pine plantations standing on the heaths, it was natural to seek an alternative species. But the preparatory and manurial treatments, tried out simultaneously, have greatly improved the growth of the Scots pine itself. Natural conservatism, which justifies the use of a native species of known value as a timber producer, as against planting exotics of apparently higher production, is reinforced by the dying-back of Corsican pine, as also by the evidence now advanced that the production of Japanese larch may in fact be lower over the rotation than that of Scots pine.

Lodgepole pine, *Pinus contorta*, has an increasingly important place as the pioneer species on sites too poor, too high, or too exposed for Scots pine. While often regarded as a nurse for Scots pine or Sitka spruce on appropriate ground types, it is now being employed as a productive species in its own right. No other species can approach its tolerance of extreme heath sites, although it is not as resistant to exposure as is Sitka spruce on sites suitable for that species. On the poorer heaths the production of lodgepole pine is considerably greater than that of Scots pine. The provenance of this species is an important factor.

Corsican pine, *Pinus nigra* var. *calabrica*. Until the existing plantations in north-east England have shown that they can survive or escape dieback, the use of Corsican pine will remain at the present low level. Its production is very comparable to lodgepole pine, for though height growth is slower, diameter growth is much greater. The handling of Corsican pine planting stock was the subject of several experiments, owing to heavy losses after planting; the use of 1+1 transplants from local heathland nurseries proved most successful.

European larch, *Larix decidua* is only of importance as the main species on the more fertile heath sites, often on slopes where a hard pan has not developed. The losses due to dieback of this species have led to caution in its use, and today it is planted mainly in mixture with pine, often in a low proportion as an "enrichment" species; almost all planting is now from carefully selected seed sources.

Japanese larch, *Larix leptolepis* has great value for firebreaks owing to its rapid early growth, and has been shown to be unrivalled among the conifers as a nurse to more exacting species; nevertheless its future position on the heaths is not clear. It is valuable on steep unploughable ground unsuitable for European larch, yet not poor enough for lodgepole pine, but is not widely used as the main crop. Japanese larch has proved most responsive to increased cultivation and manuring.

Sitka spruce, *Picea sitchensis*. The extensive experimental work with this species has led to its widespread use in mixture with Scots pine, and to a lesser extent with lodgepole pine or with Japanese larch. The contrast between experimental results and those obtained in general practice is often large, and indicates its sensitivity to conditions at planting. It would appear wise to confine its use to the wetter heaths with rainfalls approaching forty inches, where it is particularly useful at high altitudes; and also to topographically wet areas on those heaths with lower rainfall. Large areas of heath now carry young pine/spruce mixtures, and until their success is demonstrated it would be unwise to "overplant" this species on the heaths.

Mountain pine, *Pinus mugo*, has a special role in forming a wind-firm edge to plantations, but is not a timber-producing species nor as good a nurse crop as Japanese larch.

Other Conifers. Small-scale trials of fifty other species have been summarised, and from them several species may be selected as likely to play a part in the heath forests in later rotations, though few are now used in afforestation. The most successful examples of these species have been obtained with nurse crops of other conifers or of broom (*Sarothamnus scoparius*) following intensive ground preparation and manuring. Western hemlock, *Tsuga heterophylla*, is the outstanding success in these trials, and is of particular value for underplanting and filling gaps. Should its subsequent growth and timber prove satisfactory it could be widely used in later rotations. *Abies grandis*, Lawson cypress (*Chamaecyparis lawsoniana*), *Picea omorika*, Douglas fir (*Pseudotsuga taxifolia*) and *Thuja plicata* have all grown on more fertile areas. The place of Norway spruce (*Picea abies*) is more difficult to decide, as it suffers most severely from competition in the presence of heather; with the establishment of forest conditions it may be used far more widely.

Broadleaved Trees are unlikely to be used for timber production at all on typical upland heath, but are important for the maintenance of the fertility of the soil. Planting has proved difficult, and few effective crops of any species exist, apart from recent trials less than ten years old. Although there have been many failures with these species also, grey alder (*Alnus incana*) and Oregon alder (*A. rubra*), and the two birches, *Betula pubescens* and *B. pendula*, have survived and grown sufficiently well to appear effective in local soil improvement. A most important problem of the future is to determine whether and to what extent such species should be used, and how they should be introduced. A proportion of birch is likely to appear in any regeneration method which opens the canopy, but clearly more knowledge on the handling of these species would be valuable, and the results of recent experiments and forest-scale plantings will be important.

Manuring

On the poorest heaths, typified by stunted *Calluna* and frequent *Trichophorum*, the value of small doses of phosphate at planting has been clearly demonstrated, and there is no doubt that production over the rotation will be increased owing to the faster early growth. The practice on such sites is to spread 1½ to 2 ounces of ground mineral phosphate around the planting position of each tree. (With spacings of 4½ × 4½ feet, this is 200–270 lb. per acre, equivalent to 60–90 lb. P_2O_5, per acre, or 70–100 Kilograms P_2O_5 per Hectare).

On more fertile heaths, such as those in Yorkshire, the results are less marked, and though widely tested in experiments, phosphate is rarely employed there in practice. When phosphate is used it is for some special short-term purpose, such as to obtain rapid early growth in a Japanese larch fire belt, or to help spruce in a pine mixture. It might also be used to compensate for low standards of ground preparation or poor quality plants.

Many attempts have been made on the heaths to use phosphate top dressings to stimulate checked plants, notably spruce, in the manner which has proved so successful on peat areas. Under the conditions where check develops, nitrogen has been shown to be the limiting factor, whereas at the time of planting, when phosphate is effective, nitrogen is made available by the decay of the surface peat after cultivation. Application of nitrogen at planting time has given short-term improvements in growth, but not equal to those obtained with phosphate.

Nursing and Mixtures

The majority of the mixed plantings include Scots pine. Admixture may serve one of two objects, either to increase early returns by the use of fast-growing species such as Japanese larch or lodgepole pine, or to increase the volume of the final crop by use of spruce, in which latter case Scots pine is used as a nurse. An adequate standard of ground preparation proved essential, and the earliest successful mixtures with spruce were obtained only by intensive measures such as recultivation, the use of broom as a nurse, and early removal of pine. Later Japanese larch was shown to be a more successful nurse for spruce.

Band mixtures of two, or more recently three, lines of "nurse" and "nursed species" set out alternately, appear to be the most successful arrangement, because concentration of the nurses leads to earlier suppression of the heather.

Differential manuring, with application of phosphate to the slower species only, has been shown to be a useful aid to evening-up the early growth. It is expected that these mixtures will prove easier to maintain and control than did the earlier intimate mixtures. On the other hand, where the second species grows faster than the main one, as with larch in a pine crop, the former may be planted singly or in small groups.

Another mixture used on some scale is that of lodgepole pine and Sitka spruce, though examples of successful balancing are rare; usually one species outgrows the other, the results varying from site to site.

The Checked State

This phenomenon of very slow growth and yellowing of foliage occurs with all species, but is particularly common with spruce and is due to heather competition. Experience has shown that it is far simpler to avoid check than to relieve it. Mulching with cut heather or branches has proved the most effective method of relief for a number of species, but can only be economic in special circumstances, i.e. for limited areas with material readily available. Interploughing and replanting with a nurse species, has been successful, but phosphate top dressings have been singularly ineffective when applied to plantations that have already checked, while the effect of nitrogen application is lost within a few years.

Trial Plantations

A number of pilot blocks have been established to indicate the long-term prospects for afforestation on particular sites in conditions of high altitude, severe exposure, or difficult soil conditions.

Other Experiments

These include a series on the use of "spaced groups" as an alternative to uniform planting; the use of advance crops for soil amelioration; the layout of shelterbelts; and a series on direct sowing which proved feasible only on certain Yorkshire heaths; none of these projects has yet led to work on a practical forest scale.

The Future

Many heathland forests have been successfully established. Over large areas it would have been only too easy to produce a mono-culture of Scots pine, and great efforts have been made to vary the crop within the limited range of species available.

Management is likely to be relatively simple. The large areas of non-heath ground showing more rapid growth than that on the heath sections, which occur in most individual forests, will aid the movement away from relatively narrow distribution of age-classes towards a more normal age-class structure.

Roading and extraction do not present the problems found in the west of Britain. Windblow is likely to be a disturbing factor on the more shallow heath soils, though by their youth and low stature all the plantations formed so far virtually escaped the devastating gale of January, 1953. Damage by *Fomes* and insects have been negligible up to the present time, but may become more important, particularly in the driest areas.

The first steps towards improvement of soil structure and fertility have been taken with the initial cultivation. The major silvicultural problem is likely to be the continuation of this improvement. Possible lines of approach are further cultivation, manuring and the use of soil-improving species, particularly broad-leaved trees. The correct application and balancing of these techniques is the crucial point on which will depend the continuity of the heathland forests. Clearly the next stages in silvicultural research must relate to the determination of the most suitable silvicultural system and methods of regeneration.

ACKNOWLEDGEMENTS

The author was fortunate enough to be given the task of writing up over thirty-five years' work on the heaths with an abundance of experimental data such as has perhaps never before been available to a forester. The difficulty has been to reduce it to manageable proportions. The number of officers of the Forestry Commission who have contributed to the laying out and management of the heath experiments is considerable and in addition many officers in charge of heath forests have contributed to advancing the level of knowledge and techniques. Among the latter it would be invidious to select individuals but mention should be made of the great personal interest always taken in this project by the late Lord Robinson, first as Technical Commissioner and later as Chairman, and in particular of his furtherance of the use of ploughing and of pine spruce mixtures, and of Mr. W. H. Guillebaud as Chief Research Officer during the formative years 1925-1947.

The officers directly in charge of the heath experiments have been 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 1932-47. From 1947 until 1951 all the upland heath areas came under Mr. J. A. B. Macdonald, and since then under Mr. M. V. Edwards, the present work being undertaken during this period.

The author is indebted to Head Foresters J. Farquhar and A. Macdonald who have each been in charge of experimental areas in Scotland for many years, while in England Head Forester J. Weatherell has a remarkable record, having been actively engaged in heath afforestation research at Allerston since 1933. These officers have contributed much data and together with Mr. Edwards have read and criticised much of the proofs.

In addition many foresters in Britain and in the heath forests in north-west Europe have shown the author their plantations and contributed records or forest histories. In particular Mr. B. Steenstrup, head of the Forestry Section of the Danish Heath Society has read over the draft of Chapter 2. In spite of much assistance the views expressed must remain those of the author.

BIBLIOGRAPHY

Anderson, M. L., 1951. Spaced group-planting and irregularity of stand structure. *Emp. For. Rev.* 30, pp. 328-341.

Anderson, M. L., 1953. Spaced group planting. *Unasylva* VIII, pp. 55-63.

Benzian, Blanche, 1955. Nutrition problems in forest nurseries. *Rep. For. Res.* 1954, pp. 47-48.

Bilham, E. G., 1938. *The Climate of the British Isles.* London.

Bradley, J., 1872. On planting exposed and barren moorland resting on moorland pan. *Trans. of the Highland and Agric. Soc. of Scot.* 4th Series, Vol. 4, p. 92. Reprinted *Journ. of For. Com.* 21, pp. 57-63, 1950.

Crowther, E. M., 1951. Nutrition problems in forest nurseries. *Report on Forest Research for the year ending: March* 1950 pp. 104-5.

Crowther, E. M., & Benzian, B., 1952. *March* 1951 pp. 121-2.

Crowther, E. M., & Benzian, B., 1953. *March* 1952 pp. 103-4.

Crowther, E. M., & Benzian, B., 1954. *March* 1953 pp. 97-8.

Day, W. R., 1945. Causes of dying back of corsican pine with special reference to frost injury. *Forestry* XIX, pp. 4-26.

Dickson, J. D., 1951. *History of the Black Isle Forests.* Unpublished Paper, Forestry Commission.

Dimbleby, G. W., 1952a. Historical status of moorland in north-east Yorkshire. *New Phyt.* 51, pp. 349-54.

Dimbleby, G. W., 1952b. Pleistocene ice-wedges in north-east Yorkshire. *Journ. Soil Science* 3, pp. 1-19.

Dimbleby, G. W., 1952c. Soil regeneration on the north-east Yorkshire moors. *Journ. of Ecol.* 40, pp. 331-342.

Dimbleby, G. W., 1953. Natural regeneration of pine and birch on the heather moors of north-east Yorkshire. *Forestry* XXVI, pp. 41-52.

Dimbleby, G. W., 1954. The origin of heathland podsols and their conversion by afforestation. *Reports and Communications of the 8th International Congress of Botany. Paris.* Section 13, pp. 74-80.

Dimbleby, G. W., 1958. *Experiments with hardwoods on heathland.* I.F.I. Paper No. 33. Oxford.

Edwards, M. V., 1953. Provenance studies: Scots pine. *Rep. For. Res.* 1952, pp. 53-56.

Edwards, M. V., 1954. Scottish studies of the provenance of European larch. *I.U.F.R.O., 11th Congress, Rome;* pp. 432-7.

Edwards, M. V., 1954-5. A summary of information on Pinus contorta. *For. Abs.* 15 (4), pp. 389-96, and 16 (1), pp. 3-13.

Edwards, M. V., 1956. The hybrid larch, Larix x eurolepis Henry. *Forestry* XXIX, pp. 29-43.

Edwards, M. V., 1959. Use of triple superphosphate for forest manuring. *Report on Forest Research for the year ending March* 1958.

Edwards, M. V., Zehetmayr, J. W. L., and Jeffrey, W. W. 1959. *Direct Sowing Experiments in Scotland and Northern England.* Forestry Commission Research Branch Paper No. 22. (Departmental).

Fabricius, L., 1938. Bodendeckung mit Pflanzenstoffen. *Forstwissenschaftliches Centralblatt*, LX (1). Reviewed by W. H. Guillebaud, *Forestry* XII, pp. 53-56.

Faegri, K., 1952. Bedømmelse av Lyngmark for granplanting. (Evaluation of heathland sites for spruce planting).*Tidskrift for Skogbruk*, 4-5, p. 99.

Flensborg, C. E., 1939. *The Danish Heath Society.*

Forrester, S., 1951. *History of Hamsterley Forest.* Unpublished paper, Forestry Commission.

Fraser, A. M., 1951. *History of Culloden Forest.* Unpublished paper, Forestry Commission.

Galoux, A., 1954. *La fertilisation minerale en sylviculture.* Station de recherches, Groenendaal, Belgium. Paper B.16, pp. 62.

Guillebaud, W. H., & Steven, H. M., 1930. *Report on ploughing trial at Allerston Forest.* Unpublished paper, Forestry Commission.

Guillebaud, W. H., 1938. The afforestation of difficult peat and upland heath soils. *Forestry* XII, pp. 80-93.

Hummel, F. C., & Christie, J., 1953. *Revised yield tables for conifers in Great Britain.* Forest Record No. 24, Forestry Commission, London.

Jacks, G. V., 1932. A study of some Yorkshire moorland soils. *Forestry* VI, pp. 27-39.

Juttner, O., 1954. 70 *Jahre Heideaufforstung.* (70 years of heath afforestation). Bremen. Horn.

Leyton, L., 1954. *The growth and mineral nutrition of spruce and pine in heathland plantations.* I.F.I. Paper No. 31. Oxford.

Leyton, L., 1955a. The influence of artificial shading of the ground vegetation on the nutrition and growth of Sitka spruce in a heathland plantation. *Forestry* XXVIII, pp. 1-6.

Leyton, L., 1955b. The influence of heather mulching on the growth and nutrient status of Lawson cypress. *Forestry* XXVIII, pp. 147-151.

Leyton, L., 1957. Personal communication.

Leyton, L., and Weatherell, J., 1959. Coniferous litter amendments and the growth of Sitka spruce. *Forestry* XXXII, pp. 7-13.

Macdonald, J. A. B., & Macdonald, A, 1952. The effect of inter-planting with pine on the emergence of Sitka spruce from check on heather land. *Scottish Forestry* 6, pp. 77-79.

McEwan, John, 1930. Planting tools and Methods. *Forestry* IV, pp 15-25.

Maxwell, H. A., 1951. *History of Drumtochty Forest. History of Fetteresso Forest.* Unpublished papers, Forestry Commission.

Muir, A., 1934. The soils of Teindland State Forest. *Forestry* VIII, pp. 25-55.

Muir, A., & Fraser, G. K., 1940. The soils and vegetation of the Bin and Clashindarroch Forests. *Trans. Roy. Soc. Edin.* LX, pp. 233-333.

Redmond, J., 1950. *Abies procera* in Northern Ireland. *Scottish Forestry* IV, pp. 87-93.

Rennie, P. J., 1950 & 1953. Research into the physical and chemical properties of forest soils. *Reports on Forest Research for the years ending:—*
March 1949, pp. 71-75.
March 1952, pp. 108-116.

Rennie, P. J., 1951. *Physical and chemical properties of forest soils with special reference to Allerston (and Langdale) Forest.* Unpublished report, Department of Forestry, Oxford.

Robinson, R. L., Garthwaite, P. J., *et al.* 1950. *History of Allerston (and Langdale) Forest.* Unpublished paper, Forestry Commission.

Sanzen-Baker, R. G., 1939. Report on an excursion to Allerston Forest. *Forestry* XIII, pp. 148-154.

Tansley, A. G., 1939. *The British Islands and their vegetation.* University Press, Cambridge.

Weatherell, J., 1953. The checking of forest trees by heather. *Forestry* XXVI, pp. 37-41.

Weatherell, J., 1957. The use of nurse species in the afforestation of upland heaths. *Quart. J. For.* LI, pp. 298-304.

Woolridge, T. H., *et al.* 1951. *History of Clashindarroch Forest.* Unpublished paper, Forestry Commission.

Yeatman, C. W., 1955. *Tree root development on upland heaths.* Forestry Commission Bulletin No. 21.

Zehetmayr, J. W. L., 1954. *Experiments in tree planting on peat.* Forestry Commission Bulletin No. 22.

Printed in England under the authority of HER MAJESTY'S STATIONERY OFFICE
by Joseph Wones Limited, West Bromwich

(4669) Wt.2760/2583 K20 5/59 Gp.356

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
York House, Kingsway, London w.c.2
423 Oxford Street, London w.1
13A Castle Street, Edinburgh 2
109 St. Mary Street, Cardiff
39 King Street, Manchester 2
50 Fairfax Street, Bristol 1
2 Edmund Street, Birmingham 3
80 Chichester Street, Belfast 1
or through any bookseller