FORESTRY COMMISSION

REPORT ON
FOREST RESEARCH
FOR THE YEAR ENDED
MARCH, 1960

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1961

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INTRODUCTION

By JAMES MACDONALD

Deputy Director General

The new building at Alice Holt was completed during the year and its coming into service was marked by a visit from the Forestry Commissioners on April 16th 1959. On the 16th of July, the Commission held an Open Day at the station, at which about 150 guests were present. On the previous day there was a visit by representatives of the Press. The various sections of the Research Branch, stationed at Alice Holt, have settled down in their new quarters.

There was a sharp increase in the number of visitors to Alice Holt during the year, 485 attending as against 316 the year before. Among those who called, there were visitors from Australia, Belgium, Canada, Cyprus, Denmark, France, Germany, India, Ireland, Malaya, the Netherlands, New Zealand, Nigeria, Norway, Nyasaland, Pakistan, Poland, Portugal, Sarawak, Swaziland, Sweden, Uganda, West Indies, United States and Yugoslavia. Students from the Imperial Forestry Institute, Oxford and from the universities of Aberdeen, Edinburgh and Wales again visited the Research Station.

Students from Oxford, Aberdeen and Bangor also visited experimental areas in different parts of the country, while the Edinburgh students continued to make use of the Bush Nursery on the outskirts of that city. Experimental areas were also visited by members of the Society of Foresters of Great Britain, representatives of the Highland Panel, and members of the British Association. Visits were also paid by County Planning Officers from Lancashire and by a party from the Manchester Parks Department. In addition, special visits were arranged for parties of school children and for a number of overseas visitors.

During the year, Mr. T. R. Peace took up duty as Chief Research Officer in place of Professor M. V. Laurie. Mr. J. R. Aaron of the Utilisation Development Section was transferred to the South Conservancy in Scotland and was replaced by Mr. H. G. M. Dowden. Dr. R. G. Pawsey was appointed to the Pathology section and Mr. J. Atterson and Mr. A. I. Fraser joined the Silvicultural sections, the former in Scotland and the latter at Alice Holt. Dr. F. C. Hummel returned from his assignment with F.A.O. in Rome, after an absence of nine months.

The Director visited Poland in July 1959 where he presided over a meeting of the Permanent Committee of the International Union of Forest Research Organisations and also visited various research stations in that country. Mr. J. D. Matthews attended the ninth International Botanical Congress at Montreal in August 1959, Mr. G. D. Holmes the Congress of the International Seed Testing Association at Oslo in July and Mr. J. Jobling the International Poplar Commission at Rome in October 1959. Mr. R. F. Wood was present at a Symposium on Hydrology at Hann-Münden in Germany in July 1959 and Mr. M. V. Edwards attended a meeting to discuss international co-operation in provenance studies in the same town in October. Dr. M. Crooke paid a visit to Denmark in June 1959 to study the dangerous bark beetle, *Dendroctonus micans*, while Mr. A. F. Mitchell studied problems of tree breeding during a short visit to Ireland in November 1959. Mr. E. G. Richards attended the tenth session of the European Forestry Commission of F.A.O. held in Rome in July 1959. He also visited Paris and Oslo in connection with the work of the Joint F.A.O./E.C.E. Committee on Forest Working Techniques and the training of Forest Workers and he was present at a meeting at Geneva in April 1959 of an E.C.E. Study Group on the Utilisation of small-sized roundwood and fuel wood. Various members of the research staff lectured at courses conducted by the Commission at Northerwood House in the New Forest and at the short courses for woodmen held at Chatsworth in Derbyshire.

The programme of research into the properties of home-grown timber has continued in close co-operation with the Forest Products Research Laboratory at Princes Risborough and substantial progress has been made. Close liaison has been maintained with the Imperial Forestry Institute, Oxford in a number of projects, with Rothamsted Experimental Station and with the Macaulay Institute for Soil Research at Aberdeen. Thanks are due to the Directors of these Institutions for the help which they have given.

With the help of the Fire Service Research and Training Trust a programme of research into the spread of fire in fuels of various types and into the threshold conditions of ignition in forests, has been undertaken for the Commission by the Joint Fire Research Organisation at Boreham Wood in Hertfordshire. This is a new departure and it is hoped that it will lead to a better understanding of forest fire hazards.

The Advisory Committee on Forest Research held a meeting in September 1959 at Alice Holt when members were able to inspect the new building and see some of the activities of the various sections. No meeting of the sub-Committee on Nursery Nutrition was held during the year.

The following Committees each held two meetings during the year: the Mechanical Development Committee, the Advisory Committee on the Utilisation of Home Grown Timber, the Advisory Committee on Westonbirt Arboretum, and the Committee of Management of the National Pinetum at Bedgebury.

SUMMARY OF THE YEAR'S WORK

By T. R. PEACE
Chief Research Officer

There have been no major changes of emphasis in the work undertaken during the year, but elm now appears definitely together with poplar, forming a study of trees growing mainly outside the forest. It is gratifying that the number of reports on work undertaken for the Forestry Commission at universities and other institutions now totals fifteen.

Part III of this report has now become a regular means of publication for progress reports on continuous investigations and for papers on lesser projects or well defined and separable parts of larger projects.

The Season

The year will long be remembered for its hot, dry summer, which is being made the subject of special study. Numerous meteorological records were broken, but immediate impressions were that damage to trees was certainly much less noticeable than in 1947. Autumn windblow in east Scotland affected young pines only a few feet high. Large scale damage of this type is a new phenomenon, and merits further investigation, especially as it involves possibilities of effects due to planting on ploughed ground.

PART I

This part of the Report deals with current work carried out by the various sections of the Forestry Commission's Research Branch. Only the more important items of work are mentioned in this summary.

Forest Tree Seed Investigations

As in previous years, routine seed testing formed a large part of the seed laboratory's activities. Improvement and standardization of test methods continued to be a major subject of investigation.

A seed drier was installed during the year, and a drying procedure worked out.

Experiments on breaking the dormancy of seeds of *Crataegus monogyna* and *Sorbus intermedia* gave successful results.

The maintenance of quality of conifer seed in storage was found to be generally satisfactory, but *Abies*, which is the most " short-lived " genus, is being made the subject of a special series of trials.

The toluene-distillation method of estimating seed moisture content, which is considered superior for forest tree seeds, was introduced during the year.

Nursery Investigations Further work was carried out on partial sterilization of soil, using sistan in comparison with orthodox treatments. The results were not encouraging.

The effects of nitrogen applications on the time of formation of resting buds was observed for a number of species. There was not sufficient frost to give any information on the effect of delayed bud-formation on frost injury.

Experiments on dates of sowing were combined with irrigation at one nursery. Irrigation gave very favourable results, but it was of course, a dry year.

Further work was carried out on the date of sowing and pre-treatment of Silver fir seed. Early sowing and pre-chilling of the seed both gave improved yields. Various dates of sowing and methods of storage for acorns nearly all gave about the same yield.

An experimental Dunemann seedbed was maintained. The yield was, as usual, slightly higher than from conventional seedbeds, but the cost was greater.

The most promising new substance for weed control was simazine. It proved safe and satisfactory for post-emergence application to seedbeds, for transplant lines and in poplar stool beds.

Further work on plant storage in polythene bags again indicated the high tolerance of pines and spruces to this treatment, that larches survived well if they were planted out before they came into leaf, but that more work was required before Douglas fir, Western Hemlock and some other species could safely be handled in this way. Some success was achieved in the storage of seedlings of Douglas fir. Japanese larch and Sitka spruce at low temperatures; but mid-summer planting, which ensured a high survival, produced too much growth (the idea being to hold the plants in virtual check for a year), and autumn planting did not allow the plants to survive the winter.

Silvicultural Investigations in the Forest:

(A) South and Central England and Wales

AFFORESTATION PROBLEMS—New work in this field was restricted to a series of species plots on disused gravel and sand workings, but observations were continued on the large number of trial plantings of difficult sites established in earlier years.

REGENERATION PROBLEMS From now on, replacement of existing plantations will become more and more important, and it is clear that a number of problems will arise. These are now the subject of preliminary study.

FOREST STAND IMPROVEMENT—Emphasis has now shifted from manuring at the time of planting to the treatment of established crops. Experiments are still being laid down in checked plantations, and in some cases have yielded spectacular results. Recently, however, manuring on an experimental basis has been extended to plantations of reasonably good quality. So far no effects on growth have been observed, but nitrogen and calcium appear to have had a profound effect on litter decomposition and on the fungal development in the surface layers.

A number of experiments on mixtures have been laid down, and the possibility of extracting useful information from the study of existing mixed plantations is being studied.

Work on the rehabilitation of derelict woodlands is nearly at an end; it has been possible to draw a number of useful conclusions of rather limited application from the work already done.

WIND STABILITY—Reafforestation will undoubtedly bring in its train problems concerning windblow; the continued stability of conifers on some of the shallower-rooting soils is problematical; part of the losses due to the root fungus *Fomes annosus* arise from its effect on wind stability. For this reason work on wind and its effects has been considerably increased. Particular attention is being given to the possibility of measuring mechanically the forces necessary to uproot trees of different kinds under different conditions, and the forces actually exerted by the wind.

WEED CONTROL—New substances continue to come onto the market, so that testing of all types of weedkillers must continue. Continued progress can be recorded, however, both in the effectiveness and in the cheapness of the substances tried. Particularly noteworthy are new substances for the control of grass, and advances in stability, with greater persistence and less translocation from the surface layers, thus giving better chances of controlling shallow-rooted weeds among deeper-rooted crops.

FIRE CONTROL—Further work has been done on fire-retardant materials for fireproofing vegetation.

ARBORETA—The Research Branch continues to maintain and improve the arboreta at Westonbirt and Bedgebury. A note is appended on a putative hybrid between *Nothofagus procera* and *N. obliqua*, which arose from seed collected at Bedgebury.

THE HOT, DRY SUMMER OF 1959—The effect of this exceptional summer on trees was made the subject of a widespread questionnaire, which is now being analysed.

Silvicultural Investigations in the Forest:

(B) Scotland and North England

REPLANTING OF RECENTLY CLEARED AREAS—Two experiments have been established on ground where the crop was felled for the purpose. The object is to compare the behaviour, on two difficult sites, of a range of species established, either after ploughing or by direct notching in otherwise undisturbed ground.

AFFORESTATION PROBLEMS—It appears likely that potash, and possibly phosphorus, deficiencies may arise in pine and other plantings on peat, despite manurial treatment at the time of planting. These may involve further manurial applications.

Now that pines have been successfully established on deep peat, larger areas are to be planted with Lodgepole pine, so that crops of this type can be handled on a larger scale.

Further plantings are being made at high elevations. These are now mainly carried out by the Conservancies with Research Branch advice.

An experiment on the effect of shelter in a smoke-polluted area has been improved by the inclusion of a series of zinc-plate pollution recorders.

MIXTURES—A number of experiments which have been set up to study the behaviour of mixed crops as compared with pure, are described. New experiments include mixtures of Japanese larch with Lodgepole pine, and Scots pine with birch. Both include pure plots for comparison.

MANURING IN THE FOREST—Another pole-crop manuring experiment has been started in Scots pine. The Macaulay Institute has continued its work into the nutrient content of needles of conifers growing under different manurial conditions.

THINNING—The layout of the large scale thinning experiment in Sitka spruce at Loch Eck forest was completed. Several problems of plot size and uniformity were brought to light.

THE DETERIORATION OF POLE-STAGE SPRUCE CROPS—Deteriorating spruce crops, mainly those growing on shallow soils over heavy clay, are being regularly observed, in order to evaluate the different factors involved at each site.

Provenance Studies

A series of experiments comparing twenty-five provenances of Japanese larch suffered negligible losses, despite the dry summer. It is already possible to distinguish certain provenances as having a proportion of plants of poor stem form.

Early differences in height growth shown by twelve provenances of Sitka spruce are being maintained. Seven planting sites have been selected to give this collection a wide coverage over the range of Sitka spruce sites in Britain.

In a six-year-old experiment, Sitka spruce raised from Alaskan seed, have grown more slowly on three sites than those from Queen Charlotte Islands or from home-collected seeds.

Neomyzaphis attack on an older experiment on Sitka spruce did not show any provenance differences in degree of damage.

A collection of eighteen provenances of Western hemlock has been raised. Differences in growth rate, and time of formation of the terminal buds were noted, even in the first year of growth.

Attack by the needle-cast fungus, *Rhabdocline pseudotsugae*, was studied on Douglas fir provenance experiment. It was significantly worse on interior as compared with coastal provenances.

Failure of the Continental seed crop delayed the start of a proposed provenance experiment on European silver fir.

Poplars

Sixty-six varietal trial plots were laid down during the past season. Twenty one of these were to replace failed plots, and forty-five were planted on new ground. Planting took place at ten sites, six in England and four in Scotland. The varietal collection now contains 389 clones, a net increase of 16, and 248 clones have been planted in the Populetum. A number of short-term establishment experiments have been re-assessed, and all long-term experiments have been maintained. Studies on the use of chemical weed killers and artificial fertilisers in the nursery have continued. Large scale production of clones difficult to root from hardwood cuttings was commenced, using the 'mist' technique for rooting softwood cuttings. Over 31,000 cuttings of eight standard varieties were distributed during early spring 1960.

Elms

The field survey of elms was continued, and to date 32 clones have been selected for further study. These were propagated, using the mist technique, with an average of 57% successfully rooted. Success appeared to be tied to the quality of the cuttings rather than to individual clones. Rooted cuttings are now being used in elm disease inoculation trials in preference to grafted plants.

Forest Ecology

Mr. J. M. B. Brown gives an account of his large-scale investigation of Corsican pine, with particular reference to its failure on certain sites. Sufficient information has now been collected to define, with some degree of usefulness, the conditions under which this tree can be grown successfully, but these conditions are too complex for easy summarization.

It is suggested that insufficient attention has been paid to provenance in *Pinus nigra*; though the fragmentary evidence available gives little ground for supposing that a variety will be found suitable for planting much beyond the present known limits of successful growth of trees of Corsican origin.

Forest Soils

The soil laboratory in the new wing of the Research Station is now sufficiently equipped and staffed to undertake work on quite a large scale. A brief account is given in this report of the more important apparatus that has been installed.

Several long-term studies of the nutrient relations of forest crops and sites have been started. These include examination of Sitka spruce from a number of contrasting sites, and of needles from different parts of the same tree in a closed stand of the same species. The latter appeared to indicate that the relation of nutrient level and needle weight is little affected by the position of the needles on the tree, and that therefore, it should be possible to sample material from lower down the tree, instead of from the top whorl (the normal sampling source), when access to the latter proves difficult.

Some work has been carried out on the distribution of phosphorus in a phosphate manuring experiment on a highly deficient site at Wilsey Down.

Preliminary work has also been done on lime-induced chlorosis of beech and pine on calcareous soils. This has included the application of foliar nutrient sprays.

Forest Genetics

In the Genetics Section, work continued to develop along the lines of past years. The total number of plus and special trees of all species is now 2,939 and the pines, larches and Douglas fir account for two thirds of these. More spruces have been selected and the techniques of taking small wood samples from Sitka spruce have been studied. More than half of the plus and special trees, (1,771) have been propagated vegetatively, and over one third (1,229 clones) are now established in tree banks.

Propagation by grafting was continued at Alice Holt, Grizedale and Bush nurseries. 14,256 grafts were attempted and the overall success was 65 per cent. Attempts to root needle fascicles and to air-layer branches of Scots pine have failed, but the range of summerwood cuttings rooted in the "mist" propagation units was further enlarged to include *Betula verrucosa*, *B. jacquemontiana* and Sitka spruce. More attention can now be given to the grafting of the spruces and an extensive trial of grafting both Norway and Sitka spruce was begun at the three propagation centres.

A second larch seed orchard, that at Mabie Forest, Dumfries-shire, began flowering, and the inter- and intra-specific hybridisation programme in larch was further extended. Inter-provenance crosses were made in a Lodgepole pine provenance trial at Kirroughtree Forest, Kirkcudbrightshire.

The pattern of management of seed orchards, which is emerging after the first ten years, includes treatments to encourage fast early growth of the grafted plants, leading to early development of flowers; partial or complete diallel crosses followed by progeny tests to identify good parent clones; treatment of trees and ground to maintain good flowering and seed production; and protection against insect attack, especially the *Adelgids* attacking Scots pine, European larch and Douglas fir.

A mobile laboratory has proved useful for crossing work on isolated sites. An important item of technique is the statistical analysis of the growth of progenies, to enable estimates of combining ability, and of heritability, to be made for characters such as early height and diameter growth.

Forest Pathology

The Forest Pathology section continued to work on a large number of diseases. The hot, dry summer of 1959 introduced or accentuated a number of troubles, and appeared to render possible the parasitism of trees by fungi, such as *Phomopsis occulta*, which are normally regarded as saprophytic or only weakly parasitic.

The work on the Keithia disease caused by the fungus *Didymascella thujina* on *Thuja* has been increased, both as regards research on its biology and on its control. Among other nursery diseases *Meria laricis* on larch and *Botrytis cinerea* on a wide variety of conifers are receiving increased attention. Efforts are being made to find the meteorological factors which control infection by *Botrytis*.

Fomes annosus continues to provide the biggest project for the section and work includes research on the behaviour of the fungus on peat and old woodland soils, as well as on alternative materials to creosote for stump treatment.

Widespread investigation of Norway spruce stands has failed to indicate any general relationship between crown dieback and thinning. The occurrence of this trouble appears to be dependent on the presence of other special site factors.

Forest Entomology

The annual survey of the Pine looper moth, *Bupalus piniarius*, showed a fairly consistent population increase in Scottish forests and a decrease in English ones. Work in the Elveden study plot has been hampered by the very low population there. Work on the parasites of *Bupalus* has been confined to *Cratnichneumon nigritarius*, because other species were so rarely found. A fairly detailed account is given of work, which has thrown considerable light on the life history and behaviour of this parasite.

Work on *Anoplonyx destructor*, the commonest of the larch sawflies in Britain, has included the elaboration of sampling methods, a study of parasites, predators, diseases and other causes of loss, and a laboratory study of larval development. A large-scale experiment has been established to measure the effect of the defoliation on increment. A general, though incomplete, survey of this and other larch sawflies, showed little change in population levels.

Work on the pinhole borer, *Trypodendron lineatum*, continued in collaboration with the Forest Products Research Laboratory. Exposure of test logs indicated that the flight and attack period was longer in Argyll—the main area of attack in Britain—than on the Continent. A series of experiments has been laid down to test whether the creosoting of stumps, carried out as a preventative measure against the fungus *Fomes annosus*, attracts this borer.

Ips cembrae, a bark beetle which was accidentally imported into northeast Scotland, has spread slightly to the south.

Control of the Pine weevil, *Hylobius abietis*, by dipping plants in D.D.T. solution, resulted in damage and death to some lots of nursery stock. This may have been associated with the exceptionally hot, dry weather, but since numerous experiments had previously been conducted without any phytotoxic effects, the matter is being further investigated.

Management

This section now includes subsections on Economics (the subject of a separate report), Working Plans, Census and Mensuration.

Working Plans has concentrated during the year on setting up and training the necessary organisation. Surveys have, however, been completed in a number of forests.

Active Census work has drawn to a close pending the initiation of a sampling survey, probably in 1965.

Work in Mensuration has been restricted by lack of staff, but a start has been made on the provision of multiple yield tables. The large-scale thinning experiment in Lock Eck Forest, has now been laid down.

Forest Economics

A considerable number of projects were continued during the year, including studies on profitability and on roading. A good deal of time was devoted to smaller semi-advisory investigations. But the main bulk of this year's report is devoted to a consideration of the economics of hardwood production, the investigation of which included a sawmilling study. As a result of this study, it has proved possible to draw certain firm conclusions on the effect of log length and diameter on sawmilling costs.

Design and Analysis of Experiments

The design and analysis of experiments and surveys has continued to be the responsibility of the Statistics Section. The work of this Section has been very greatly strengthened by the transfer of all computing to electronic digital computers, mainly to a Pegasus computer at the Royal Aircraft Establishment at Farnborough. All types of statistical analysis can now be carried out quickly and economically, and the range and depth of the experimental work of the Research Branch has therefore been increased enormously.

Advisory work on the design and analysis of experiments and surveys has also been undertaken for Colonial Forest Departments and for other organisations and research stations interested in forest problems, particularly for the Forest Products Research Laboratory and the Tropical Products Laboratory. Work has also continued in co-operation with the Working Party of Section 25 of the International Union of Forest Research Organisations, and with the Advisory Group of Forest Statisticians of that Organisation. The handbook, prepared by the Statistics Section, on the application of methods of statistical analysis to forest problems, has also been published.

Machinery Research

An entirely new approach to the problem of cleaning forest drains has given promising results. A further development in the policy of using large wheels to increase vehicle performance across country has produced a very modified Land Rover capable of negotiating a wide variety of obstacles.

The peeling of bark from rough and bent hardwood logs has become an urgent problem and investigation is being made into the possibilities of mechanising this operation. A new test rig for power saws has been built at the Forest Products Research Laboratory. Experiments are in hand with a light monorail railway for extractions. Conversion on the line system has been developed, but it has been shown to need a large throughput to make it profitable. Nursery mechanisation has been confined to local developments to meet individual needs.

Utilization Development

Investigations into home-grown pitprops have continued and have shown the suitability of properly prepared and seasoned material.

An extensive sampling of 20 to 40 year-old conifers, to determine their specific gravity and moisture content, is under way.

Intensive work on the properties of home-grown timber, in collaboration with the Forest Products Research Laboratory, has commenced on Sitka spruce.

Using the experience already gained on the preparation of timber from small diameter logs, plans were made for the erection of another bungalow made from softwood thinnings.

The Library and Photographic Section

The Library and the Photographic sections continued to provide a very valuable general service, not merely to the Research Branch, but to the Forestry Commission as a whole. Particularly noticeable was the steady increase in the number of colour slides sent out on loan.

PART II

This part reports progress made by workers attached to universities and other institutions. Much of this work is aided by grants from the Forestry Commission.

Mycorrhiza

The experiments carried out during the year by Dr. Ida Levisohn at Bedford College, University of London, were mainly concerned with tests of various forms of a mycorrhizal fungus, *Boletus scaber*, as regards their influence on the growth of certain tree species, and with an assessment of the effects of gibberellins on fungal root infection in forest trees.

In order to investigate the specificity of three isolates of *Boletus scaber* of different ecological origin, inoculations with their mycelia were carried out in pot-cultures of birch seedlings. The results of these experiments showed unequal effects on the young plants in different growing media.

Researches with gibberellins were prompted by reports of undesirable interference of these substances in the nodulation of various leguminous crops. Application of *Gibberella fujikuroi* (the soil-borne fungus which produces gibberellic acid) and the 'pure' gibberellic acid, to three different soils, was observed to induce considerable changes in their water-holding capacity, in the development of the roots of the experimental seedlings (Scots pine) and in their mycorrhizal status. Inoculation into the soil of *Gibberella fujikuroi* brought about a reduction in mycorrhizal associations and an increase in certain harmful root-infections. Gibberellic acid application to the soil was responsible for the development of reduced root systems, uninfected, and equipped with root-hairs.

Studies in Soil Mycology

Dr. D. A. Griffiths, working with Dr. C. G. Dobbs, continued in the Department of Forestry at the University College of North Wales, Bangor, his work on mycostasis in soils. Monthly germination tests continued to show a seasonal rise in spore germination in winter, especially in the litter layers. Average percentage germination for the three soil layers during the three years up to March, 1960 were: litter 38; humus 10; mineral 9 (controls 95). The two sites with beech-oak mixture showed more germination than the conifer sites.

Correlation of spore germination level with the amount of reducing sugars in the soil samples was confirmed, and was shown to be highly significant; preliminary chromatographic analysis showed the presence of ribose, sorbose and galactose as well as an unidentified polysaccharide in water extracts of pine humus soil. Such polysaccharides have been found by other workers, and it seems probable that the winter rise in sugar content, which is accompanied by a parallel rise in spore germination, may be accounted for by the slow hydrolysis of these polysaccharides.

Satisfactory soil extracts of the inhibitor, not masked by sugars, can be made only during the summer months, and soon lose activity when exposed to the air. An effective method of making and storing such extracts under nitrogen, and testing on washed agar discs also incubated under nitrogen, has now been devised and is in use during the current season.

Forest Soils Research in Scotland

Dr. W. O. Binns, based on the Macaulay Institute for Soil Research, has carried out investigations at a number of forests.

At Culbin Forest, the height responses in Corsican pine to added phosphorus and nitrogen have been maintained, and a small response to added potassium has been observed for the first time.

At the Lon Mor, Inchnacardoch Forest, potassium deficiency has now been confirmed in 31-year-old Lodgepole pine, and measurement of girth increment in 30-year-old Sitka spruce has shown significant increases due to added potassium and nitrogen. A significant increase in height growth due to potassium applied to 12-year-old Lodgepole pine in 1957 has been observed for the first time. Foliage analysis of 14-year-old checked Sitka spruce has shown a severe nitrogen deficiency and a probable potassium deficiency; this is being tested by fertilizer trials.

A chemical survey of deep peat areas has been started, sampling both the natural vegetation and the top twelve inches of the peat. Results will be expressed both on a dry weight and a per acre basis, and it is hoped that this will enable fertility comparisons to be made between different peat types.

Soil Faunal Investigations

Mr. G. W. Heath is working at Rothamsted Experimental Station on the decomposition of beech and oak leaves under natural conditions. Mites living on fallen leaves are being cultured in the laboratory, and two types of apparatus to investigate their respiration are being developed.

Juvenility in Trees

Mr. L. W. Robinson, working under Dr. P. F. Wareing in the Department of Botany at the University College of Wales, Aberystwyth, has studied the physiological basis of juvenility in woody species, with special reference to factors determining the transition from the juvenile to the adult state. Experiments have been set up to ascertain whether the flowering of juvenile scions of birch, larch, etc. is hastened by grafting them on to mature trees. The effect of the age of the scion parent on the subsequent flowering of the grafts is being followed. Attempts are being made to reduce the juvenile period of larch by forced growth of seedlings to obtain a large size as rapidly as possible. The effect of environmental conditions on flowering of grafts of birch, beech and larch is also being studied.

Larch Canker

Dr. J. G. Manners, working in the Department of Botany at Southampton University, continued his anatomical investigation of potted plants of European larch having cankers produced by artificial local frost treatment, followed by inoculation with *Trichoscyphella willkommii.* This showed that subsequent further frost treatment, though not affecting the trees as a whole, checked the healing of the cankers, and resulted in further fungal activity. It is suggested that both the fungus and periodical frosts are prerequisites for the perpetuation of cankers.

Initial difficulties in the operation of the Hirst spore trap having been overcome, an analysis of slides exposed in the late autumn of 1959 indicated that spores of *T. willkommii*, though sparse, did occur in the air of a larch plantation in frosty conditions.

Shelterbelt Research

Mr. R. Baltaxe, working under Dr. J. M. Caborn at the Department of Forestry, Edinburgh University, is carrying out investigations on shelterbelts. Work on air flow has been concerned with the occurrence and nature of changes of the shelter effect of certain types of shelterbelt, as a result of change in the incident wind speed and of seasonal changes in their permeability to wind.

Wind-tunnel experiments have been carried out which enabled the direction of flow in the wake of barriers of known geometrical permeability to be mapped. Apart from throwing some light on the quantitative relationship between permeability and air flow pattern, the experiments were also useful in indicating the limits of the zones in which velocity measurements made with horizontally-orientated pitotstatic tubes were likely to be sufficiently accurate to be worth making.

The main preoccupation has been with instrumentation. The available anemometers have been fitted with solenoid-operated levers, making possible their remote and simultaneous operation. Recently the single-handed execution of wind studies has been facilitated by using a contact pattern anemometer connected to a continuous recorder as the control instrument, thus saving considerable equipment, time and movement of personnel.

For the matching of anemometers outside a wind-tunnel, it was found that the only wind blowing sufficiently smoothly was one coming off the sea. It was noted that the irregularities of a not abnormally gusty wind were sufficient to mask completely any windward shelter effect, when short measurement periods were used.

Soil Faunal Research

Mr. D. R. Gifford, working at the Department of Forestry, at Edinburgh University, continued his studies on the relationship between mites and fungi in the soil, on the differences between populations of mites in unplanted and planted moorland, and on the ecology of mites in the Forest of Ae.

Studies on the Morphological Variation of Conifers

The (late) Dr. E. V. Laing continued his work at the Forestry Department at Aberdeen University on the characters of the young plants of *Picea omorika*, in view of the reported hybridisation of this species with Sitka and Norway spruce. Very young *P. omorika* is very unlike adult trees, being for instance devoid of hairs on the shoots, and having stomata on the upper sides of the leaves.

Work has also continued on the variation in *Pseudotsuga taxifolia*, and keys for the recognition of its variations have been compiled.

Hydrological Relations in Forest Stands

Dr. L. Leyton and Dr. E. R. C. Reynolds, assisted by Mr. B. J. Kemp, continued studies on rainfall interception by forest trees at the Imperial Forestry Institute, Oxford. Using a seventeen-year-old plantation of Norway spruce, they studied the proper type and placement of instruments to record throughfall and stem-flow.

Over the period concerned, interception by the canopy was generally of the order of 30% of the incident precipitation, though occasionally as low as 18%.

Tracheid Length in Young Conifers

Mr. J. Ladell, working with Dr. L. Chalk at the Imperial Forestry Institute, Oxford, is concerned with the prediction of tracheid length in mature wood from tracheid measurements in young material. The results so far obtained suggest that the genetic 'possibility' may be measurable in the terminal bud, the tracheid lengths in the first year shoot being modified by its elongation.

Fomes annosus

At the Botany School, Cambridge, where Dr. J. Rishbeth is continuing his work on this fungus, research is proceeding into protective stump treatments. Numerous chemicals are being screened for this purpose and the use of a fungal competitor, *Peniophora gigantea*, is being investigated. Observations on forest air spora have been continued.

Utilization of Tan Barks

Work on tanning materials extracted from conifer barks is described by Dr. D. E. Hathway of the British Leather Manufacturers' Research Association, at Egham, Surrey. Larch bark was found to be unsuitable, but Sitka spruce gave a useable product.

N:N-dimethylformamide (IMF) appeared to be particularly suitable as an extractive for spruce and other tan barks. Successful laboratory tanning trials were carried out using methanol as the extracting agent. A larger scale trial produced sufficient material for the tanning of several hides, which were subsequently used for upholstery purposes.

Nutrition of Trees in Forest Nurseries

During the year Miss B. Benzian, working at Rothamsted Experimental Station, was mainly concerned with working up the very large bulk of experiments already completed on nursery nutrition. The tables are mainly completed and a start has been made on the text.

An interesting case of phosphorus toxicity to yellow lupins is reported.

PART III

In this section, the results of certain investigations carried out by the Forestry Commission Research Branch are reported in the form of short papers on specific subjects.

Seed Testing of Western hemlock

Mr. G. Buszewicz and Mr. G. D. Holmes describe the results of purity, weight and germination tests completed on seed lots of Western hemlock, *Tsuga heterophylla*, during the period 1950-60. Results for home-collected and imported seed are compared. The reasons for rather striking differences in quality are discussed.

A close relationship was found between seed weight (size) and latitude of origin.

Five different germination test conditions were examined and it was concluded that, subject to further study of temperature/light interactions, the best method is the Jacobsen apparatus used in light at a constant temperature of 20°C.

Variations in seedling yields from test sowings in the field are discussed.

The use of Herbicides in Fire Breaks

This paper by G. D. Holmes and D. F. Fourt reports on experiments carried out during 1956-59 on a range of soil types to test the practical and economic aspects of using herbicides in the establishment and maintenance of efficient, non-inflammable firebreaks. Nine substances were applied, at 3 different rates, with and without prior cultivation.

It was concluded that weed-free firebreaks can be obtained using herbicides without much difficulty on non-calcareous soils; the most effective compounds being monuron, simazin and the borates. Many treatments failed to produce bare soil conditions, but resulted in a vegetative cover which was reasonably fireproof due to its succulence, stature, or the absence of inflammable debris. On calcareous soils, arsenites, chlorates, borates and tri-chloracetates of sodium showed much reduced toxicities.

Efficient ploughing alone is capable of burying and killing much of the surface vegetation found on firebreaks. However these studies show that if rhizomatous species such as *Holcus mollis*, *Pteridium aquilinum*, *Juncus acutiflorus* or *Pulicaria dysenterica*, are present in any quantity they soon recover.

Herbicides are likely to be more costly than mechanical cultivation and mowing for formation and maintenance of firebreaks. However, they certainly have a place where ground conditions will not permit the use of mechanical methods. Thus for vegetation control on steep ground, banks, verges, paths, roads, etc. monuron or simazin deserve more extensive practical trial in conjunction where necessary with selective herbicides such as 4-CPA, 2,4,5-T or dalapon.

The Drainage of a Heavy Clay Site

Mr. D. F. Fourt describes the response of water levels in two types of bore-hole layouts to three drainage intensities, on a heavy clay soil recently cleared of derelict woodland. During periods of wet weather, especially in winter and early spring, the drainage treatments usually showed that these effects were significant at either the 1% or 5% level. Inversion of the winter order of the water levels took place occasionally in the summer, sometimes reaching significance, suggesting greater moisture availability on the treated plots. Daily readings after heavy falls of rain in winter show that the drained plots have 2 and 4½ days waterlogging (above the 12 inch levels) for ⅓rd and 1 chain spacing of drains respectively, compared with more than 10 days on the control. The comparison of the boreholes in the woodland, with those in the cleared area, implies greater water loss from the former, with marked delay of the onset of winter waterlogging. It was shown, by using fluorescein as a tracer, that deeper movement of water takes place in the drained plots at a time when lateral movement has ceased below 12 inches in the control. Drain spacing and depth are discussed and it is concluded that intensive and deep drains are necessary on heavy clay sites; there are indications that progressive improvement in soil conditions as the crop develops will result from this treatment.

Experimental Introduction of Alternative Species into Pioneer Crops

In this paper, G. G. Stewart analyses the results of a large number of experiments. He concludes that a considerable number of species have been established successfully by using a pioneer crop. On the upland heaths the most successful have been Western hemlock, *Abies grandis* and Douglas fir. On the *Molinia* site, the best have been European, Japanese and Hybrid larches, Western hemlock, Grey alder and birch. The growing of Sitka spruce on the upland heaths, by using a pioneer crop, has proved as uncertain as growing it on the open moor.

There is evidence that the early growth of many species is greatly improved by the use of a pioneer crop. Making introductions in a lane cut for the purpose is satisfactory. The complete suppression of the vegetation before the introductions are made is most important. The use of a fairly wide lane (5 to 7 rows of trees) in a crop sufficiently tall to have killed the ground vegetation might be the best method of making the introductions. To make introductions before the pioneer crop can give saleable produce appears economically wasteful.

Stewart finally concludes that one of the main hazards in these methods of establishment is the browsing of roe deer.

Pruning of Conifers by Disbudding

A series of experiments on the pruning of conifers by disbudding is discussed by D. W. Henman. He concludes that this type of pruning has been a total failure on Douglas fir and Sitka spruce. The results with Norway spruce indicated that this method cannot be applied to checked or very slow-growing crops. With pines it is impracticable for clear lengths greater than eight feet. For this length some success was achieved, but survival of the pruned trees is so uncertain, the cost of the operation so high, and the rate of diameter growth so much reduced, that the method could not be contemplated on a forest scale.

The Pine Looper Moth, Bupalus piniarius, in Rendlesham and Sherwood Forests

In this paper on *Bupalus piniarius*, the Pine looper moth, D. Bevan and R. M. Brown describe the investigations at Rendlesham and Sherwood Forests following the high pupal counts recorded in 1959. Though the emergence of adults was normal, at every subsequent stage there were severe population reductions, so that in fact there was no need for control measures to be applied in 1960. The most significant reduction was at the egg-laying stage, when the adults appear to have been prevented, by some unknown factor or factors, from laying more than a fraction of their full complement of eggs.

The Propagation of Elms and Poplars from Summerwood Cuttings

In this paper J. D. Matthews and J. Jobling describe how summerwood cuttings of 90 poplar and 25 elm clones were inserted under "mist;" in 1958 and 1959, in a series of experiments and an extensive trial of the method. Tip cuttings at least five inches long, taken in June or July depending on the clone, can be rooted. Indole butyric acid applied in talc increases the speed of rooting. The after-care of cuttings is simplified if they are inserted and rooted in peat or similar pots, and work continues to further develop this procedure. They consider that the "mist" method is a most useful technique, supplementing dormant cuttings in poplars and grafting in elms.

Yields of Coppice Hardwood for Pulpwood

Mr. C. D. Begley and Mr. A. E. Coates have made measurements of a number of temporary one-tenth acre sample plots of coppice hardwoods. Estimates were made of the yield in green and dry weight of oak, birch, alder, sycamore, ash, white willow, poplar and lime coppice, cut to 3½ inch and also to 2 inch top diameter. The weighing was done on a sampling basis. Stem analyses were carried out on sample poles from each plot, so that an estimate could be made of the past growth and increment of each species.

The high yield of lime, poplar and willow coppice in the early years was particularly noticeable. The results also showed clearly the rapid increase in yield that took place, usually between 16 and 25 years of age, as the majority of the poles reached measurable size.

PART I

Reports of Work carried out by Forestry Commission Research Staff

FOREST TREE SEED INVESTIGATIONS

By G. BUSZEWICZ and G. D. HOLMES

Service Work

Seed Testing

As in previous years, testing of the quality of the Commission's seed continued to be the main function of the Seed Testing Laboratory at Alice Holt. During the year, 750 samples were received on which the following tests were completed:—

Purity Analyses	357
Seed weight determinations	371
Germination Tests....	1,084
Tetrazolium Tests	44
Moisture Content Tests	456

Reports were also issued on 14 cone samples received from Conservancy collection areas. The above numbers include 158 germination tests, and 200 seed moisture tests carried out as part of the experimental work described below.

The only major addition to the equipment of the Seed Laboratory was a toluene distillation apparatus for seed moisture content determination.

Seed Storage

During the period under review, the turnover of stored seed lots for experimental sowing was about 300 lb. The despatches involved over 5,000 measured and packeted lots during the period March-April, 1960.

In the Central Seed Store, a specially designed seed dryer was installed and tested on a range of species. A drying procedure was worked out and the moisture content adjusted for 4,100 lb. of stored seed. The machine, which has a drying capacity of about 200 lb. per day, functions by forcing a large flow of warm air through static columns of seed. The system of a large air-flow rate and a relatively low air temperature, has been adopted to combine efficient drying with a low risk of heat injury to seed.

Research Work

Germination Tests

Improvement and standardisation of test methods continued to be a major subject of investigation. The work involved both experiment and analysis of data collected during the course of routine service work.

Experimental work was devoted mainly to comparative tests on a series of referee samples issued to the members of the Forest Tree Seed Committee of the International Seed Testing Association. The testing methods for Douglas fir and Sitka spruce were critically examined and the revised test prescriptions were approved by the I.S.T.A. Convention in Oslo in 1959. For the future work it is planned to organise a similar investigation for several *Abies* species and *Pinus pinaster*.

Many tree species have seeds which germinate very slowly even under ideal conditions. This presents a serious problem to the seed analyst who is concerned with completing germination tests in the shortest possible period of time. On this theme, a small investigation on hawthorn, *Crataegus monogyna*, and Swedish whitebeam, *Sorbus intermedia*, seed was carried out to examine the effect of acid pretreatment and the duration of moist stratification at different temperatures on germination. These species are not commonly used in forestry work in Britain, but have proved difficult to germinate both in the laboratory and in the field.

Crataegus monogyna. Normally, the seeds of this species are stratified for over one year. However, there is evidence that they can be germinated following collection, if the seed is first soaked in acid or stratified first at a high temperature (20°C), followed by a period at a low temperature (2°C). This idea was checked by a small nursery experiment and the results can be found in Table 1. These indicate that 5 months stratification at 2°C alone, or combined with acid digestion of the seed coat, is inadequate. Also, warm stratification preceding cold only slightly improved the germination. The best results were obtained by 2 hours acid digestion followed by 2 months warm and 3 months cold stratification before sowing.

Table 1

Production of Crataegus monogyna seedlings with several methods of seed treatment

H_2SO_4 Hrs.	Description of Treatment: Mths. Stratification at 20°C	2°C	No. of seedlings from 1,000 seeds.
—	—	5	Nil
1	—	5	3
2	—	5	Nil
3	—	5	3
—	1	4	11
—	2	3	20
—	3	2	4
1	1	4	18
2	2	3	161
3	3	2	1

Sorbus intermedia seeds are less dormant than those of *Crataegus*, and a simple trial suggested that one can expect quite reasonable production of seedlings after 3 to 4 months stratification of seed in moist peat at 2°C. (See Table 2). It was observed that the seeds started to pregerminate after 4 months, and after 5 months almost all seeds had produced well developed radicles. All pregerminated seeds died after being transferred into the nursery bed.

Table 2

The production of Sorbus intermedia seedlings following moist stratification

Description of Treatment	No. of seedlings from 1,000 seeds
Control—Seed stored dry, sealed at 2°C	Nil
1 month's stratification in moist peat @ 2°C	7
2 ,, ,, ,, ,, ,, ,, ...	177
3 ,, ,, ,, ,, ,, ,, ...	292
4 ,, ,, ,, ,, ,, ,, ...	355
5 ,, ,, ,, ,, ,, ,, ...	8

The analysis of over 800 purity and germination test results on Western hemlock, *Tsuga heterophylla*, obtained during the period 1950-59, was completed. (Results are reported in full in Part III page 110).

Storage of Seed

The Central Seed Store at Alice Holt has now been in operation for two years. The seed quality is keeping well and there has been no evidence of any important deterioration of seed germination quality in this period. The sampling procedure for drawing test samples has been revised to suit the new type metal seed containers. It is quite intensive, in order to permit critical observation on the suitability of the containers and storage methods applied. The sampling procedure will be revised in two years time, according to the experience obtained.

In storage investigations, most attention has been paid to *Abies* spp. as these seeds show the shortest life-span of the main conifer species. *Abies nobilis* seeds were chosen as the subject of special storage trials which were started in 1959 and are planned to run for 10 years. The object is to examine the influence on seed longevity of storage atmosphere (hermetic seal, vacuum seal and CO_2 gas seal), seed moisure content (4-16%), and storage temperature (−20°C to +20°C). The storage treatments will be checked by germination tests each year.

An experiment on a small scale with the seed of *Abies grandis*, *Abies concolor*, Douglas fir, *Thuja plicata* and Lawson cypress is running into its third year, and the results will be analysed shortly. This experiment is carried out in sealed containers at a range of temperatures from −10°C to +20°C but only one level of moisture content.

During the period, the long-term storage experiment of beech nuts, described in the last report, was continued. In 1960 the experiment was concluded after 3 years and a final report is being prepared.

Seed Moisture Content

This determination is important, particularly if seed is to be stored for long periods. The number of tests is continuously increasing and there has been some difficulty in standardising the technique. In routine testing, the air-oven method at 105°C is used. There is, however, evidence that this method is not suitable for forest seeds which as a rule contain volatile oils, and some which are easily oxidised. The most suitable method for this kind of seed is the toluene-distillation method which is officially recognised by the International Seed Testing Association. The advantage of this method is that moisture content is assessed on the basis of distilled water and the oils remain in the toluene solution. During the period, the apparatus was assembled and initial trials will start in 1960/61.

Seed Fumigation

Some seed samples are found infested with insects, mainly with larvae of *Megastigmus* spp. As a rule no action is taken as the damage is not likely to increase in storage, because the insects do not migrate from one seed to another. On imported seeds there could be reason to destroy the infestation, if there was any question of introducing a new pest into the country. Such a case arose during the year with *Cryptomeria japonica* seed imported from Japan. The seeds were heavily infested with *Megastigmus cryptomeriae*, not previously recorded in this country. The insects were killed by exposing the seeds to a temperature of 50° C for 4 hours. A small fumigation experiment, using methyl bromide, is being carried out on Douglas fir seed in cooperation with the Imperial College of Technical Science.

Other Activities

Mr. Holmes attended the Congress of the International Seed Testing Association at Oslo in July, 1959. The staff has also participated in the work of the Committee on Transactions in Seeds and the newly formed Tree Seed Association for England and Wales.

NURSERY INVESTIGATIONS

By J. R. ALDHOUS and J. ATTERSON

Introduction

The investigations reported here are additional to the major programme of research initiated by the Sub-Committee on Nursery Nutrition (of the Advisory Committee on Forest Research), which is now being written up.

During the year, experiments were carried out in six English nurseries. Three of these are research nurseries, i.e. those at Kennington, Oxford, at Sugar Hill, Wareham, Dorset and at Alice Holt Research Station, Farnham, Hants; and three are in parts of the Conservancy nurseries at Elvetham, Bramshill, Hants., at Harling, Norfolk and at Fen Row, Suffolk. The last two have been used only for experiments on the manuring of poplar.

In Scotland, experiments were carried out at one research nursery, Bush, Midlothian, and in part of the Conservancy nurseries at Benmore, Argyll, at

Fleet, Kirkcudbrightshire, at Inchnacardoch, Inverness, and at Newton and Teindland, both in Morayshire.

Long Term Fertility Demonstrations

These demonstrations were continued at a number of nurseries and useful results are steadily accumulating. The treatments include continuous tree cropping, green crops, fallow, artificial and organic manures and partial sterilization.

Chemical Sterilization

A new proprietary, partial soil-sterilizing agent, known as "Sistan", produced for the control of root-rot fungi in glass-houses, was tried out at six Scottish nurseries on conifer seedbeds. This chemical is less objectionable to handle than chloropicrin, while the cost of the material and the method of application are approximately the same for both, application being carried out by injection with a tractor-mounted "D-D" injector.

The "Sistan " was applied at two rates, one above and one below the recommended rate of 110 gallons per acre, on three dates—60, 45 and 30 days before sowing, and was compared with unsterilized beds, and also with beds sterilized by the normal formalin method.

Sitka spruce seed sown on "Sistan" sterilized soil yielded significantly fewer seedlings of a significantly smaller mean height than did similar seed sown on unsterilized or formalin-sterilized soil at most nurseries; the results at the remaining nurseries were not significant.

"Sistan" is known to have herbicidal properties, in addition to those of sterilization, and this was borne out at all six nurseries, as weed growth was very significantly decreased by the application. The earliest treatment (60 days before sowing) checked weed growth more than the latest (30 days before sowing) at all but one nursery, where, however, the difference was small and not significant.

Rates and Times of Application of Nitrogen Fertilizers

Experiments on the effect of heavy or late application of nitrogen fertilizer, and the effect of these applications on the frost-hardiness of seedlings, were continued for the sixth year in Scotland and England. As in previous years, no severe early autumn frosts occurred, and no frost damage, selective or non-selective, was evident from the slight early frosts which did occur.

In Scotland, the application of nitrogen fertilizer ('Nitrochalk') generally resulted in the later setting of terminal buds, more so with Japanese larch than with Douglas fir. In England, nitrogen fertilizer had no effect on bud formation of Douglas fir and Japanese larch, at any of the three nurseries in which the experiment was carried out. However, it was observed that most of the Douglas fir seedlings had formed terminal buds by the middle of September, whereas the Japanese larch seedlings continued to grow until the end of October, a greater difference than usual.

At Kennington nursery, an experiment was carried out to compare the effect of two newly formulated nitrogen fertilizers as top dressings to seedbeds of Sitka spruce. The new materials were (a) pelletted urea containing 47% N and (b) 'Nitrochalk' with 21% N. They were compared with ammonium sulphate (21% N.), 'Nitra-shell' (20·5% N.) and the old formulation of

'Nitrochalk' with 15·5% N. All materials were applied as top dressings in mid-June and mid-July at the rate of 4½ grams nitrogen per square yard per application. At the end of the season, there were no significant differences in growth or yield of seedlings from any of the treatments.

Date of Sowing

Experiments on the effect of date of sowing on growth and yield of seedlings are repeated annually to give some measure of effect of the season on growth and yield of seedlings, and to facilitate the comparison of experiments sown at different dates in the same nursery. At Wareham and Bramshill nurseries, seed was sown at fortnightly intervals from the beginning of March until the Middle of May. Yields of all four species (Sitka spruce, Douglas fir, Western hemlock and *Sequoia sempervirens*) at both nurseries were highest from the sowings in middle and late March. Yields from sowings at the end of April and the middle of May were very poor, which can be attributed to the dry summer.

At Kennington, the date of sowing experiment was combined with irrigation. Two watering regimes were included:—in one, from sowing until mid-June, 0·13 inches (⅛″) of water was applied whenever the estimated soil moisture deficit exceeded 0·13 inches; from mid-June onwards, 0·25 inches of water was applied whenever the estimated soil moisture deficit exceeded 0·25 inches. The second watering regime was similar to the first except that the application rate and critical deficit were 0·25 inches before mid-June and 0·50 inches after mid-June.

Where no water was applied, both the yield and mean height of seedlings sown in late April and early May were reduced to about a quarter of that achieved from seed sown in early March. In contrast, where water had been applied, there was very little fall-off in yield, and the heights of the last sown seedlings were two-thirds that of seedlings sown in early March. There was little difference between the two watering treatments, but the second treatment was to be preferred, since it involved watering on only thirty occasions, compared with the fifty-three for the first treatment. In addition, 11·5 inches of water was required for the second as against 12·7 for the first treatment.

Of the other three species included in this experiment, two, Douglas fir and *Sequoia sempervirens*, gave results very similar to those for Sitka spruce. The fourth species, Western hemlock, also responded well to irrigation. However, yields of seedlings were significantly higher in plots irrigated more frequently than on plots receiving less frequent waterings.

Date of Sowing and Pre-treatment of Abies Seed

Seed from the same seed lots as those used in the experiment on this subject in 1958 (mentioned in the Research Report for that year) were sown at Kennington nursery. Seed was sown (i) dry at monthly intervals between January and May, (ii) after stratification for 3, 6 or 9 weeks and (iii) after moist pre-chilling treatment. The most successful treatments were the January and February dates of sowing of dry seed, the moist pre-chilling and the longest period of stratification. Previous years' experiments have shown the benefits of early sowing and of pre-chilling, and these treatments appear both beneficial and reliable. Stratification is sometimes beneficial, but it does not appear to be so consistently good as early sowing and pre-chilling.

Date of Sowing of Oak and Methods of Storage of Acorns

An experiment comparing two methods of storing acorns was undertaken at Kennington. The methods of storage were (a) seed stored in sufficient dry peat to ensure that the seed were well separated, and (b) seed heaped in a shallow open pit and covered with a 2-inch layer of broadleaved litter, the whole heap being protected with mouse netting. These treatments were compared with (c) seed stored in a cool shed in the normal way, (d) seed sown in the autumn and given the normal depth of soil covering, and (e) seed sown in the autumn and given an extra three inch layer of soil during the winter as protection against birds and mice. (This extra layer is removed in early spring before germination commences). The differences in yield between treatments were relatively small, though seed stored dry in a cool shed yielded approximately 20% fewer seedlings than the other treatments. There was no difference between the heights of seedlings of any treatments.

Intensive Methods of Raising seedlings—Dunemann Seedbeds

The small Dunemann seedbed constructed in 1957 was cropped again for the third year to gather further experience of this technique. Sitka spruce, Western hemlock and *Sequoia sempervirens* were sown, one plot of each species at the end of March, and the other four weeks later. The yield of seedlings per square yard was about 20% higher than that for the irrigated plots in the "date of sowing" experiment mentioned above, and the seedlings were about the same height. These results confirm experience from other Dunemann beds, namely that the yield from Dunemann beds which are regularly watered is slightly higher than the yield from mineral soil seedbeds. However, the cost of production of the Dunemann seedlings is inevitably higher than that of the seedlings from the mineral soil seedbed, at any rate on a light, easily worked soil.

A survey has been made of the Dunemann seedbeds in Great Britain, the results of which are being published elsewhere.

Weed Control

In the Seedbeds

Two new materials were tested as weedkillers in seedbeds, endothal* and simazine.*

Endothal is a contact weedkiller of limited selectivity which had not previously been tested on conifer seedbeds in this country. In an experiment at Kennington nursery it was applied as a pre- and post-emergence weedkiller at rates of 2, 4 and 6 lb. per acre to seedbeds sown with Sitka spruce, Japanese larch, Scots pine and Western hemlock.

All species were seriously damaged by the *pre-emergence* application of endothal at all rates.

Three of the four species in the experiment were also damaged by endothal applied as a *post-emergence* spray, commencing *four weeks* after the pre-emergence spray. Scots pine was the only species resistant to the post-emergency spray, when so applied.

* For the full names and properties of all materials marked with an asterisk in this section of the report, see *Weed Control*, prepared by the British Weed Control Council, and published by Blackwells, Oxford, 1958.

On the other hand, post-emergence sprays of endothal, commencing *eight or twelve* weeks after the date of the pre-emergence spray, did no damage to the crops.

Weed growth was slight during the latter part of the growing season, because of the hot weather, and it was not possible to get a good estimate of the effect of endothal on weeds during this time. The control of weeds by endothal during the early part of the season was very good.

This experiment shows endothal to be unsuitable as a pre-emergence weed-killer and as a post-emergence weedkiller applied soon after germination. It may be suitable as a post-emergence weedkiller later in the season.

Simazine is a persistent residual weedkiller which, at high rates, is used as a complete weedkiller, but at low rates can be used as a selective herbicide to control germinating weeds. In experiments at Kennington and Bramshill it was applied before and after seedling emergence at rates of 1, 2 and 4 lbs. per acre (active ingredient).

Applications before seedling emergence caused damage to the four species included in the experiment (Sitka spruce, Scots pine, Douglas fir and Japanese larch), the damage appearing two-three weeks after application, i.e. when the seedlings had emerged and were in the "drumstick" stage (seedling erect but with cotyledons still inside testa); or the cotyledon stage (cotyledons emerged from testa and spread out). The damage took the form of browning and withering of the cotyledons and stem from the tips of the cotyledons down.

Applications of simazine after the emergence of the conifer crop had no significant effect on growth or yield of the crop at either nursery, nor on the time taken to remove weeds, (there was, however, very little weed growth from the middle of the summer onwards.)

In the Transplant Lines

One new material, dalapon,* was tested in the transplant lines, and further experiments were done with simazine,* and with the mixtures of fenuron, CIPC and 2, 4-DES.*

Dalapon was applied in an experiment at Kennington nursery to determine whether it could safely be applied to transplant lines in nurseries infested with grasses. Dalapon applied at 2½, 5, 10 and 20 lb. per acre (acid equivalent) at intervals of eight weeks, commencing 4 and 8 weeks after lining out, damaged or killed all the five species in the experiment. Norway spruce and Western hemlock, both of which were small when lined out, were severely scorched or killed by application of 10 and 20 lb. per acre; Douglas fir, beech, and Japanese larch were also severely scorched but fewer plants were killed. Dalapon at 5 lb. per acre caused slight to moderate scorch to all species and at 2½ lb. per acre slightly scorched beech, Western hemlock and Sitka spruce, but left the other two species unharmed.

Simazine* was applied as an inter-row spray to transplants of eight conifer species at rates of 1, 2, 4 and 8 lb. active ingredient per acre. The species were:—Scots and Corsican pines, Sitka spruce, Japanese larch, Western hemlock, Western red cedar, Douglas fir and *Abies nobilis*. Neither at Brams-

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* For the full names and properties of all materials marked with an asterisk in this section of the report, see *Weed Control*, prepared by the British Weed Control Council, and published by Blackwells, Oxford, 1958.

hill nor Kennington nursery was there any damage to any species included in the experiment. Weed control was good, treated plots requiring scarcely any hand weeding during the whole of the season. This is a better result than has been obtained in other countries, where conifers have been damaged by simazine applied at between 2·5 and 4 lb. per acre. On the other hand, it agrees with the result of the very small scale trial carried out with simazine on five species of transplants at Alice Holt in 1958.

Mixtures of 2, 4-DES and fenuron, and CIPC and fenuron, were applied to transplants at Kennington and Bramshill nurseries. Fenuron was applied at rates per acre from ½-1½ lb.; CIPC at 2-8 lb.; and 2, 4-DES at 3-12 lb. Crops were damaged by mixtures containing 1½ lb fenuron per acre or 6 or 8 lb. CIPC per acre, but were not affected by mixtures containing 2 or 4 lb. CIPC per acre, ½ or 1 lb. fenuron, or by any rate of 2, 4-DES.

Frequency of Weeding

The experiment on the effect of frequency of weeding on growth and yield of seedlings, on weeding time, and growth of weeds was repeated for the third year. The frequencies of weeding were 1½, 3, 6 and 12 weeks. The results of this experiment were very similar to those reported in detail in the Research Report for 1958 as far as weeding times and data on weed numbers and weights are concerned. However, they did differ from previous results in that for the first time, the number of seedlings was significantly less on plots weeded least frequently (at 12 week intervals). This is the longest weeding interval in any experiment of this series. It was included in an attempt to reproduce in an experiment what has been observed in normal practice, that delayed weeding results in serious losses of plants. Total weeding times were least for plots weeded once every three weeks and were greatest for plots weeded once every twelve weeks. On the latter plots, the longer weeding time is accounted for partly by the additional care required to remove very big weeds without removing the seedling crop, and partly by the increased number of weeds resulting from the seeds produced by the older weeds on the plot.

Weed control in Poplar Stool Beds

Following two years successful experiments on poplar cuttings, monuron* was applied at 4 lb. per acre to poplar stool beds to control weeds on an area of approx. 1½ acres. Two control strips were left untreated and another strip was treated with simazine at ½, 1, 2 or 4 lb. per acre in order to give some information on the relative merits of simazine and monuron.

The control of weeds by monuron was good, but there was considerable damage to stools of a number of clones. Damage took the form of blackening of the leaf margins, followed by dying of tissue between the veins and then death of the whole leaf. Severely affected shoots were completely defoliated except for a few young leaves at the tip. Height growth, shoot diameter and leaf size were very much reduced on the damaged plants. Slightly damaged

* For the full names and properties of all materials marked with an asterisk in this section of the report, see *Weed Control*, prepared by the British Weed Control Council, and published by Blackwells, Oxford, 1958.

stools suffered only the blackening of leaf margins with no reduction in height growth of shoots.

There was some difference in the ability of clones to resist the effects of monuron. *P.* 'gelrica', *P.* 'berolinensis' and *P.* 'laevigiata' were resistant, while *P.* 'serotina', *P. trichocarpa* or *P. trichocarpa* hybrids were moderately or seriously damaged. Some clones of *P.* 'eugenei' and *P.* 'robusta' were quite unaffected, while others were very seriously damaged. Generally, the more recently planted stools suffered more than the older ones.

In contrast, there was no damage to any variety in beds treated with simazine. Control of weeds was good both on the monuron plots and on the plots treated with simazine at 2 and 4 lb. per acre, and was quite good on plots treated at ½ and 1 lb. simazine per acre.

Handling and Storage of Plants

Use of Polythene Bags for Transport and Storage

Experiments were repeated for the third year to test the ability of seedlings and transplants to survive storage in polythene bags. The periods of storage ranged from one to six months and included storage at all periods during the winter and spring. The results confirmed those of previous years, namely that the spruces and pines are most tolerant of storage in polythene bags, transplants surviving storage for three to four months without loss, and seedlings surviving for at least three months. The larches survived excellently, provided they were planted out before they had come into leaf, but Douglas fir, Western hemlock, Lawson cypress and the *Abies* species were less reliable, survival in some experiments being as good as that for the pines, but in others being very poor. For these species, (and to a lesser extent for the others), survival was poorer if plants had been packed into the bags in wet condition. Two species not previously included in these experiments, *Sequoiadendron-giganteum* and *Sequoia sempervirens*, were stored as first-year seedlings at Kennington and proved to be extremely intolerant of any period of storage.

Storage of Plants at Low Temperatures

At Alice Holt, seedlings were stored in cold chambers for periods up to fourteen months in order to determine the practicability of storing surplus seedlings from one year to another.

In an experiment commenced in 1958, seedlings lifted in February were stored in a cold chamber at 2°C. Table 3 gives the percentage of live plants when the plants were brought out of the cold chamber, the percentage of live plants at the end of the experiment (October, 1959) and the mean height of plants at the end of the experiment. The three species included in the experiment were Sitka spruce, Douglas fir and Japanese larch.

Table 3 shows that when plants were stored until June they were in good condition and when planted out survived very well. Their growth also was good, though not as good as that of plants transplanted in the spring, but better than one might wish for seedlings which are intended to be held over for a year.

Table 3

Percentage Survival after Storage and at the End of the Experiment. (i.e. after two years), and Mean Heights after Two Years, of Plants Stored in a Cold Chamber. Experiment: Alice Holt 51 FY 58.

Treatment	Date of lining out	Sitka spruce: Percentage of Live Plants: After period of storage	Sitka spruce: Percentage of Live Plants: At end of second year after lifting	Sitka spruce: Mean Height at end of Second year. Inches	Douglas fir: Percentage of Live Plants: After period of storage	Douglas fir: Percentage of Live Plants: At end of second year after lifting	Douglas fir: Mean Height at end of Second year. Inches	Japanese larch: Percentage of Live Plants: After period of storage	Japanese larch: Percentage of Live Plants: At end of second year after lifting	Japanese larch: Mean Height at end of Second year. Inches
Control: Lined out immediately after lifting	Feb. '58	99	96	17·8	100	75	12·2	100	79	32·3
Plants stored in polythene bags in sheds at air temperature ..	April '58	100	98	17·0	100	87	16·8	100	72	39·7
Plants heeled in, in open ground in nursery, until required for lining out ..	April '58	100	99	18·0	99	90	20·9	98	82	38·8
Plants stored in polythene bags in cold room at 2°C ..	April '58	100	96	18·3	100	99	15·6	100	80	40·9
Plants stored in polythene bags in cold room at 2°C ..	June '58	100	100	11·7	95	95	14·0	91	78	29·4
Plants stored in polythene bags in cold room at 2°C ..	July '58	100	86	2·9	98	56	6·0	100	0	—
Plants stored in polythene bags in cold room at 2°C ..	Feb. '59	56	42	3·6	47	7	7·3	0	0	—
Plants stored in polythene bags in cold room at 2°C ..	April '59	28	6	3·0	44	3	7·0	0	0	—

Plants transplanted in October were alive when lined out, but they started to grow and were unable to form a winter resting bud and harden off before the autumn frosts. Although a fair proportion of Sitka spruce and Douglas fir appeared alive when planted out in February and April (after twelve and fourteen months storage respectively) they were in poor condition and very few actually grew.

The satisfactory growth and survival of plants held in the cold store until June points to another application of cold storage for plants—namely their safe storage when late planting or lining out is unavoidable through pressure of work or other circumstance.

In a similar experiment commenced in 1959 and still in progress, plants were stored in a cold chamber at either +2 or −5°C. Interim observations show that there has been an excellent survival of three of the four species when stored for six months at +2°C, but that plants stored for longer periods have not survived. Plants stored at −5°C for any period have also failed to survive. Sitka spruce, Scots pine and Japanese larch survived six months cold storage excellently and are now (spring, 1960) growing as though they were recently lined-out one-year seedlings. Douglas fir seedlings did not stand six months storage at all well. The failure of plants transplanted in September and October may be due to the dry, warm weather of that time rather than to deterioration in storage, but the failure of plants stored at −5°C can only be attributed to deterioration in the cold chamber.

SILVICULTURAL INVESTIGATIONS IN THE FOREST
(A) SOUTH AND CENTRAL ENGLAND AND WALES

By R. F. WOOD, G. D. HOLMES and A. I. FRASER

Afforestation Problems

Afforestation of Particular Types of Land

New work in this field was restricted to establishment of a series of species trial plots on the "hill-and-dale" formations of disused sand and gravel workings in the Wareham area of Dorset. There is a small but steadily increasing area of disused workings in the district, and pilot plots will provide useful general information, and, if successful, will serve as a demonstration to encourage owners to plant other workings.

Observations were continued at existing experimental areas on several contrasting types of land. At Croft Pascoe, Lands End Forest, Cornwall, plots planted 1954-56 on an exposed shallow heath soil over Serpentine rock showed a general slowing down of growth of many species, and large sections will be top-dressed with additional phosphate in 1960. Six years after the field trial plantings on this type of ground, the results indicate that successful afforestation is possible, but the choice of species for the first rotation will be restricted to Lodgepole pine (coastal Oregon and Washington origins), *Pinus radiata*, and Sitka spruce in the wetter hollows. Ploughing, preferably complete ploughing, and phosphate manuring are essential for satisfactory early growth.

Trials on the most difficult land at Wareham Forest, Dorset, on Bagshot Sand overlying an impermeable clay, show very promising growth of a wide range of species with deep single-furrow ploughing and phosphate dressings. Five years after planting, *Pinus radiata* and Western hemlock are outstanding, and Sitka spruce, Lawson cypress and Leyland cypress are promising. On this evidence, it seems likely that much of the poorest parts of the forest, now under unsatisfactory pine, are capable of supporting rapid initial growth of demanding species with more intensive ground preparation and manuring.

Observations were also continued at Coed Taliesin Forest, Cardigan, which has now become a centre for experiments on afforestation methods on mineral soils over shale in Wales.

Afforestation of Exposed and Elevated Sites

Field inspections were completed during the year in preparation for planting a series of high-elevation species trials in Wales. Four sites have been selected, all over 1,800 feet elevation and above the present planting limit, and observational plots will be established in 1961. As noted in the 1959 Report, data is also being collected in existing older woods on elevated sites, both on private and Commission land.

It is noteworthy that, until very recently, a major part of the work of the Research Branch has been concerned with afforestation and the problems of establishing crops on bare land. However, with the increasingly large area of established plantations, new problems arise and a greater proportion of research effort is now being given to the requirements of the stand and its regeneration.

Regeneration Problems

Many of the earliest Commission plantations are now reaching the stage when they are due for replacement, notably for larch which has been frequently planted as a pioneer species. Further, the time is ripe to consider the problems which may arise in the next few decades when large areas of other species, notably spruce and pine, approach rotation age. Investigations are being carried out to enable the main problems to be defined, and observational and experimental studies are being started in selected areas. The areas chosen initially in the South are the pine plantations of Thetford and East Anglia, and the extensive areas of larch in Wales. The work will be extended in due course to spruce in Wales and the West of England.

The work done so far has been restricted to observational study of existing conditions and experience. Many of the problems arising are immediately apparent and embrace management and economics, as well as silviculture. The main questions to be posed fall into four main groups, viz:—

(1) Choice of rotation and method of manipulating the existing crop to combine the most profitable yield and favourable conditions for regeneration. The main points arising relate to the timing and type of felling, and its effect on wind stability and growth conditions for the new crop, i.e. shelter, soil conservation, and vegetation suppression.

(2) Choice of species for the second rotation. In many instances it should be possible to establish a higher-yielding species, or improved varieties of the existing species. In some localities, the feasibility of natural regeneration should be considered.

(3) Preparation for Planting. Where necessary, drainage presents special problems on stump-covered areas. Similarly, brash disposal and weed control may be problems in some crops.

(4) Protection may be a paramount consideration where deer, *Fomes* or Honey fungus are present.

These and other problems will be examined in a programme of field experimentation extending over a period of years.

Forest Stand Improvement

Manuring of Trees at Planting

Field experimentation was confined to supplementary phosphate dressings applied 2 to 4 years after planting and initial manuring, on very deficient sites at Wareham, Haldon, Croft Pascoe and Wilsey Down, i.e. all sites with a subsoil level of 200-400 p.p.m. total P. Results have been impressive on a wide range of species, suggesting that the standard rates of 1 oz. triple superphosphate or 2 oz. ground mineral phosphate per plant, should be *doubled* on such sites.

Recent experiments examining forms of phosphate fertilizer show little difference between mineral or rock phosphate forms, and superphosphate, in terms of growth responses to a given rate of P. These experiments are being extended to include a wider range of rates to compare dose-response curves in terms of growth and nutrient uptake and the persistence of effects.

Potash manuring at planting has been tested on a variety of soils in recent years, with largely negative results. Also, nitrogen additions have had only transitory effects in the few cases examined. Some of the slowly-soluble nitrogen materials, notably urea formaldehyde, warrant more thorough tests, and these will be carried out on a range of more demanding conifer species.

Improvement of Checked Plantations

The experimental work reported in the 1959 *Report* was extended in several areas, to examine methods of improving the growth of checked and slow growing spruce, pine and Douglas fir crops on infertile sites.

At Wareham and Haldon Forests, on poor sandy and gravel soils dominated by *Calluna*, experiments were laid out in thicket-stage pine, testing rates of phosphate and rates and forms of nitrogen additions. Nitrogen forms included pelleted urea, ammonium nitrate and ammonium phosphate. Despite the dry season, responses to broadcast top dressings have been striking at both centres, especially to urea and ammonium phosphate. Both materials gave rapid crop responses, the most notable effects being on the colour and size of needles. There is evidence that the effects of these nitrogen forms may be more persistent than that of ammonium nitrate. These experiments should provide evidence on this point, and indicate practical treatments. Results of experiments at these two centres over the past three years have shown that both phosphorus and nitrogen supplies must be increased to ensure rapid crop growth on *Calluna*-dominated sites. It seems this can be achieved by dressing with a suitable NP fertilizer, or by application of phosphorus together with chemical eradication of *Calluna*. The choice of method for practical use will depend on the effectiveness and persistence of the new N forms now under test.

Similar experiments on lodgepole pine showing retarded growth and severe 'needle-fusion' symptoms at Wareham have shown a most dramatic crop recovery within a single season, following dressings of triple-superphosphate at 3 cwt. per acre.

At Wilsey Down and Halwill Forests, work has continued in poor spruce crops on phosphate-deficient Culm soils Experimental work started in 1954 has shown that the crops can be restored to vigorous growth by broadcast phosphate dressings at 70 lb. P per acre. Checked crops receiving this rate in 1954 have now closed canopy and continue to grow vigorously. A highlight of the year was the experimental aerial top-dressing of over 100 acres of the worst checked areas of Wilsey Down Forest. As reported last year, the operation was most successful, and using a fixed-wing aircraft, 3 cwt. granular triple-superphosphate per acre was applied at an application cost of about £1 per acre. Detailed results of these trials were published in *Forestry*, May 1960.

It was noted in 1958 at these forests, that phosphorus applications exceeding

45 lb. P per acre caused a temporary dwarfing and yellowing of needles at the tips of current year shoots in the second year following treatment. The appearance of these "yellow-tip" symptoms suggested an 'induced' deficiency, and test plots of nitrogen, potassium, magnesium and several minor elements were laid down during 1959. The first results of these tests indicate that the trouble is an "induced" potash deficiency which disappears within three seasons, or can be prevented by addition of potash. Trials of highly-concentrated, low-soluble potassium metaphosphate, of a range of granule sizes, were laid down in 1959 to examine its effectiveness and persistence compared with soluble fertilizers. No crop effects were apparent from potassium metaphosphate at the end of the first season, although marked improvement in foliage colour had occurred in superphosphate plots.

In Wales, several new experiments were started in poor-quality spruce crops at Tarenig, Coed Clwyd and Myherin and Clocaenog forests. These sites are not generally so deficient as the Culm and Bagshot soils discussed earlier, but nevertheless growth responses to late phosphate additions have been obtained in experiments started in 1956 and 1957. At Coed Clwyd there have been early responses of pine and spruce crops in *Calluna* to dressings of nitrogen (urea) and phosphorus applied in the spring of 1959.

Poor growth of Douglas fir on the acid and impoverished silty soils of the Weald of Kent and Sussex was studied during the year. Mineral deficiencies, notably phosphorus, potash and calcium, could be important, and experimental top-dressings were applied to a range of crops at St. Leonards, Bedgebury, Hemsted and Maresfield forests. No crop responses were apparent at the end of 1959.

All the experiments described are located in problem areas and in some cases results may justify large-scale manuring to restore the crop to normal growth. Foliar nutrient analyses are being completed in the majority of these experiments, both to track the uptake of added nutrients, and to provide material which will help build up standards for rapid diagnosis of nutrient deficiencies by means of foliar analysis. Foliage form and colour symptoms may sometimes provide a clue to nutrient disorders, but little is known of precise symptoms for most forest species. Accordingly, preparations were completed during the year to establish a nutrient deficiency symptom "display" on a selected site at Wareham. Major element deficiencies will be induced by unbalanced manuring of specimens of the major species, as an aid to diagnosis.

Manuring of Pole-Stage Crops

During 1959, experiments were established at eight forests over a wide range of soil conditions to examine the growth responses of Quality Class II-V. Sitka spruce crops to fertilizer additions at first or second thinning stage. Similar plots were established in pole-stage crops of Douglas fir and Norway spruce at two forests. These trials, together with three experiments laid down in Scots pine stands in 1958, are the first involving manuring at this stage of growth. Little is known of the likely responses, so that the trials have a broad coverage taking the form of factorial tests of nitrogen, phosphorus, potassium, calcium and magnesium. Assessments include girth, height and foliar nutrient determinations in all cases.

Assessments to date have not yet been analysed, but first impressions are that there have been no increases in girth or height increment of the order encountered following manuring of certain checked plantations. Nitrogen and calcium dressings have had marked effects on the progress of litter decomposition in treated stands. Both have accelerated litter breakdown, and have encouraged development of fungal mycelia. Further developments on this project must await results of this first extensive series of experiments.

Crop Composition—Studies of Long-term Mixtures

Long-term mixture experiments with pure and mixed crops of Douglas fir/hemlock, Sitka spruce/hemlock and Scots pine/Red oak have been established in eight forests since 1954. The objects of these replicated trials is provision of material for study of the increment and form effects of mixture of species, as well as providing direct comparison of the effects of pure and mixed stands on soil conditions in controlled experiments. These objects will not be achieved for many years and attention is now being paid to studies of the conditions in existing non-experimental mixed stands. Site conditions, species composition and past management vary so greatly from one stand to another that comparisons are difficult. However, work is proceeding to devise forms of record which can be used in large numbers of stands.

Derelict Woodlands

No new work has been done on this project, other than that reviewed later under "Weed Control"; but a number of experiments comparing different methods of manipulating cover continue to be observed, and will give further useful information for some time to come. It is now generally accepted in the field that the solution to the problem of converting uneconomic broadleaved types is to underplant wherever the cover is tall enough and of suitable species, though there is still some doubt about the degree of cover to leave. The method has of course become possible due to the growing-up of many of the cleared or devastated woodlands dating from war-time (1939-1945) exploitations. Many of our experiments were laid down in lower cover types not suitable for underplanting, and their results will only be applicable should circumstances reproduce such conditions, locally or generally. Several experiments have however included underplanting in comparison with complete clearance (and other methods). In these, some of the advantages claimed for the use of underplanting have been confirmed, notably the considerable reduction in early weeding costs. None of the experimental underplantings have as yet had the overwood completely removed, and from comparisons of the accrued costs it seems likely that the final cost of removing the overwood will be a rather critical item. In certain instances where local markets were (at the time) favourable for the sale of coppice products, complete clearance was effected at very low net cost, or event at a 'profit'. In spite of high weeding costs, in some of these cases it is now clear that the total costs of establishment will be less for complete clearance than for underplanting.

There seems little evidence to support the conclusion that cover should *always* be maintained, or that it should generally be used for underplanting in a homogeneous manner. There seems to be some confusion of thought about the benefits of shelter. These may be very large and conspicuous in some environments and with certain species: for instance with beech in exposed situations on thin soils. In the conversion of hazel coppice to beech woodland on such sites it has been observed that the use of side shelter from strips of coppice is highly effective, and it seems likely that the important factor is the favourable moisture micro-climate. The reduction of light by using overhead cover does not seem to be beneficial to the underplanted crop, except insofar as it controls weed growth. In fact where comparisons have been possible, reduction of light has usually been accompanied by poorer growth. Optimum light conditions are often mentioned, but the term should only be used in the special sense of the most favourable compromise.

Another type on which the use of cover has important beneficial effects is the heavy clay soil. Here complete clearance often produces serious upsets in the water regime, and there may be much winter waterlogging, particularly if the site is poorly drained. Planting under cover on such sites is at least initially an attractive proposition, since the dense growth of grasses and the frost hazard are obviated. The maintenance of too heavy covers on clay soils have however been accompanied by serious losses; firstly in cold wet summers such as that of 1958, when Douglas fir suffered particularly; and again in the hot dry summer of 1959, when heavy clays became exceptionally dry under canopies late in the summer. Under the latter conditions, any benefit from shade in reducing the transpiration of the young trees may be outweighted by the high total evaporation of the overwood, which may dry out the soils to a considerable depth. The article entitled *The Drainage of a Heavy Clay Site*, by D. F. Fourt, in Part III of this Report (p. 137) may be referred to in this connection.

Wind Stability Studies

Large areas of the Commission's plantations are reaching a size when they may become susceptible to windblow, and studies in this field are being intensified to define the causes of windblow and to study the effect of species, site and silvicultural treatment on crop stability. These studies have been divided into three phases:

Firstly, observations on windblow as it occurs, with observations on the characteristics of crops and sites liable to blow. These records have been kept for some time and will continue with periodical analysis.

Secondly, measurement and study of the stability of individual trees as samples of crops, so that numerical values can be applied to stability of trees in different situations. This is being done mainly by measuring the force required to pull over trees and relating these forces to the external dimensions of the tree. It is hoped that with this data, site stability factors can be calculated which can be used as a measure in comparing silvicultural treatments and assessing the risk of windblow.

Thirdly, comes the study of the wind itself to determine the effect of edges etc., on wind force, and the order of forces applied to trees of varying species and size.

During the year a technique was developed for measuring the forces required to pull over trees, using a light hand winch with a spring dynamometer attachment. As the test tree is pulled over, dynamometer readings are recorded for each 1° of deflection of the tree from vertical. These values can be plotted against the angle of deflection to give a characteristic pattern of forces which can be used in comparative studies.

This technique was used to assess the influence of *Fomes* infection on the stability of Douglas fir. It was found that trees with an estimated 16% of

Fomes attack, corresponding to one main root dead, gave a 30% lower pull than a healthy tree of the same size, while a similar tree with 70% *Fomes* attack gave a 60% lower pull.

It was also shown that whereas a tree on a thin loam over clay may require a pull of around 1,500 lb. to pull it over, a similar tree of the same species on deep well-drained sand may require about 4,000 lb., i.e. an increase of 170%.

These trials are at an early stage, but with further work this technique could be invaluable in providing an objective measure of tree "root-hold" in examining the influence of site, species and silvicultural treatment on crop stability.

Weed Control

Weed control in all its aspects in the forest remains one of the most costly operations in establishment and maintenance of plantations, and a large programme of experiments on weed control methods was continued.

Total Weed Control

Extensive trials were laid down in 1956-1958 to examine the effectiveness of non-selective herbicides for total control of vegetation in fire-breaks, fence-lines, etc. The most promising results have been obtained with simazine and monuron, both of which are persistent, root-absorbed herbicides. Both materials have a useful role to fill for weed control in situations where mechanical cultivation or mowing equipment cannot be used. (See page 119).

Control of Grass Weeds

Work has been greatly extended in this field to evaluate the promising new herbicides now available for grass control. The herbicides under test, both before and after planting, include dalapon, amino-triazol (ATA), simazine and diquat. The main conclusions to date may be summarised as follows:

Dalapon. Applied at 8-10 lb. per acre in early summer or autumn, dalapon has given a high degree of control of established grasses, notably *Agrostis*, *Bromus*, *Dactylis*, *Deschampsia*, *Nardus* and *Molinia*. On the other hand *Festuca* and *Holcus* were more difficult to control. The most effective treatments were those applied to short regenerating grass in the spring-early summer, or following cutting at any season. Following a successful spray the grass growth collapsed to produce a mulch-like mat of dead vegetation, reducing the rate of weed regeneration, and conserving moisture. In the second season on many sites, the weed population is changed to predominantly broadleaved herbaceous species. Application of 10 lb. per acre in the spring or autumn *prior* to planting could be of practical value as no harmful residual effects have been found, and the control achieved makes for easy planting and reduced hand weeding costs. *Post*-planting sprays can cause extensive damage to foliage and young shoots, if applied during the growing season. In contrast, dormant-season spraying appears to cause little crop damage, and results suggest that directed spraying of crops in autumn and early spring would be of value at rates not exceeding 5-10 lb. dalapon per acre.

Simazine. Application as a localized 'spot' treatment at 5 lb. (active) per acre gross, shows promise for general weed control after planting. The compound has the advantage of being non-selective and persistent while its low solubility has permitted safe post-planting treatment of Norway spruce and poplar. Used at low rates in conjunction with dalapon, this compound could give near complete weed control around each plant position.

Diquat. (1, 1′—ethylene—2′,—dipyridilium dibromide). Preliminary trials on *Molinia* showed that mid-summer spraying at 2-4 lb. per acre kills top growth rapidly. It was noted that the inflammable dead top growth breaks down much more quickly than with any other treatment. This could be of value in reducing the fire hazard after treatment.

Current experiments are concerned with more detailed assessments of tree-crop susceptibility to these compounds to enable a safe practical treatment prescription to be made. In the future, further work will be done to examine the effectiveness of low volume (5-10 gal. per acre) sprays, and trials of combinations of herbicides for complete weed control.

Control of Woody Weeds

Work has continued on the lines described last year, with special emphasis on the practical utilisation of the well-known growth regulator-type herbicides. Progress is best discussed under the heads of the main methods of treatment, i.e. foliage sprays, basal bark or stem treatment, and stump treatments.

Foliage Sprays. Large scale trials were laid out for control of bramble under larch crops in preparation for underplanting, with the object of assessing practical results with several formulations of 2,4,5-T applied at low and high volume. Promising results have been obtained using a motorised knapsack-type "Mist-blower" for application of volumes of 10-15 gal. per acre to dense bramble thickets. This result is considered of great importance, as the slow rate of work and the high spray volumes required to give adequate coverage with conventional spray equipment are major factors in holding up more widespread use of herbicides for control of low brush. The "Mist-blower", together with new and cheaper formulations of 2,4,5-T, could be of considerable practical value.

Current experiments include tests of invert (water in oil) emulsion formulations, as well as conventional oil in water emulsions of 2,4-D and 2,4,5-T, for selective control of broadleaved and herbaceous and woody weeds in young plantations, applied at low volume by "Mist-blower". Indications are that applications in late summer, after bud formation in conifer crops, can achieve a high degree of weed control without serious injury to the crop. This is also being investigated this year by helicopter spraying of underplanted hardwood scrub for release of the underplanted crop.

Basal Bark Sprays. The relatively high quantities and cost of 2,4,5-T and diluent oil has prevented more general adoption of this treatment. However, recent experiments include tests of cheap unformulated 2,4,5-T esters which are giving promising results at about one-third the cost of normal fully-formulated esters. Tests are also under way with invert emulsion formulations as a possible means of reducing the proportion of costly oil diluent in the spray. Trials of the "Mist-blower" for basal bark treatment in inaccessible multi-stemmed coppice stools, e.g. hazel, are encouraging.

Stump Treatments. There is little new to report. This is the most widely adopted stage of treatment and trials in 1958/59 confirm conclusively that the periphery and bark of stumps are the main targets for treatment.

Bracken Control

During the year a survey was made to assess the status of bracken as a weed in Commission areas. Provisional conclusions are as follows:

(i) Bracken can be an important weed in afforestation of old grazing land or woodland. The main effect on young trees is competition for light in the growing season and crushing when the fronds die in autumn.

(ii) Pure vigorous bracken is the most troublesome in practice. However, the most widespread type is less vigorous bracken associated with grass.

(iii) Normal weeding practice is to cut the fronds by hand, two cuts being made in the first year, and thereafter, one cut per year for about three years on most sites. Costs range from £1:10:0d. to £6:0:0d. per acre (average £3) per annum=£4:10:0d to £18:0:0d. (average £9) per acre total weeding costs to establish the plantation.

(iv) Foresters are sceptical about the use of herbicides on bracken, mainly because of the preponderance of the bracken/grass type, and the view that bracken control will result in increased expenditure on grass weeding. Interest in herbicides is largely centred on limited areas of pure bracken, or areas where there are obstacles to normal weeding, e.g. old woodland.

(v) Application of herbicides presents a problem and it is estimated that 70% of areas requiring bracken weeding are inaccessible to tractor-mounted sprayers. Also, many of the areas are in small blocks which are not attractive for aerial treatment. Mist-blowers could be useful in small areas.

(vi) There is concern about drift into young plantations of herbicides such as 4-CPA and ATA which can be used for bracken control. Field tests in 1959 showed appreciable damage to shoots of Japanese larch and Douglas fir, and browning of needles of Norway spruce and Corsican pine following a drift spraying of thicket-stage trees with 4-CPA.

Field experiments testing 4-CPA, dalapon and ATA for control of bracken were established in 1959, and include planting tests to assess the susceptibility of tree species to chemical residues.

Protection of Trees Against Damage by Animals

A new development was the trial of nylon netting as a cheaply-erected alternative to conventional netting and wire-strand fencing for exclusion of deer from regeneration areas. Using 6-foot wide lengths of 6-inch square mesh nylon, a fence can be erected very rapidly at low cost, especially in situations where the netting can be suspended from surrounding trees. First observations on the effectiveness of the net are encouraging.

Fire Control

Further trials were completed testing sodium calcium borate and mono-ammonium phosphate as fire-retardant materials for fireproofing vegetation. Both materials proved effective retardants applied as drenching sprays at 4 lb.

per gal. and 2½ lb. per gal. respectively. The borate material is insoluble, forming a heavy abrasive slurry with water, and requires specially designed pumping and spraying equipment. This is a serious and costly disadvantage and ideally a retardant for general use must be capable of application through existing spraying equipment. Monoammonium phosphate goes some way to meet these requirements and could be of value in controlled burning operations and enabling safe counter-firing during actual fire fighting.

An alternative technique of controlled burning which will be tested this summer, involves desiccation of vegetation by herbicide treatment to permit safe burning during months of vegetative growth.

Arboreta

The Research Branch is concerned with the management of two large arboreta in the South of England, namely the National Pinetum, Bedgebury, Kent and Westonbirt in Gloucestershire. Perhaps the most notable development at these arboreta has been the sudden rise in their popularity with the general public, a trend which is most encouraging, but which brings various problems. It has been found necessary to provide extensive car parks at both places.

Westonbirt Arboretum

This well known arboretum passed into the hands of the Forestry Commission in 1956, and its management is a Research responsibility. It will continue to be managed as a great collection of trees and shrubs of horticultural value and botanical interest. Arboreta such as Westonbirt are of value to forest research as a display and store of the rarer exotic trees. A large section (Silkwood) of the arboretum, which is only partially developed, may be used to display some of the more important broad-leaved genera, such as the elms, which contain much variation. Here also coniferous species unsuited to the climate and soils at Bedgebury will be represented.

The glasshouses at Westonbirt have been reconstructed for the installation of mist propagating frames to serve the arboretum, and also to provide facilities for grafting in connection with the Geneticist's programme. Progress has been made with a detailed survey and catalogue of the arboretum, and also with many urgent arboricultural measures.

The National Pinetum and Forest Plots, Bedgebury

It has been decided that the Pinetum should display variations in forest species of economic importance, in addition to the chief botanical varieties, which have always been represented. For certain trees this will mean that the more contrasting provenances will be represented, but where a genus of species has been subject to deliberate selection or other tree breeding techniques (including hybridisation), some of the more important products of such work may be represented. The general object is to increase the scientific interest of the collections.

The Forest Plots now total 128 and over 90 species are represented. It is now noticeable that on this site, an acid silt of poor rooting properties, some of the first planted species (now about thirty years of age) are beginning to show signs of debility. This is specially noticeable in *Abies grandis*, which till recently showed the best volume increment amongst the conifers. Douglas fir is also unhappy.

A Putative Nothofagus Hybrid

In the Bedgebury Forest Plots two Chilean species of *Nothofagus* are represented, *N. obliqua* and *N. procera*. Both species have shown some promise as exotic forest trees in Britain, though the latter has not been particularly successful in the eastern parts of the country, and appears suspect in its tolerance of low winter temperatures. At Bedgebury, the plot of *N. procera*, which was planted in 1930, grew well to start with, but the majority of the trees were killed during the severe winter of 1939/40, when temperatures below zero F were recorded locally. Several trees however survived, and in recent years have borne viable seed. A further plot of *N. procera* has been established at Bedgebury from seedlings of these parent trees in the hope that they may represent some selection for winter cold resistance. No winter conditions comparable with those of 1940 have yet allowed us to test this fully. *N. obliqua* at Bedgebury has behaved very much better. Planted in the seasons 1930-1934, the growth of the plot has been extremely fast. The dominant trees are now some 60 feet tall. The plot of *N. obliqua* is about 200 feet from the surviving *N. procera* trees of the original planting.

In 1957, seed of both species collected at Bedgebury the previous summer, was sown at Alice Holt. A number of untypical seedlings were observed in the *N. procera* seedbed towards the end of the growing season; these were noticed largely because of their especial vigour, which seemed to single them out from the surrounding population. The abnormal seedlings (8 in number) have been lined out in comparison with typical seedlings of *N. procera* and *N. obliqua*, and have been kept under observation, A number are apparently worthless, but three appear to be maintaining their vigour and may prove of some interest.

No full analysis of the morphological characters has yet been carried out, but inspection of the more obvious features certainly suggests that the abnormal plants are intermediate in the following respect; (i) in numbers of veins in the leaf, (ii) in the characters of the leaf margins, and (iii) in the quantity of glandular hairs on the young shoots. So far as is known, no hybrid between *N. procera* and *N. obliqua* has yet been described, and it would not be safe to assume that these plants are hybrids on the present evidence. The circumstances however suggest that this is a plausible explanation, and the plants will be submitted to a more detailed examination as more mature characters develop.

The Effects of the Hot Dry Summer of 1959

Over most of Britain 1959 was an exceptional season. The sunshine was well above the average, in fact for England and Wales it was the sunniest year since 1911. The summer was generally very dry, and warm, except in the north west of Scotland. According to the Meteorological Office "the total general rainfall for the period May to October was the lowest for any such period since before 1870 and probably since 1750" (Meteorological Office "Monthly Weather Report" October 1959 H.M.S.O.)

Some of the effects of exceptionally warm dry summers are well known, for instance many trees flower very freely in the subsequent season. One may also expect a number of undesirable results from long droughts. The season of 1959 appeared sufficiently remarkable to warrant some special effort to record the more outstanding occurrences. Accordingly a questionnaire was issued to all Commission forests asking for information about some of the more observable phenomena which might be expected, such as planting losses, mortality in older plantations, stem crack, defoliation, etc. Information was also sought on the behaviour of nursery stocks; on cone and fruit size; and on the effect of the dry summer on cultural operations such as weeding.

Certain other investigations have been conducted directly. While the evidence is still being studied, it is clear that the season of 1959 will not appear as one of exceptionally heavy general losses, and there may prove to have been more drought phenomena in certain other seasons for which the meteorological statistics have been less striking.

SILVICULTURAL INVESTIGATIONS IN THE FOREST

(B) SCOTLAND AND NORTH ENGLAND

By M. V. EDWARDS, G. G. STEWART, R. LINES and D. W. HENMAN

Replanting Areas of Recently Cleared Conifers

During the previous two years, experiments concerning the problems involved in the replanting of hill land have been confined to windblown areas. This year, two experiments have been established on ground where the crop was felled for the purpose. The first was at Lennox Forest, Stirlingshire, where 4 acres of 26 year-old Sitka spruce, growing unsatisfactorily on a very heavy clay soil, were felled. The experimental replanting is designed to compare the survival and growth of a number of species planted on ploughing (hydraulically-mounted tine plough) and by direct notching. The species plots are sufficiently large to allow assessments to be continued into the crop phase.

The second experiment, which is similar in design, is at Allerston Forest, Yorkshire. About 10 acres of Japanese larch, 38 years old, were felled last year. The larch appeared to be growing only very slowly, but might have reached maturity on this upland heath site. As at Lennox Forest, a number of species have been planted on ploughed land, and by direct notching into the undisturbed ground. After some preliminary trials of tine ploughs, it was decided to use a very heavy "rooter" consisting of a number of tines without mouldboards, and this very heavy machine was pulled by a crawler tractor more powerful than it is normal to employ for ploughing. The result of the cultivation was good, although no conventional "ridge and furrow" was produced, and the work was done quickly. Thus it is possible that if cultivation is found to produce a worthwhile advantage, the employment of heavier machinery and more powerful tractors than have hitherto been used in afforestation practice, may be necessary.

Draining

One of the main difficulties in determining whether peat bogs are suitable for planting is the doubt as to whether the slope is adequate to run the water off after ploughing. At the southern end of the Watten experimental area in Caithness there is a very wet and flat area which was too soft to plough, but which was drained and turfed by hand. Some of these drains run water freely, while others do not. By means of a 'Dumpy' level it was ascertained that where the fall was 1 in 174, the water was able to run, but that where the fall was 1 in 600 it was not. In order to avoid pools accumulating in irregularities, and to ensure a fast enough flow for a drain to keep itself clear, the minimum slope needs to be greater than 1 in 174, possibly 1 in 120, which is approximately equal to $\frac{1}{2}°$. This angle is often recommended in agricultural practice. More evidence is being accumulated on this point.

Afforestation Problems

Peatland

Further evidence has been obtained by the Forest Soils Section of the Macaulay Institute of deficiencies in potash and other elements in pine crops growing on deep acid peat. These crops have been established successfully by deep draining and cultivation of the peat, and by the aid of phosphatic fertilizers at the time of planting. It appears that by the time the crop phase is reached, when there is a considerable volume of material in the trees, potash supplies may become deficient; additional phosphate may also be needed. This has been found to be the case with both Scots and lodgepole pines, and it appears to be even more important for Sitka spruce, of which very few plantations have been brought to the crop phase as yet.

Now that successful experimental pole crops of pines have been produced on deep acid peat, it is intended to try out the techniques on a large scale. Large areas of such peat have been acquired, and plantations of lodgepole pine will be made on them to the extent of 50 to 100 acres annually in each of three experimental forests. This will be done by Conservancy staffs as part of their normal programme, to ensure that the test is carried out under normal conditions, but the Research Branch will hold a watching brief.

Trial Plantations at High Elevations

Many plantations made under the normal afforestation programme have been extended to abnormally high elevations. In the last few years some additional plantings have been made above what is usually considered to be the planting limit. More such trial plots are now being planted as part of Conservancy afforestation programmes. The Research Branch is giving advice on the methods to be employed and has assumed responsibility for recording exactly what is done in each plot. After some years, when the success or otherwise of the plots becomes apparent, they should provide evidence for adjusting the planting limit to suit local conditions. These trial plantations are larger in extent than the plots created by the Research Branch in the past as, under limiting conditions, a large plot, in which the centre is protected by a wide margin, is more likely to be successful.

Trial Plantations on other Limiting Sites

In a part of the Pennines, which suffers from heavy atmospheric pollution, an experiment laid down last year has been extended. This experiment was designed to test the effect on lodgepole pine and Sitka spruce of planting inside and outside a circular lath shelter fence. This year 33 zinc plates have been hung from small gallows at 2 feet (about half the height of the shelter fence), along a series of radii from the centre of the circle and extending beyond the fence. The pollution will be estimated by the corrosion of the plates as determined by their weight. Four lead peroxide gauges, one of them not protected by the fence, are also being used to record pollution.

Comparison of Pure and Mixed Crops

The project for establishing long-term experiments with two-species mixtures described in earlier reports (1955-57) has continued, and three further experiments have been planted. Two of these designed to test pure and mixed plots of Japanese larch and lodgepole pine, are on upland heath sites at Fetteresso, Kincardineshire, and Elibank in the Tweed valley. The third has Scots pine and birch in pure plots and in two types of mixture: 50 per cent of each species, and 25 per cent birch and 75 per cent Scots pine. Study of the soil beneath the different crops will be an important aspect of this investigation, which it is proposed to repeat on sites in the Yorkshire Moors and on a lowland heath in the south of England.

The experiment undertaken in 1955 with the co-operation of the Nature Conservancy at Gisburn, Yorkshire, has run into some early difficulties in establishing the broadleaved species, sessile oak and common alder. In the case of the latter, very extensive beating up has been required over a period of several years. Very little beating up was needed with the Scots pine and Norway spruce. It can now be said that the experiment is successfully established.

Unfortunately the same cannot be said for the mixture experiment with Sitka spruce and Western hemlock planted in 1955 at Carron Valley, Stirlingshire. The hemlock suffered severe losses in the year after planting, necessitating an almost complete replant, and these replacements have now been badly attacked by an increased vole population. These animals prefer the hemlock to the spruce, and, as poisoning them is out of the question since the area lies within a water catchment, the future of the experiment remains in the balance.

The experiments planted in 1956 at Speymouth, Morayshire, and Devilla, Fife, using Scots pine and Western hemlock in mixture, are now successfully established. Here also early losses were considerably heavier in the hemlock than the pine, but both species are now growing well. The mean height of the Scots pine was greater than that of the hemlock at both sites at the end of the third growing season. It is too early to expect any difference in growth rate due to mixing the species.

The mixtures of Douglas fir with Western hemlock planted in 1957 at Yair Hill, Selkirkshire, and Hamsterley, Co. Durham, have grown well and form an interesting contrast. The former has a rather exposed position, with bare hillsides on every side, while the Hamsterley site, though only 100 feet lower, is more sheltered both topographically and because of surrounding woodlands. This difference in exposure may account for the rapid early growth of the hemlock (some trees already exceed four feet in height three years after planting) at the latter site. The hemlock has outgrown the Douglas fir on the average by about six inches. At Yair Hill, the Douglas fir is slightly taller than the Western hemlock, but has suffered some leader die-back from cold winds during the winter 1959/60, as the plants have now grown above the shelter of the plough ridges.

Manuring in the Forest

Another experiment in the manuring of pole-stage crops was added to the series begun last year. The new experiment was in slow-growing, 30 to 35 feet tall, Scots pine at Ardross Forest, Ross-shire, As before, the responses to the nutrients applied (nitrogen, phosphate. potassium, magnesium and calcium, each at three levels) will be estimated on a plot basis by basal area and top height and by measuring girths of selected trees using aluminium-band dendrometers. This type of experiment is complicated and time-consuming to establish; each represents a major effort on the part of field staff.

The Macaulay Institute has continued its investigation into the nutrient content of the needles of conifers growing under different manurial conditions. By this most important work, information is gradually being built up about the optimum levels of the major nutrients for satisfactory growth.

Spacing

In collaboration with Silviculturist (South), a survey of all the 1935-36 spacing series of experiments was undertaken to determine the suitability of each for long-term study. Suitable series were selected to form the blocks of replicated experiments, in which the results of different initial spacings, and of different thinning methods superimposed on these, can be examined statistically.

Thinning

The thinning experiment in Sitka spruce, mentioned in last year's report, was established at Loch Eck Forest, Argyll, during the year, and will have its first thinning in April, 1960. The study is confined to low thinning, and compares the effect of different grades of thinning applied at different intervals of time, this combination of grade and periodicity being termed the "intensity" of the thinning. Grades are specified in terms of percentage of yield table basal area after thinning, and five grades are being compared: 120 %, 100 %, 80 % 60 % and 40 % of that yield table basal area which corresponds to the top height of the plot. Thus, the emphasis is on much heavier grades of low thinning than those used in the sample plots on which the yield tables are based, and it is thought that the heaviest thinning may lie beyond the limit at which thinning grade has no effect on the final total production of the crop. Thinning intervals of three, six and nine years are compared, with the lightest grade being applied only at the shortest interval and the heaviest grade only at the longest interval. The treatments are summarised in tabular form below, the intensities which are to be compared being indicated by bars.

Initial periodicity	120%	100%	80%	60%	40%
3 years:	–	–	–	.	.
6 years:	.	–	–	–	.
9 years:	.	.	–	–	–

The principal object of the experiment is to compare the effect of these intensities on volume yield, both total yield and by assortments, and on timber quality; but other crop and site characteristics which later prove to be of interest, will be studied. The establishment of the experiment has already raised important problems of plot size: e.g., what is the minimum plot size permissible in crops to be grown on long rotation?; and also of site uniformity, e.g.: should plots be arranged to exclude small irregularities, which appear important in the early stages but may become relatively less so as the crop develops, or should these irregularities be accepted and treated as part of the variation between plots, to be estimated in the analysis of results?

Pruning

The disbudding experiments begun in 1947-1949 and described in the Annual Report of 1955 were finally closed. A detailed report of the experiments after 11 years is included in Part III of this report, as the article "Pruning of Conifers by Disbudding", by D. W. Henman. It shows that the method was unsuccessful with Douglas fir and Sitka spruce and was of little practical use for pines, except where very short lengths of knot-free stem might be required, regardless of cost. (See page 166).

Loss of Increment, Windthrow and Disease in Pole-stage Spruce Crops

The investigation of unhealthy spruce crops on shallow soil over heavy clay, which the spruce roots failed to penetrate, was referred to in the *Report on Forest Research for* 1957, p. 46. Subsequently it was shown that Oregon alder (*Alnus rubra*) on the same site was able to root more deeply than Sitka spruce. Loss of increment in other crops has since been investigated, sometimes but not always on shallow soils over heavy clay. Sometimes the damage has been attributed to fungi, sometimes to insect attack, e.g. *Neomyzaphis abietina*. Regular observations of affected crops are to be made in order to isolate the different factors at each site. A similar case in Japanese larch on an upland heath is also being examined, and a series of experimental treatments, designed to find the effect of the removal of grass competition, is being employed. Both these experiments are linked with the reforestation experiments mentioned in a previous section.

Protection against Deer

Trials to find methods, cheaper than conventional fencing, of excluding roe deer from newly replanted areas within a forest continued. So far results have been disappointing. After the first winter an experiment at Grizedale Forest, Lancashire, showed that plots protected with branches from brashing suffered less from browsing than unprotected controls; but after the second winter, there was little difference between any plots. The use of seven-foot tall, wide-mesh nylon netting has been tried for the first time this year. The netting is erected rather like an ordinary fence. Its effectiveness has not yet been fully tested.

PROVENANCE STUDIES

By R. LINES and J. R. ALDHOUS

Japanese Larch

The series of experiments comparing twenty-five provenances, planted in the spring of 1959 and described in last year's report, suffered negligible losses despite the long dry summer. At Fetteresso, even the poorest provenance had a survival of 94%, while at Broxa in Allerston Forest the overall survival was 99%. Losses were also low at Ystwyth. Growth, however, has been small, so that little has been added to the nursery information on vigour. At Fetteresso the poorest site of the three, the plants in the experiment were given a dressing of ground mineral phosphate which improved their appearance and shoot growth compared with similar plants on adjacent unfertilized ground. It is already possible to distinguish certain provenances, such as those from Asamayama, Hontaniyama and Nagakurayama, which have a proportion of plants with poor stem form.

Sitka Spruce

The collection of twelve provenances ranging from Alaska to Southern Oregon, which had been sown in 1958, was lined out in the spring of 1959 at Benmore and Fleet nurseries in Scotland, and at Wareham nursery in England.

The differences in height growth which appeared in the seedling stage were maintained in the transplants, plants of the two most northerly origins being about half the size of plants from Washington, at the end of the growing season.

Phenological observations showed little variation in the time of commencement of growth, the two most northerly provenances being slightly ahead of the other races. However, these two provenances completed their growth and formed terminal buds in early July, and while a small proportion of the plants broke bud and had a second period of growth, this did not amount to much. The other provenances continued to grow in height well into September, the most southerly provenances into October, none of them forming terminal buds in mid-season.

Seven planting sites for this collection of provenances have been chosen in the most important parts of the Sitka spruce range in Britain. The same provenances will also be planted in 1961 on two or three other sites in order to complete the range of environment.

Brief mention was made in the Report on Forest Research, 1954, of an experiment planted that year comparing an Alaskan provenance from Hollis, Prince of Wales Island, with others from the standard Forestry Commission seed source —the Queen Charlotte Islands—and home-collected seed from a stand thought to be of Washington origin at Stonefield Estate, Argyll. The sites chosen were Strathy, Sutherland and Kielder, Northumberland, which are separated by more than three degrees of latitude. It was thought that the Alaskan provenance might show relatively better growth at a higher latitude, though Hollis is in fact on the same parallel of latitude as Kielder. It will be seen from Table 4 that the Hollis plants were somewhat smaller than the other provenances and this difference in height has persisted through the first six years. The Alaskan provenance has grown nearly as fast as the Queen Charlotte Islands one, but the home collected origin has grown highly significantly faster than either of these. However, both the Queen Charlotte Island and the Alaskan provenances compare more favourably with the home provenance at the northernmost locality, i.e. Strathy.

At Kielder there was frost damage to all provenances in the spring of 1958, and as a result many double leaders developed during 1958 and 1959. A count after the 1959 growing season showed 48% of the Hollis plants with forked stems, while the Queen Charlotte Islands and Stonefield provenances had 56% and 35% respectively. It is encouraging that the home provenance, despite its Washington origin, seems to be less affected by frosts than the other two.

Table 4

Height Growth of Three Provenances of Sitka Spruce at Strathy and Kielder

Feet

Provenance	Strathy				Kielder				Mean			
	At Planting	1 yr	3 yr	6 yr	At Planting	1 yr	3 yr	6 yr	At Planting	1 yr	3 yr	6 yr
Hollis, Alaska	0·34	0·79	1·07	3·37	0·38	0·58	0·99	2·56	0·36	0·68	1·03	2·96
Queen Charlotte Is.	0·37	0·84	1·08	3·42	0·43	0·66	1·07	2·85	0·40	0·75	1·08	3·13
Stonefield, Argyll	0·37	0·73	1·14	4·02	0·42	0·67	1·42	3·97	0·40	0·70	1·28	4·00
Standard error of means	—	0·03	0·04	0·14	—	0·01	0·04	0·01	—	—	—	—
Significant at	—	5%	not sig.	1%	—	1%	0·1%	0·1%				

In June 1959 it was observed that there were apparent differences in infestation by *Neomyzaphis abietina* in the experiment planted in 1950, in which six provenances from Washington and one from the Queen Charlotte Isles were represented at Kielder, and a full assessment was carried out. The infested trees usually had pale green to off-white needles. Trees with a normal healthy green colour were normally not infested. The assessment showed considerable variation in *Neomyzaphis* attack within each provenance, and no significant differences between provenances could be detected.

Western Hemlock

At Benmore, Fleet and Wareham nurseries, seed of eighteen provenances was sown in spring, 1959. Sixteen of the provenances were from natural stands in North America and two were from plantations in the British Isles (Avondale Co. Wicklow, Eire and Inveraray, Argyll).

All provenances germinated within a few days of each other, but the yields at the end of the season of the two British provenances were significantly higher than those of the North American provenances. Within the North American provenances, seed from Shuswap Lake had an abnormally low yield.

Seedling height at the end of the first season varied considerably between provenances. For instance, at Fleet Nursery the largest seedlings (Inveraray, Argyll) averaged 3·65 inch, while the smallest (Juneau, Alaska) averaged only 1·29 inch. Height growth was strongly correlated with the latitude of origin of the seed, southern provenances (as might be expected) being generally taller than northern; it was also related to seed size (1,000 seed weight), but less clearly. (The relationship between seed size and provenance of seed is discussed by Buszewicz and Holmes in the paper entitled " A Summary of Ten Years Seed Testing Experience with Western Hemlock", in Part III, page 110). The best explanation of seedling height is obtained by taking into account distance from the coast as well as latitude, since inland provenances have generally made poorer growth than coastal ones.

As in the Sitka spruce experiment described above, there were considerable differences in the time of the formation of terminal buds in the autumn. The northern provenances formed buds earlier than the southern ones, and the Enumclaw provenance was also among the early group, perhaps because it comes from a comparatively high elevation. The two European lots behaved very differently; Avondale having set buds on 80% of the plants by 19th December, while Inveraray had set buds on only 5% on the same date. Slight frost damage, restricted to this provenance, was recorded at the time despite the protection of lath covers. The majority of plants had formed no proper resting buds and later inspections showed an appreciable amount of frost damage to the tips.

Douglas Fir

The attack of the needle-cast disease *Rhabdocline pseudotsugae* on the experiment planted in 1943 at Glentress Forest, Peebles which was noted, in the *Report on Forest Research* for 1955, has continued and a more detailed investigation has since been carried out. Height was measured at the end of the 1957 growing season and the following spring a sample of ten outside trees per plot was selected. The stage of flushing of these trees in early June, 1958 was noted, and later in the same month the Pathologist scored them for incidence of *Rhabdocline*. Dates of flushing varied considerably between the provenances. The interior British Columbia group flushed later than the coastal (Vancouver Island) group, and trees from the West coast of Vancouver Island flushed later than trees from the East coast of the island.

The attack by the needle-cast disease *Rhabdocline* was highly significantly worse on the interior British Columbia provenances than in the Vancouver Island ones. There were no significant differences in incidence of *Rhabdocline* within either the coastal or the interior groups. Although there is not as yet any significant difference in height between the provenances in this experiment, recent height growth in the interior British Columbia provenances is appreciably poorer than in the Vancouver Island ones, and there seems little doubt that the former have lost vigour from their relatively more severe attack of *Rhabdocline.*

Other Species

After some preliminary investigations into the Common silver fir, *Abies alba,* (published in *Scottish Forestry* Vol. 14 (1) 1960), it was decided to make a collection of different provenances in the hope that one or more might be found which were sufficiently resistant to attacks of *Adelges nüsslini* to justify more widespread use of this potentially useful species. Owing to a general crop failure on the Continent, only five seed lots were obtained, but further efforts will be made to get a representative collection during 1960.

A collection of 14 provenances of *Thuja plicata* has been sown at Tulliallan nursery, Fife, and Wareham nursery, Dorset. It concludes eight provenances from British Columbia, four from Washington, one from Oregon and a home collected seed lot from Hampshire.

POPLARS AND ELMS

By J. JOBLING

I. POPLARS

Varietal Studies

Varietal Trial Plots

Sixty-six plots were planted during the winter at ten trial areas. Of these 21 were to replace plots which had failed in otherwise successful trial plantations at Doncaster Forest, Yorkshire; Wynyard Forest, Co. Durham; Harling, Thetford Chase, Norfolk; Hallyburton Forest, Angus and Perth; Greskine Forest, Dumfries; and at Brahan Castle Estate, Ross-shire. The remaining 45 plots were planted on new ground at Wynyard Forest; Rogate Forest, Sussex; Ledbury, Hereford Forest; Quantock Forest, Somerset; and at Whittingehame, Stenton Forest, East Lothian. In the trial at Ledbury, only clones of *P. alba*, *P. tremula* and *P. canescens*, and hybrids between them, will be tested. During the year under review six clones of *P. canescens* and one of a *P. alba* hybrid were used.

Assessments were started or continued at trials where plots have reached the age of six years.

Varietal Collection

This now contains 389 clones, a net increase of 16 over the previous year. The most recent introductions were received from Canada and Hungary, mainly of hybrids between *P. tremula* and *P. tremuloides*, for inclusion in trials of resistance to bacterial canker.

Populetum

Only eight clones were planted during the year, bringing the total to 248, out of a probable maximum of 320 clones. Some 20 clones are at present being propagated specifically for inclusion in the populetum, while an equal number will be observed for a two- or three-year period in the nursery before a decision on their suitability is made.

Silvicultural Experiments

A number of short-term experiments have been maintained and assessed during the past season. These are mainly concerned with methods of pit preparation and with planting treatments, though several experiments comparing the behaviour of different age-types of planting stock have remained under observation. Current results have again tended to confirm earlier findings, and sufficient data have become available to warrant the preparation of reports on these projects.

Methods of Pit Preparation

At two sites, trees planted in holes prepared by explosive, 1·6 ounce and 4·0 ounce cartridges of Poplar Ammon Gelignite, have continued to grow at a faster rate than trees planted in normal hand dug pits, after five seasons at Alice Holt Forest and three seasons at Gaywood Forest, Norfolk. At each site, recent assessments also show that trees planted in holes prepared by the larger quantity of explosives are slightly more vigorous than trees in holes prepared by the smaller quantity. This appears to be due, partly, to planting in a larger pit, but it is probable also that much of the benefit results from the more extensive soil movement, facilitating better root penetration around the pit, resulting from the larger charge.

Planting Treatments

Experiments planted in 1957 at Gaywood Forest and Creran Forest, Argyll, continued to be observed. In these the effects of different mulch materials, applied at different depths and maintained over several periods, are being tested. At Gaywood Forest any mulches were effective, but cut green vegetation proved superior to bark peelings, and used fertiliser-bags were the least effective of the materials tried.

At Creran Forest similar results have been obtained, though in addition it was noted that a mulch 12 inches thick, of either cut vegetation or bark peelings, has given better shoot growth than a mulch only 6 inches thick of these materials, during the second season.

Age and Type of Planting Stock

In an appraisal of the experiments in this project, certain conclusions have been reached which have enabled a report to be prepared for publication. These conclusions can be briefly summarised:—

(1) Of four age-types of plant tested, one-year rooted cuttings stumped and transplanted for one year, have a higher rate of survival, and grow at a faster rate during the establishment period, than any of the other three types, namely one-year rooted cuttings; one-year rooted cuttings stumped and transplanted for two years; and unrooted sets.

(2) One-year rooted cuttings exhibit the next best survival and growth after planting. By widening the nursery spacing their quality may be improved as regards height, stem diameter and branchiness; and their behaviour in the field may then be nearly as good as that of one-year rooted cuttings stumped and transplanted for one year.

(3) One-year rooted cutting stumped and transplanted for two years were the least satisfactory of the three rooted types of plant tested for both survival and early growth. Due to their initial height advantage at planting, however, surviving plants may still be substantially taller than either of the younger ages for some years after establishment.

(4) Unrooted sets had the lowest rate of survival and slowest growth during the establishment period of any age-type of plant tested. Two-year-old sets are preferable to one-year sets, unless the latter are of very high quality. Sets are most likely to succeed on moist sites where competitive weed growth can be suppressed, when surviving two-year-old sets may be taller at the end of the establishment period than stock planted with only a one-year shoot.

(5) Small plants, which are sturdy and well branched, (3-4 feet for one-year rooted cuttings and one-year transplants, and 5-6 feet for two year transplants) may grow at the same rate during the establishment period as stock substantially larger.

(6) The results obtained are applicable to all species and hybrids of poplar commonly cultivated in Britain.

No new long-term experiments have been started during the year and work has been confined to maintenance of those laid down since 1955. The spacing experiments at Gaywood Forest and Blandford Forest, Dorset, have both been assessed. The first was planted in 1953-54, the second in 1954.

Nursery Investigations

Studies have continued on the use of herbicides for control of weed growth in cutting and transplant beds, and on the use of inorganic fertilisers in poplar nurseries. Propagation of difficult clones, mainly of *P. tremula*, and related species and hybrids, and of *P. canescens*, was again carried out by rooting softwood cuttings by the mist technique, and 718 plants were raised during the summer by this means. A few of these, (especially of *P. canescens*) from cuttings rooted during the early part of the growing season, were considered sufficiently well-grown to be transferred to field trials during the winter. The majority, however, have been lined out in the poplar nursery at the Research Station, where they will be retained for one or two years until large enough for planting out. Techniques for improving the quality of rooted summerwood cuttings are being studied.

Distribution of Cuttings

Eight standard varieties were again distributed during early spring, to private estates, trade nurseries, Forestry Commission nurseries and to the Government of Northern Ireland, as shown in Table 5. 31,543 cuttings were dispatched, as against 43,036 for the previous season.

Table 5

Distribution of Cuttings of Standard Varieties

Destination	1. *P.* 'eugenei'	2. *P.* 'gelrica'	3. *P.* 'laevigata'	4. *P.* 'robusta'	5. *P.* 'serotina'	6. *P. tacamahaca* × *trichocarpa* 32	7. *P. tacamahaca* × *trichocarpa* 37	8. *P.* 'berolinensis'	Total
Forestry Commission ..	562	212	962	1,212	962	3,087	1,687	232	8,916
Private Estates ..	1,610	160	1,650	2,660	310	1,344	260	110	8,104
Trade Nurseries ..	1,325	1,000	1,012	2,024	1,400	1,325	2,137	300	10,523
Govt. of North. Ireland	—	—	—	1,000	—	1,000	2,000	—	4,000
	3,497	1,372	3,624	6,896	2,672	6,756	6,084	642	31,549

In addition, gifts of cuttings of a number of non-standard clones were made to research workers in Belgium, Canada, Eire, Holland, New Zealand, Pakistan and Poland.

Bacterial Canker Investigations

Some 160 clones were planted at Fenrow Nursery, Rendlesham Forest, Suffolk, during the winter, each generally represented by 10 'long cuttings'. These will be inoculated with bacterial slime during mid-May 1960. Material of six clones of known susceptibility or resistance to bacterial canker was sent to the Phytopathologisch Laboratorium "Willie Commelin Scholten", Baarn, Holland, and equivalent material planted at Fenrow Nursery, as part of a joint study of methods of inoculation and assessment. Material was also received from Holland for planting at Fenrow.

II. ELMS

The field survey, started in the previous year, was continued in the south and east of England. Attempts were again made to locate potentially valuable trees, and some 20 specimens were selected for inclusion in the clonal collection. The growth of elm in woodland was also studied, and several stands were visited or noted for future inspection. To date, 32 clones have been selected of trees in hedgerows, parkland and woodland, of which 19 are *U. carpinifolia* x *glabra* hybrids. The remainder are representative selections of *U. carpinifolia*, *U. glabra*, *U. procera* and *U. stricta* and its varieties.

Propagation of softwood cuttings, using the mist technique, was carried out on a larger scale than previously during the summer. Some 620 plants of 24 clones were successfully raised, representing a take of 57% of the total number of cuttings inserted. A few clones appeared to root easily, and a take of over 80% was recorded in three instances. Eleven other clones had a take of between 60% and 80%. The least satisfactory results were obtained with three out of four clones of Dutch elm; material was collected with difficulty from mature trees and the poor take of 20% may be attributable to the low quality of the cuttings used. Otherwise there appeared to be no clear relationship between rooting ability and origin of material, as cuttings taken from other mature trees were rooted without difficulty, nor was it possible to determine whether some species or hybrids rooted better than others.

Rooted cuttings are now being used in elm disease trials in preference to grafted plants. The former reach a size at present considered suitable for planting out after only one year in the open nursery. It will be interesting to compare their early field behaviour with that of grafted plants, which have been difficult to establish in some trials. Rooted cuttings have also been planted in a nursery at the Forest Research Station, where it is hoped to give selected clones a preliminary screening for resistance to elm disease, by inoculating the plants after they have become established. During the winter, 23 clones were planted in this trial; 10 are selections made during the past two years of particularly well-grown trees, 10 others are clones received from Holland and 3 are selections made in this country, during the early study of elm disease, which have since proved particularly vigorous in field trials.

FOREST ECOLOGY

By J. M. B. BROWN

Extended field studies, principally in central and north-east England, the South and West Conservancies of Scotland and South Wales, have contributed to an understanding of the behaviour of Corsican pine in the British climate. Recent observations fall well in line with inferences previously drawn and the foundations are laid for a discussion of the place of this tree in British silviculture. It is, however, recognised that the provenance factor has, for lack of opportunity, received less attention than it merits in the survey carried out over the past few years. The known superiority, in form and rate of growth, of Corsican over other provenances of *Pinus nigra* has led to almost exclusive use, in the past 40 years, of seed from Corsica: while, in the case of older stands, it has very seldom been possible to obtain any evidence about seed origin. It may be the case that, for particular localities in Britain, or in their reaction to certain environmental factors, other provenances of *Pinus nigra* are potentially superior to Corsican. This is demonstrably so in the case of highly calcareous soils, on which Austrian pine and the variety *caramanica* (or *pallasiana*) display a tolerance not shared by Corsican pine (sens. strict.). However, the fragmentary evidence relating provenance with dieback on upland sites gives little ground for supposing that a variety will be found suitable for planting much beyond the limits within which trees of Corsican origin have been found to succeed at least for 30-40 years.

These limits are set more by altitude than by latitude, and appear to be modified in an important degree by other features of local relief. On marginal land, south and west aspects are preferable to north and east, while depressions in which cold air lodges are particularly unsuitable: but, at the higher altitudes, dieback is not confined to the less favourable positions. Exposure to wind is, within limits, no barrier to the healthy growth of Corsican pine in upland Britain: in some forests the sites sheltered from the prevalent winds have been found more prone to the onset of dieback. In the same way coastal sites are generally suitable, though close to the sea front salt spray may burn the foliage. The most northerly plantations in Scotland are at low altitude near the sea, where winters are mild in relation to latitude and sunshine relatively more plentiful. For Britain as a whole the altitude limit for Corsican pine is about 1,000 feet (300 m.): in the north east it is very much lower, but variable in accordance with the factors alluded to. If the stand climate is the decisive factor—and there is some evidence for this—the forester may be in a position to effect a limited control of the disease, but it cannot be supposed that the useful range of Corsican pine can be greatly extended thereby.

These observations attempt to relate the survival and healthy growth of Corsican pine with climate and topography. Within its range of tolerance, the tree shows a considerable spread in rate of growth, justifying the recognition of four quality classes, with dominant heights of about 80, 70, 60 and 50 feet respectively at 50 years. It is expected that the measurements from nearly 200 stands will indicate in what way such differences in yield are dependent on factors of climate, soil and topography within Britain. A first scrutiny of the data shows that, in England generally, but not in Scotland, Corsican pine grows considerably faster than Scots pine when the two species are planted on comparable sites. As regards soil properties, while it is broadly true that Corsican pine is a frugal tree, it does not reach its best development except in soils of at least moderate fertility. This may be the reason why some coastal dune plantations (e.g. in Culbin and Pembrey Forests), after encouraging early growth, are now showing a disturbing fall-off in increment.

A somewhat different problem (though alkalinity may well be an adverse trait on sand dunes) is set by shallow calcareous soils, on which plantations of Corsican pine have been examined in several localities in England, but principally on the Cretaceous chalk in the south. Other things being equal, Corsican pine maintains healthy growth for longer than Scots pine on the chalk; but the occurrence of chlorosis, sometimes at an early age, imposes some restriction on the use which can be made of this tree in regions where it is well suited climatically. It has been seen growing satisfactorily on soils of every kind (among those represented in Britain), except peat: but freely drained, rather coarse textured soils appear to suit it best, particularly in the cooler parts of the country. On these soils the better aeration favours deep exploitation by roots: but the earlier warming of the soil in summer may be of greater significance for a tree from the Mediterranean climate.

FOREST SOILS

By Dr. W. H. HINSON

The Soil Research Section in the new buildings occupies two large laboratories, two stores—for sample material and laboratory supplies—instrument and balance rooms and two small research rooms. There is also an outside room equipped for milling, grinding and other preparatory operations.

Some soil analysis has been carried out for sections other than Silviculture and in connection with general advisory work; but the number of foliar analyses carried out in connection with silvicultural manuring trials has increased greatly during the last few years. Thus, in the Forest Year, 1958, over 1,000 samples were received from 19 experiments, but in 1959, 2,000 samples were received from 26 experiments. Moreover, in many more cases than previously, analysis for three or more nutrients was required. Owing to this very large load of work, it has not been possible to make as much progress as desired with other work requiring analysis. However, some increase of staff has been approved and the situation should improve after the appointment and training of new assistants. Attempts are constantly being made to increase the capacity for analysis and the accuracy of results by improvement of techniques. Virtually the whole of the routine chemical calculations are now carried out by computer, including the interpretation of instrument readings in terms of the standard curves. The adoption of this method has not been without its difficulties in the initial stages, but there is a considerable saving in time and gain in accuracy. The results are not only printed out in a convenient form for checking, but are also immediately available on punched tape ready for statistical compilation.

A type CF4 grating spectrophotometer (Optica Ltd.) has been purchased, after exhaustive practical tests on comparable prism instruments; a flame unit for the atomic absorption method (Hilger and Watts, Ltd.), and a stabilised power supply for operation of hollow cathode source tubes has also been acquired for the determination of calcium, magnesium, and certain other metals.

An ion-exchange resin column system for removal of anions, which interfere in the analysis of plant ash extracts, has been devised. This system seems to possess advantages over other ion-exchange methods, and if it continues to give good results, practical details will be given in the next report.

Long-term Studies of the Nutrient Relations of Forest Crops and Sites

Samples representing whole trees in Sitka spruce stands at Haldon, Quantocks and Alice Holt Forests have been obtained, and the field work on these sites completed. Briefly the field procedure is as follows: Sample trees are felled and measured. The crown and branch wood are divided into convenient lots; these are each weighed and chipped. The chips are well mixed on a tarpaulin and duplicate samples of about 14 lb. are removed and accurately weighed. The timber is divided into logs (usually 5 feet), weighed, and disc samples removed from each log and the fresh weight of the sample recorded. The site is described, with special attention to soil profiles, and samples are taken from each soil horizon.

In the laboratory, the chipped material is oven-dried, milled, and mixed in a drum rotating end-over-end for 20 minutes, and sub-sampled in duplicate for analysis. The discs are somewhat more difficult to deal with. They are oven-dried, split into pieces by hand, the bark separated and each sample milled separately through a coarse screen. A portion of the product, proportional to the weight of the log from which the disc was cut (corrected for moisture content) is then combined from each disc to form a large sample representative of the whole of the bark-free timber. This is mixed by hand, remilled through a finer screen, mixed again and remilled a third time. This cumbersome procedure seems necessary for Sitka spruce owing to its very great fibre length and tendency to produce a "kapok-textured" product on milling, which is almost impossible to mix or sub-sample. However, the multiple milling results in a good deal of mixing, and the hand mixing between the millings removes any tendency to stratification. Duplicate sub-samples are used for analysis. The bark samples are combined in a similar way to the discs, but do not present a serious mixing problem.

An investigation of a "rates of phosphate" experiment at Wilsey Down, Cornwall, has been carried out by means of whole-tree analysis. In this case the vegetation and the upper layers of the soil were also analysed. The foliage and roots of the crop and ground vegetation were handled separately. Amongst the points of interest revealed by the analysis is the fact that by far the largest increase in phosphate due to the application is in the inverted turf, consisting of a mineral and an organic layer. Even at very high levels of applied phosphate, no increase was detected below this level. The large increase in phosphorus in the crop as distinct from the ground vegetation was also notable; and of the phosphorus in the crop, a very high proportion (50-60%) was contained in the foliage, as other workers have found. The increase in depth of rooting associated with the phosphate applications was considerable. Further work on this site is continuing.

The analytical work has been completed in the investigation of the distribution of nutrients in the current year's needles, from different parts of the crown, in closed stands of Sitka spruce. Sample trees were felled at sites in the New Forest, Glasfynydd and Kerry Forests. Shoots were removed from the leader and from each live whorl of branches, both primary and secondary. The compass point position, length of branch, length of shoot and length of the succeeding internode of the main stem were recorded. The data are somewhat difficult to co-ordinate, and the final computation has not been completed, but there are indications that the regression of nutrient level on needle weight is little affected by the position in the crown, and it will therefore be possible to sample material other than from the uppermost whorl (as is the current practice), when access to the latter is difficult.

Chalk Downlands

Problems associated with the afforestation and health of stands on these sites continue to receive some attention. In collaboration with Dr. P. C. DeKock (Macaulay Institute for Soil Research), some trials have been made of the foliar application of nutrients to chlorotic and normal beech and Corsican pine on a shallow rendzina at Weston Common, Hants. The sprays were applied to newly expanded leaves. No improvement in colour was obtained with beech over the season, but the pine showed some response to manganese at the October assessment. Leaf analysis of the sprayed shoots was carried out by Dr. DeKock, but the amounts of material were insufficient for determination of all the elements involved. The trials will continue.

During a survey of several sites in South-East England, where pines and some other species were reported to be showing signs of debility, it was noted that two apparently distinct conditions obtained. On true rendzina soils, where much calcareous material was present at the surface, Scots pine and occasionally Corsican pine were chlorotic, and the Scots pine were liable to die from an age of 20 years onwards. Where at least 6 inches of non-calcareous loam was present, there was no chlorosis, but frequently poor needle retention, associated with the needle-midge (*Cecidomyid baeri*) and pine shoot beetle (*Myelophilus* species) and very dry soil conditions. Several such cases were noted on as much as 24 inches of non-calcareous loam over chalky rubble. These conditions require further investigation.

Drainage of a Heavy Clay Site

An investigation of the effects of drains at 1-chain and ½-chain spacing on soil conditions and the water regime at Bernwood, an old hardwood site on the Oxford clay, has been conducted since 1954. A general account of this work and the results obtained is given by D. F. Fourt in his article entitled "The Drainage of a Heavy Clay Site", in Part III of this *Report*, page 137.

FOREST GENETICS

By J. D. MATTHEWS, A. F. MITCHELL and R. FAULKNER

Progress of the General Programme of Improvement

During the period under review, the work of the Genetics Section continued to develop along the lines of past years. Progress can be reported in the breeding of the larches—a first attempt having been made to estimate the heritability of height and diameter growth in two-year old transplants. A limited number of controlled intraspecific crosses were attempted on Lodgepole pine and a second larch seed orchard flowered sufficiently to make possible controlled crosses between several clones of European larch. These and other subjects are discussed below.

Survey of Seed Sources

The object of this survey is to locate suitable seed sources for current planting programmes so that the practising forester may know where to obtain seed of the best of the existing varieties and cultivars. The greater part of the survey work in 1959 was done in the South-west Conservancy of England, and forty-three additions were made to the Register of Seed Sources for England. An important event during the year was the formation of the Forest Tree Seed Association of England and Wales. The object of the Association is to encourage in all possible ways the use of seed of the best known quality and origin, and both technical advice and data on seed sources were provided by the staff of the Genetics Section.

Selection of Plus Trees

The selection and propagation of outstanding phenotypes (Plus trees) and other trees of more specialised interest (Special trees) was continued. The total number of plus and special trees of all species which have been marked and recorded is now 2,939. Table 6 gives the position by species on 31st March, 1960.

It will be seen that the pines, larches and Douglas fir make up just over two-thirds of the trees that have been selected and registered. The number of spruces selected has however increased and in Sitka spruce work started on the techniques of obtaining small timber samples for wood anatomy studies. Another development was the increase in the number of plus trees of Lodgepole pine; plus trees of this species make up a large part of the total given in Table 6 under "Other pines".

Table 6

Selection, Registration, and Propagation of Plus and Special Trees

Common Name	Selected and Registered	Propagated Vegetatively	Planted in Tree Banks
Scots pine	703	602	464
Corsican pine	96	64	46
Other pines	103	46	5
European larch	452	326	252
Japanese larch	129	115	70
Other larches	43	19	13
Douglas fir	473	284	215
Norway spruce	67	15	7
Sitka spruce	149	28	12
Other spruces	15	3	3
Silver firs	51	—	—
Western hemlock	35	9	—
Western red cedar	61	42	36
Other conifers	110	37	20
Total Conifers	2,487	1,590	1,143
Sessile and Pedunculate oak	167	29	14
Beech	121	66	42
Sycamore	25	2	—
Ash	42	24	10
Birch species	74	53	20
Other broadleaved species	23	7	—
Total Broadleaved	452	181	86
Grand Total	2,939	1,771	1,229

Over half of the selected trees have been propagated by grafting or by the rooting of cuttings; and more than one third are now established in Tree Banks.

Formation of Tree Banks

The establishment of the National Collection of Plus and Special Trees of two-needled pines, the larches, Douglas fir, the spruces and beech continued during the year, and a total of 1,229 clones has now been planted. Details of the number of clones planted by species are given in Table 6. The plus and special trees selected in the forest are represented in these tree banks by grafted plants or cuttings and by this means are preserved against loss by windblow, fire or felling and are brought together into convenient centres. The tree banks are themselves duplicated as a protection against loss, and eventually there will be two more or less complete collections, one for England and Wales and the other for Scotland.

A provenance and progeny collection of two-needled pines was begun in 1959 on a twenty-five acre site at Saltoun Forest, East Lothian. This collection will be used in future inter-species crossing work as a source of valuable genes. Each selected provenance or progeny is represented by fifty or 100 plants, and the collection will eventually contain material of all the two-needled pine species hardy in Scotland.

Vegetative Propagation

Grafting, the rooting of cuttings and layering, were again used to raise clonal material for inclusion in tree banks, field trials and seed orchards. The final total of grafts attempted during the spring of 1959 was 14,256 and the number of successful grafts surviving to the spring of 1960 was 9,322, representing 622 parent trees. The overall success was 65 per cent, and the figures for the main propagation centres were: Alice Holt 5,390 grafts attempted and 54 per cent success; Grizedale 4,753 grafts attempted and 70 per cent success and Bush Nursery 4,113 grafts attempted and 75 per cent success.

Just over 30,000 cuttings were inserted in the propagation frames at Alice Holt, Grizedale, Bush and Kennington nurseries, most of these being clones of X *Cupressocyparis leylandii*. During the spring of 1960, 5,500 rooted cuttings principally *Thuja plicata* and X *C. leylandii* were distributed for planting in field trials and tree banks.

Tests of a number of techniques of vegetative propagation continued on an experimental or larger scale. The trials, begun in spring 1958, of the use of polythene bags for the protection of newly grafted plants of Douglas fir and the larches were repeated at Alice Holt and Bush nurseries. Although the differences in scion survival and growth at the end of the first season after grafting were not great, the technique appears sufficiently promising to be given extensive trial for outdoor grafting of larch. It does not appear necessary or desirable for Douglas fir when grafted outdoors in late April in Britain.

During the past three years a number of specialised propagation techniques have been tried out on Scots pine, with the object of producing clonal root-stocks for grafting. Attempts to root needle fascicles have resulted in almost total failure, the variables studied being time of insertion, depth of rooting medium and concentration of growth substance. Failure has also attended attempts to air-layer branches of twelve-year-old Scots pine at Bush Nursery. The branches were cut to the cambium, the cut surface was first treated with Indole-butyric acid in talc, or left untreated and then surrounded with sphagnum moss, vermiculite, or mixtures of peat and sand enclosed in polythene sheets; but although the wounds calloused well no roots were formed.

The difficulties experienced in the aftercare of graftings of the larches and Douglas fir with a plagiotropic habit of growth have been referred to in previous *Research Reports*. Most of the grafts with prostrate habit have responded to regular staking and pruning from the time of grafting, and now have an upright habit. There still remain several severe cases of grafts lacking apical dominance, particularly in Douglas fir, and it appears certain that such plants are not going to straighten up and regain a normal habit. A basic physiological approach is required for the study and solution of the problem.

Summerwood cuttings of the birch species *Betula verrucosa* and *B. jacquemontiana* and Sitka spruce were successfully rooted under "mist". Earlier work with Sitka spruce pointed to the suitability of June as a time for taking and inserting summerwood cuttings and this was confirmed. The growth substance Indole-butyric acid, applied at 4,000 parts per million in talc, increased the number of cuttings rooted. The extensive work done in the "mist" frames on rooting summerwood cuttings of many elms and poplar clones is reported in the article entitled "Propagation of Elms and Poplars by Summerwood Cuttings", by J. D. Matthews and J. Jobling, which appears in Part III of this *Report*, page 180.

Now that more attention can be given to the breeding of the spruces, the grafting of Norway, Sitka and other spruces assumes a greater importance. A comprehensive experiment was set up at three centres in the spring of 1959 in which the effects of rootstock species, source of scionwood, methods of grafting, time of grafting and method of protection are being compared both singly and in combination.

Testing the Plus Trees

The raising of progenies derived from open pollination and controlled self- and cross-pollination in the two-needled pines, the larches and beech was continued during the year. The growing importance of Lodgepole pine in British forestry is reflected in the increased amount of crossing work already begun and planned for this species. The controlled crosses attempted in a Lodgepole pine provenance experiment at Kirroughtree forest, Kirkcudbrightshire, during the spring of 1959 was intended to test the suitability of existing techniques for large scale work on this species, and to begin the production of inter- and intra-provenance crosses. Useful experience was gained for the larger programme begun during the spring of 1960 at Allerston Forest in Yorkshire.

In larch, controlled crosses were continued in seed orchards at Newton Nursery, Morayshire, in 1959 and 1960 and Mabie Forest, Dumfriesshire, in 1960. At Newton in the spring of 1960, sixty distinct crosses were attempted, involving clones of European and Japanese larch, to produce combinations within both species and the inter-species hybrid between them. In the Mabie larch seed orchard the crossing programme included a diallel cross involving five clones of European larch.

Although the earlier work on controlled pollination in Douglas fir in 1956 had been fairly successful, that done in Spring 1958 yielded no viable seed. More study of the flower biology of Douglas fir is required and this will be undertaken as soon as possible.

Formation and Management of Seed Orchards

Seed orchards consisting of clones of grafted plants derived from plus trees of Scots pine, European larch, Douglas fir and beech are being formed, both to produce seed and provide a means of further improvement of these species. Seed orchards composed of clones of European and Japanese larch are also being planted to produce seed of the first generation of Hybrid larch (*Larix* x *eurolepis*). In larch, selected first generation progenies raised from seed produced by controlled crosses between plus trees have been planted in seed orchard layouts to produce second generation Hybrid larch and the back-crosses Hybrid larch x Japanese larch and Hybrid larch x European larch.

Most of the seed orchards of all species which have been planted so far are concentrated in eastern Scotland (31 acres), south-east Scotland (40 acres), south-east England (36 acres) and the west midlands of England (13 acres). Work is in progress at nineteen sites totalling 205 acres.

The oldest seed orchard is now nine years old and some of the important problems of management are now becoming clear. The pattern of management which is emerging may be summarised as follows:—

(1) Intensive ground cultivation before planting, closer planting distance (i.e. 15 × 7½ feet for larch and pine), field grafting onto well established rootstocks, application of inorganic fertiliser and mulching are all being used to encourage speedy early growth and early development of general flowering through the seed orchard, while the trees are still quite small, i.e. from 5 to 10 feet tall.

(2) When flowering becomes general, partial or complete diallel crosses in the seed orchards are followed as quickly as possible by progeny tests to identify the parental clones with good general combining ability and to estimate the heritability of important characteristics such as early height and diameter growth.

(3) Mulches and inorganic fertilizer are being applied to the grafted seed trees and ground cover, to encourage continued vigorous and healthy growth of the seed trees, thus making possible regular and heavy seed production. Protection against insect attack is very important, particularly against *Adelgids* such as *Adelges cooleyi* in Douglas fir, *Chermes viridis* in European larch and *Adelges pini* on Scots pine. Some control of the last two pests is possible by repeated spraying with Malathion.

Technique of Tree Breeding

An important addition to the equipment available for controlled crossing work is a trailer caravan fitted out as a mobile field laboratory in which pollen may be extracted, tested and prepared for use, and field records maintained during a crossing programme. In the first season of operation the caravan has proved its value when working in provenance trials on isolated forest sites and also in seed orchards.

Observations on the phenology of leafing, flowering, length of growing season and pattern of growth during the growing season were continued with many species. The data now extend over the period 1954 to 1960. As one example of the results obtained, it is notable that the larches, which begin flowering early in the spring, i.e. in February and March, show a more erratic behaviour from year to year than does Scots pine, which begins flowering in May. Corsican pine (*Pinus nigra* var. *calabrica*) is markedly constant in its flowering date, i.e. early June, while Douglas fir which flowers in April shows less fluctuation from year to year than the larches but more than the pines.

Work continues on the physiology of flowering in forest trees in collaboration with Professor P. F. Wareing and his colleagues at University College of Wales, Aberystwyth. Their report may be found in Part II of this *Report*.

A further aspect of technique which received considerable attention during the year was that of the statistical analysis of a diallel cross in larch. In 1956 nine Japanese larch (J) and three European larch (E) clones were crossed in as many combinations as possible. The progenies have been assessed as 1+1 transplants. The combining ability of the parent clones and heritability of height and diameter growth have been estimated by analysis of variance. The following are the main conclusions from this crossing programme:

(1) For every hundred plants required for progeny testing, at least fifty and more usually 100 female flowers must be isolated and pollinated.

(2) Self fertility was generally low and there is evidence of a strong inbreeding depression for most of the parent clones.

(3) Three parent clones showed high general combining ability. The parent trees had also been, when selected in the forest, the most outstanding phenotypes.

(4) The superiority of the inter-species crosses E × J and J × E over the intra-species (J × J) combinations were striking.

(5) Heritability in the narrow sense (that due to additive genetic variance) was small for both height and diameter growth of two-year transplants. This emphasises the need for adequate progeny testing.

(6) It appears from the data available that the male parent plays little part in determining the size of its progeny at two years of age.

Enquiries

The flow of enquiries from Foresty Commission and outside sources continued, some 127 enquiries being dealt with during the year. Many of these concerned vegetative propagation by cuttings, the layout and management of seed orchards and the selection of seed sources.

FOREST PATHOLOGY

By J. S. MURRAY

Work followed along the lines described in the 1959 *Report*. There has been a tendency for the number of items to be reduced, and for work on certain projects to be intensified. Notable among the latter are *Botrytis cinerea*, Keithia disease of *Thuja*, and the plantation root diseases, *Fomes annosus*, *Armillaria mellea* and *Polyporus schweinitzii*.

Minor queries still bulked largely in the work of the section. These sometimes lead to correspondence or visits to state forests and to private estates. In addition the section was represented on the Committee which met to consider the revision of the "Destructive Insects and Pests Act" since this deals among other matters with quarantines on forest trees.

In October 1959, Dr. R. G. Pawsey joined the section as Assistant Pathologist and has started work on nursery diseases—Keithia disease of *Thuja*, *Meria laricis* and *Botrytis cinerea*.

The main factor influencing forest pathology during the year was undoubtedly the hot dry summer. This was probably responsible for the low incidence of such nursery diseases as Damping-off, *Botrytis*, *Lophodermium*, Keithia etc., reported generally. On the other hand, several examples of drought damage were reported from nurseries, but on balance the weather conditions were distinctly favourable to nursery stock as far as pathology was concerned. In the plantations there were reports of Japanese larch dying of drought in August and September. This species is probably the best indicator of a drought year of all our forest species, since it showed the same susceptibility in 1955, our last drought year. Drought cracks occurred in several species, notably *Abies*. A most interesting phenomenon was browning and death of young spruce, especially Norway spruce. Reports of this came in from September onwards until April, and the damage is regarded as late-appearing drought symptoms. Detailed examinations of several of the sites were made. The damage was worst where there was any accessory site factor likely to favour drought damage. Examples of the latter were—competition, especially with broadleaved species, and southern exposures. Many of the spruce examined had dead roots, associated with abundant fruit bodies of *Phomopsis occulta* and in one case *Phomopsis conorum*. It appeared that these fungi were facultative root parasites under the conditions of the drought, although hitherto described as saprophytic or weakly parasitic.

An interesting minor query was infection by *Phomopsis pseudotsugae* of one-year *Pinus radiata*. It is most unusual for this fungus to attack such young stock. The symptoms were tip dieback for varying lengths of the shoot, rather reminiscent of frost injury or *Botrytis* damage, and fruit bodies were found on needles and stems.

The following are the main aspects of work during the year:—

Ascochyta piniperda

The occurrence of this fungus on dying lodgepole pine seedlings and transplants was described in the 1959 *Report*. An inoculation trial using an isolate from a diseased plant resulted in infection and needle-cast of lodgepole pine of different origins but no infection occurred on spruce, larches, Douglas fir, *Thuja* or hemlock. It is most interesting that in this trial Norway spruce was unaffected, since it is the most usual host of this fungus.

Group Dying of Conifers (Rhizina inflata)

Little further work was done on this fungus, apart from assessments of existing experiments. Results have been written up for publication, and it is not anticipated that further research on the disease will be done by the section. Nevertheless, intriguing problems concerning group development and cessation remain.

Keithia Disease of Thuja

This is one of the projects on which work has been widened in scope. The rotational sowing schemes have been running for some time in Scotland and in England, and it is proposed to extend them to Wales. Attempts to make them more efficient have been made by reducing the number of nurseries involved and shortening the fallow period.

In addition experiments on control by chemical spraying have been laid down. Work is also in progress on the biology of the fungus, in particular to test whether detritus from diseased plants can act as a source of infection.

Melampsora pinitorqua

Observations were kept up on the trial plot at Alice Holt and further species of pine introduced. The rust was less obvious last year than formerly, occurring only on Scots pine and *P. pinaster*. Of the aspens, *Populus tremuloides*, the American species, continued uninfected.

Weymouth Pine Rust, Cronartium ribicola

Observations were made again on the trial plot of *Ribes* and pine species. *Pinus griffithii*, the Himalayan pine, was again noticeably resistant and *Pinus holfordiana* very susceptible. It is hoped to extend the *Cronartium* work to the introduction of resistant strains of various five-needled pines from abroad and to establish several large test areas.

Wound Protectants

No further substances were added to the trial on beech at Westbury forest. Further assessments were made and "Arbrex", as described in the 1959 *Report*, continued to give best results.

Elm Disease—Ceratostomella ulmi

Testing of Dutch resistant clones has continued. In co-operation with the Silviculture section, certain areas in Britain have been surveyed for promising clones from our varied elm population. An inoculation area has been established at Alice Holt and in this, all clones, both Dutch and British, will be tested.

The Dying of Norway Spruce

A severe case of this trouble was reported from Rockingham forest in East England. Investigation showed a clear association of the onset of the dying with the first thinning. Following this, a survey was made in twenty-three forests in five Conservancies, but no constant association of "top dying" with first thinning was found. The occurrence of the trouble seems to be dependant on certain site factors, especially any which might lead to increased wind movement through the crowns. Further detailed work has been carried out in areas where "top dying" is occurring.

"Wareham fungus", Dothistroma pini

Occurrences of this disease on pines were recorded in previous reports. As in former years, no trace of the fungus was found outside the Wareham area so that, in Britain, it is of very local occurrence. Even in the Wareham area it was very scarce in the hot dry season of 1959. This tallies with experience in America, where the current attacks are associated with wet summers.

Decay and Death due to Fomes annosus

This is still the largest of the section's projects. Survey work continued and supported earlier work in demonstrating the gradual invasion of our new forests by the disease. Examples of restricted development on deep peat and ex-hardwood sites were again found, and work is concentrating on the latter type of ground especially in the south of England.

Stump protection was introduced into many more forests. Creosote of a defined grade is still the recommended material, but trials of various substances were laid down to supplement existing experiments. Various experiments were planned and laid down in the reafforestation areas in East Anglia, where a programme of replacing the poorer pine stands is under way. This gives a very good opportunity to lay down trials of eradicative treatments.

Work on methods of infection has continued. The stump is still the chief avenue but the infection was found to occur in the roots of windblown trees and an experiment on this was laid down.

Polyporus schweinitzii

Field observations continued. Many cases of infection of conifers were found on ground previously occupied by hardwoods. On this type of site *P. schweinitzii* can be very destructive in the individual tree, causing a rapidly developing rot. A case was found, in Sussex, where many sixty-year-old European larch had died or were failing. Root rot due to *P. schweinitzii* occurred in many of the affected trees and it is thought that the fungus may have been important in the dying. This is an exceptional case, however, and it is usually found causing butt rot. Investigation into its biology continues.

Armillaria mellea

An eradication experiment, using chemical treatments and mechanica ringing of trees before felling, was laid down in old oak at Alice Holt forest. A variety of conifers will be planted on the area in 1960 and the incidence of honey fungus in the new crop assessed annually. During the course of the butt-rot survey work on old hardwood sites, many cases of *Armillaria* heart-rot in spruce have been found. This phenomenon has only lately been appreciated in Britain but is apparently fairly common.

Peridermium pini—Blister Rust of Two-needled pines

A small experiment was carried out on infection methods on Scots pine using fresh aeciospores. Infection succeeded only on artificially-made wounds on shoots, and failed on both wounded and unwounded needles and on unwounded shoots. This rust is locally significant in Britain and little is known of its biology.

Botrytis cinerea, Grey mould

Work on this disease was widened in scope. It has proved very difficult to control in forest nurseries, and trials of fungicides, including forms of the systemic fungicide, griseofulvin, were laid down. In addition, arrangements were made to take meteorological recordings in ten nurseries to see whether any relationship of temperature or humidity could be found with the onset of infection.

Meria laricis, Leaf Cast of Larch

A spraying experiment using Thiram, Captan and colloidal sulphur showed that all three substances gave significant control but that colloidal sulphur was superior. Height growth in treated plots was significantly greater than in untreated. Work on other aspects of this disease is continuing.

FOREST ENTOMOLOGY

By Dr. MYLES CROOKE, D. BEVAN, and Miss J. M. DAVIES

Pine Looper—Bupalus piniarius L.

Pupal Survey

The annual survey was originally started so that warning of any immediately impending outbreak might be obtained in time for appropriate measures to be taken. It now appears that the low percentage sampling method employed is a good deal more sensitive than had been expected, and it has proved possible to detect changes in density at quite low levels of population. An upward movement at a low density, which may be followed by further rise to critical level in subsequent generations, can, therefore, be a useful early warning of future outbreak. Thus, in the 1959 *Report*, substantial rise in numbers was recorded at four forests. Those at Rendlesham and Sherwood IV were thought to be high enough to give concern, and more detailed investigations, which are the subject of a separate paper in Part III (see page 172), were carried out during the following season. It is sufficient here to say that both populations are now considerably reduced—that at Rendlesham to the lowest overall pupal density yet recorded for the forest, and at Sherwood IV to a level where the highest compartment mean found was 6 pupae per sq. yd. Cannock Chase is the only one of the four forests which still harbours a rising population, and pupal counts now show seven compartments with over 20 pupae per sq. yd., and a highest compartment mean of 34·6 pupae per sq. yd. Here again is a situation which will require further investigation during the coming season. It may be recalled that it was at Cannock Chase that the first recorded serious outbreak of Pine looper in Great Britain occurred in 1953, and it is interesting to note that this time the highest population is in a part of the forest not sprayed on that occasion.

The other results of this year's survey show a rather curious difference in population trend between Scotland and England. In all Scottish forests, except Kessock and Tentsmuir, increases are reported, Innes, Montreathmont, and Roseisle having highest compartment means, all in the region of 6 pupae per sq. yd. In England, however, a decline in numbers is the rule, Cannock, Delamere and Sherwood V being the only areas where a rise is recorded; the highest compartment mean for the first named was 34·6; for Delamere and Sherwood V, they were 8·4 and 7·6 pupae per sq. yd. respectively.

Sample Plot Studies

Populations in the Elveden study plot at Thetford are still very low, and pupal counts made in January 1960 showed a density of less than 1 pupa per sq. yd. Accurate assessment of numbers at these low levels can be made at most stages of the life cycle, but it is almost impossible to obtain a quantitative measure of, or even, in some cases, to identify, the causes of mortality between these stages. Nevertheless, information of this kind is necessary if the epedemiology of the insect is to be understood. More attention has therefore been turned to the short-term investigations which the Section is called upon to make when and where outbreaks threaten. The influences which can operate upon an insect population, of course, vary both in nature and intensity with place, time and density, and information from these investigations can only be regarded as a lead for further study. It is, therefore, essential to have an area, such as the permanent study plot, where the gleanings from widely separated sources may be tested against a backcloth of continuous and accurate observation.

As an example of this kind of approach, investigations into mortality between adult emergence and oviposition are to be made at Cannock Chase this year. Sharp focus was brought to bear upon this period by the assessments of adults and of eggs carried out at Rendlesham in 1959, and it is felt that high populations at Cannock this year may provide an opportunity to investigate the cause of the losses.

Parasites of Bupalus piniarius

Study of certain parasites of *Bupalus piniarius* was continued, both in the forest and laboratory during 1959. Examination and rearing of the annual survey material showed that *Cratnichneumon nigritarius* was present in greater numbers than *Heteropelma calcator* or *Campoplex oxyacanthae*. Laboratory experiments were, therefore, concentrated on *C. nigritarius*.

In the past, experiments have been set up in order to discover the survival rates of adults, their fecundity, length of development, etc. Unfortunately these attempts have been made under most unsatisfactory conditions for this type of work, including the fluctuating environments provided by a glasshouse type of insectary, an out-door shelter, and a breeding cage under trees. It is obvious that temperature, humidity and light are all factors which strongly influence *C. nigritarius*, and it is hoped to make the requisite controlled conditions available in the fairly near future.

However, the laboratory work of 1959 was influenced by the data gleaned from past experiments, together with the early elementary study of the condition of ovaries at emergence and death, and the dissection and description of development from the last larval stage to pupation. A series of small cages were set up in room conditions over solutions to provide relative humidities covering a range of 65-95.

In the lower humidities, few adult parasites lived more than a week. This agreed with results from past experience, but where the relative humidity was kept at 85 or 95 the female survived from five to eight weeks. The age at which mating took place proved to be variable. Sometimes it occurred immediately after the male was some three to five days old. There was nothing to suggest that their behaviour could be linked with difference in host species origin, i.e. individuals from *Bupalus piniarius*, *Panolis flammea* or *Semiothisa liturata*.

Five pupae of *B. piniarius* were placed with each pair of adult parasites every week. The remaining parasite females were individually observed throughout their oviposition period. The choice of pupa, length of oviposition time, and position in the host were all noted. Oviposition throughout the experiment was sporadic, but suggested that *C. nigritarius* has a low fecundity. Parallel experiments under dark conditions gave no hint of the effect on oviposition. Examination of the ovaries showed in most cases at least two ripe eggs present at death.

The female tests, with vibrating antenna, the whole surface of the pupa. When ready to lay, she climbs on to the pupa, and the ovipositor commences to rotate invariably on the first abdominal intersegment near the base of the wing case. After a series of pumping actions the egg is finally inserted, the act taking from one to two minues to complete.

A small experiment was set up during this period with known parasited host pupae. *C. nigritarius* oviposited readily on pupae in which eggs had been laid either by themselves or other females.

The parasitised pupae from all these experiments were collected and bred individually under conditions of high humidity (approx. 85-95). The overall mean development time, i.e. egg to adult emergence, was found to be 36·75 days (S.E. $\pm$ 1·01). Several pupae were kept at a low humidity, but only one parasite larva survived, with its developmental period prolonged to 69 days. In general the development from egg to fifth instar appears to cover about three weeks, while prepupation, and pupation, takes two weeks. Emergence from the laboratory parasitised pupae showed a predominance of males. The females were successfully mated, and produced a second generation.

In the forest, routine sampling was carried out, as in previous years, in the study at Elvedon, but proved unsatisfactory for parasite collection since host population density remained low. However, the annual pupal survey showed an increase in *Bupalus piniarius* population at two forests—Sherwood and Rendlesham. It was therefore decided to concentrate field work in the latter. In the past, metal base emergence traps covering a yard square had been used, since this was the size of the sample plots upon which the knowledge of *Bupalus* pupal distribution was based. Further investigation suggested, however, that equally reliable data could be obtained from a smaller area, and it was thus possible this year to employ a trap of smaller and more convenient dimensions, but retaining the same basic design.

Twenty-five bowl traps a foot in diameter, were laid down diagonally across the sample area. Daily collections were made, and the traps moved every alternate day in a regular pattern. There was nothing new in the last idea, except the increased frequency of changing trap position made possible by the reduction in size. In previous years the traps had been moved once at the end of *B. piniarius* flight period, the object of the operation being to test the hypothesis that *C. nigritarius* produced a second generation on the later-hatching pest pupae. In this way it was hoped, at least in part, to explain the gap between the May emergence of parasite adults, and their September oviposition in *B. piniarius*. However, this technique, and other methods, such as sticky bands to detect adults, and laboratory pupae placed in the soil at regular intervals to attract oviposition, produced nothing of value, since the parasite population has been almost non-existent in the sample plot throughout the period of study.

At Rendlesham this year, recorded dates for the appearances of *C. nigritarius* were taken from the moving traps. After the spring emergence of over-wintering parasites (i.e. first part of May), there were two groups of dates when adults appeared in the traps—the first two weeks of July, from 9th to 16th, and again at the beginning of September. During the season, fortnightly observations on *C. nigritarius* male flight activity supported these emergence data. In June no males were observed, and at the same time a pupal collection revealed, on dissection, parasites in the last larval stage. During July, males were caught on the wing at dates corresponding to emerging males and females in the traps. At the beginning of August two males were seen, but nothing appeared in the traps until the beginning of September.

Another small experiment, first attempted unsuccessfully in 1956, was repeated at Rendlesham. As laboratory-bred pupae of *B. piniarius* appeared, these were used in the field. Five small plots were selected in the area, each containing four healthy pupae. These were first laid down on September 2nd, and replaced by fresh pupae on four subsequent fortnightly visits. Parasitism was obtained, which showed that, although no parasites appeared in traps during this period, the females must have been operating up to the end of October, since each pupal collection contained two or three parasited larvae.

The laboratory and field work at Rendlesham suggests that *C. nigritarius* emerges throughout May. The females, during an adult span of five weeks, lay eggs in the later hatching pupae of *B. piniarius*, as well as on those of *Panolis flammea*, and *Semiothisa liturata*. At least one further generation is produced before eggs are again laid on the pupae of *B. piniarius* in September and October.

Anoplonyx destructor Bens., a Larch Sawfly

The non-indigenous species, *Anoplonyx destructor*, is the commonest and most harmful of the larch-feeding sawflies in Britain. It is wide-spread throughout the country and in some localities causes recurrent and severe defoliation of pole-stage stands. Although the main features of its biology have been investigated and established, no general ecological or population studies have yet been carried out, either in this country or on the continent of Europe, where, in fact, *A. destructor* is extremely rare and went unrecognised until the species was described from British specimens. To carry out more detailed studies an observation plot, 3·6 acres in extent, has been established in a thirteen-year-old Japanese larch crop in Mortimer Forest, Shropshire. The long-term objectives of this work are to detect and measure the factors influencing changes in population density. The first season's work in the plot has been directed towards developing sampling methods for the different stages in the sawfly's life cycle, and to identify some of the causes of mortality in the sawfly population. Some laboratory studies have also been made.

Sampling Methods

Sampling for the adult, mature larval, and cocoon stages in the life cycle presents no particular difficulties. Trapping of adults emerging from the soil, collection in funnel traps of mature larvae falling from the crowns, and examination of litter samples for cocoons, appear to yield accurate measures of population density in these stages. The egg and earlier larval stages, however, are less easy to assess and no adequate methods have yet been developed for them. The counting of all eggs on a number of crowns indicates that eggs are generally distributed throughout a crown, so that sampling on the foliage of randomly selected branches may prove to be a valid approach. As regards the larval stages, an attempt was made to apply to them the cast head-capsule method of sampling, which has been devised for the pine looper. This proved abortive since, at ecdysis, the cast head-capsule remains attached to the moulted skin which, in turn, is usually securely wound round a needle. This sampling method has now been abandoned and attempts are being made to develop a technique based either on direct sampling from foliage, or on counting of larvae poisoned by the trunk implantation of systemic insecticides.

Mortality Factors

(a) **Parasites.** In previous work on *A. destructor*, eleven species of larva and cocoon parasites have been reared and identified. So far, in the Mortimer plot material, only two species—*Labroctonus westringi* Holm. and *Rhorus palustris* var. *nigriventris* Str., have been recorded. In addition, however, a hitherto unrecorded egg parasite, the Eulophid *Cirrospilus vittatus* Walk., has been taken. Various members of the genus *Cirrospilus* are known to be parasites of lepidopterous leaf miners on hardwood and coniferous trees, so that it is possible that species such as *Coleophora laricella* Hbn., which occurs in the study plot, may provide an alternative host for *C. vittatus*. Observations to check on this possibility will be made in 1960. It is not possible to indicate the numerical status or importance as mortality factors of these parasites.

(b) **Predators.** The only type of predation which has so far received attention is that of small mammals (mice, voles, etc.) attacking the overwintering cocoon stage. With many forest sawflies, mammal predation is of considerable importance.

A direct measure of the total predation loss caused by small mammals and other predators, such as ground and click beetles, in the cocoon stage, was attempted by comparing cocoon densities in November 1959 with those in March 1960. During this period the cocoon population dropped from 15·0 to 5·4 per square yard. Similar sampling was carried out in quadrats from which small mammals were excluded, and in these the November count of 16·6 cocoons per square yard had dropped by March to 3·8 cocoons per square yard. The elimination of small mammal predation does not, therefore, appear to have influenced the scale of loss in the overwintering cocoon population. This, in view of the strength usually attributed to the mortality factor, is surprising, particularly since a fairly dense small mammal population was present in the area. During the winter period an effort was made to assess this population by carrying out live trapping, followed by marking, release, and recapture, for three periods of three nights each. No statistical analysis of the data has yet been made, but the fact that 74 field mice, 12 shrews, 5 bank voles, and 2 field voles were taken in the traps indicates that the small mammal population was far from sparse.

No specific measure of predation by birds or arthropods has yet been attempted.

(c) **Disease.** During the course of rearing *A. destructor* larvae in the laboratory, a disease, causing discolouration and distortion, usually commencing at the anal end of the body, followed by death of the affected larva, was observed. It caused a mortality of 46 per cent of the larval stock in question. It was also observed in field populations. It is caused by a microsporidial infection.

(d) Loss of Immature Larvae. A high proportion of *A. destructor* larvae fall from the larch crowns before completing their development. The reason for this in the earlier part of the season is not known, but later in the year it can be explained, in part at least, by the fact that the food supply becomes unsuitable or fails as the larch needles dry and fall. The percentage of larvae which failed to reach the final instar in the plot in 1959 was 55·9 per cent. Of those which did reach the final larval stage (i.e. 230 per square yard), less than twenty per square yard (see above) entered the cocoon stage. What proportion of this loss was due to immaturity, and what to other mortality factors, is not known.

Laboratory Studies

Laboratory rearings of *A. destructor* larvae were carried out to determine the durations of the stadia. One unexpected result of this study was the finding that there were, on this occasion, six instars, and not five as has previously been recorded. The mean durations of the stadia as observed in these rearings were:—first instar, 7 days (range 6-8 days); second instar, 9 days (7-11); third instar, 20 days (13-29); fourth instar, 33 days (18-43); fifth instar, 12 days (8-24); sixth instar, 15 days (11-23). The average duration of the larval stage was 94 days.

Incremental Loss Caused by Defoliation

A long-term experiment to measure the loss of increment caused by *A. destructor* defoliation has been established in a thirty-year-old Japanese larch crop in Drumtochty Forest, Kincardineshire. This forest has for about ten years suffered recurrent and sometimes heavy attack by the sawfly. The experimental approach is to compare growth rates in unprotected blocks with those in a block where the sawfly population will be substantially reduced by insecticidal applications, either annually or when required. The first treatment, which will be made by aircraft, will be applied in June 1960.

Larch Sawfly Survey

The larch sawfly survey was again carried out in 1959, but because of pressure of work in other directions, not all of the forests usually visited were inspected on this occasion, and in some cases the intensity of the survey at any one forest was also reduced. As compared with the figures for 1955, little change in population levels was recorded.

Pristiphora erichsoni Htg.

The rather high population recorded in 1957 in the Atholl Estates, Blair Castle block, maintained itself until 1959. Elsewhere, slight increases in the numbers of clutches were recorded at Monaughty and Drummond Hill Forests and decreases at Glentress, Cardrona, Craigvinean, and Drumtochty Forests.

Anoplonyx destructor Bens.

This sawfly was nowhere present in very large numbers, the levels of population following a broadly similar pattern to that of the previous survey. At Drumtochty Forest, however, the unusually low 1957 level of population had doubled itself by 1959, to reach a moderate incidence. A precisely similar occurrence was noted at Craigvinean Forest.

Pristiphora laricis Htg.

The population of this species, the least numerous of the three commonly occurring larch sawflies, remained at low levels on all forests visited.

Pinhole Borer, Trypodendron lineatum Ol.

Biology

Observations on the biology of this species have been made in three study plots, all in Sitka spruce crops, situated in Glenbranter Forest, Glenfinart Forest, and Glenduror Forest, all in Argyll. In each of these plots monthly fellings were commenced in November 1958 and the stems left lying to provide material for pinhole-borer attack in 1959. The main practical objectives of this study were to determine (1) the time and duration of the period of pinhole-borer flight and attack, and (2) at what time after felling the logs became susceptible to attack.

Although these plots had been sited in localities where pinhole attack was prevalent, it was unfortunate that no appreciable infestation developed in either the Glenbranter or Glenfinart plots. Thus, although observations were continued at these two forests throughout the season, it was only from the Glenduror plot that any information was obtained. Here colonisation of the logs proceeded from April 30th to July 9th, with the main period of activity from mid-May to mid-June. A small number of entries also took place between July 9th and September 15th, but, since no assessments were carried out during that period, it is impossible to ascribe definite dates to these attacks or, consequently, to nominate the end of the flight and attack period. This period, as indicated by these results, is considerably longer in Argyll than it is in central European localities.

No preference on the part of the beetles to infest logs of any particular felling age was recorded and, in fact, stems felled in each month from November 1958 to June 1959 suffered attack during the 1959 flight period.

Insecticidal Control

An experiment to test the level of protection against pinhole-borer attack afforded by the application to logs of three insecticidal formulations was laid down in Glenbranter Forest. The three formulations tested were Gammexane, Lyxastan, and Hexastan, in all of which the active ingredient is benzene hexachloride. No infestation of the experimental logs, including the untreated controls, took place, and no conclusions, therefore, can be drawn from this trial.

Creosoted Stumps

Tropical experience indicates that creosote acts as an attractant for some ambrosia beetles. In this country stumps left after thinning, which provide one of the breeding sites for *T. lineatum*, are often treated with creosote to prevent their becoming foci for the spread of the fungus *Fomes annosus* to standing trees. It therefore appears possible that these anti-*Fomes* measures may have an influence on the development of populations of *T. lineatum* in thinning-stage conifer crops, and a series of experiments has been laid down in Inverliever and Glenduror Forests to investigate this matter. In each forest, five compartments carrying Sitka spruce crops ranging in age from 32 to 48 years have been selected, and in each of these approximately 100 trees were felled in December 1959. Half of the stumps have been treated with creosote and the other half left untreated. Assessments to detect any differences in pinhole-borer infestation levels in these two classes of stump will be made in 1960.

The above studies have been conducted in collaboration with the entomological staff of the Forest Products Research Laboratory. Co-operation will be continued in 1960, when it is planned to investigate host species and felling-age preferences, and the possibilities of insecticidal protection of logs, as well as to confirm and extend the biological data already collected. In addition, studies will be carried out on *Hylecoetus dermestoides* L.

Neomyzaphis abietina Walk.

Assessments of aphis incidence were carried out in the series of plots, which had been set up in 1958, as detailed in the research report for that year. Levels of population, as evidenced by foliar discolouration and loss, were low, but the indications are that populations are increasing and that marked defoliation will occur in some of the plots in 1960.

The Larch Bark Beetle, Ips cembrae Heer

This bark beetle was first detected in northeast Scotland in 1955, and surveys were carried out in that year and in 1958 to map its area of distribution. The results of the latter survey were presented in the 1959 *Research Report.*

A further survey was carried out in 1959. At the northern end of the range occurrence was recorded at Dornoch, Craigs, and Balblair Forests. It is not known if these records represent recent spread, since these localities had not previously been surveyed. It can now be said, however, that on the east coast *Ips cembrae* occurs as far north as there are any appreciable areas of larch. At the southern end of its range a new record was obtained in the Auchosnish Wood, near Grantown-on-Spey, on the Seafield Estates. This is some ten miles from the previous most southerly recorded locality near Ballindalloch. No changes in the eastern or western distribution boundaries have been noted.

Insecticidal Control of the Pine Weevil, Hylobius abietis L.

Reports received during the year indicate that phytotoxic effects of varying degrees of severity have occurred on plants of a number of coniferous species which had been dipped in 5 per cent DDT for protection against weevil attack. In some cases, most of the treated plants died; in others, needle browning and defoliation took place although the plants survived; and in yet others the dipping treatment gave effective protection from weevil attack and no plant poisoning effects were observed. These field results are at variance with those obtained during experimentation, where, although phytotoxicity occurred, it was acceptably slight. It is not known why this has happened but it is thought that the hot, dry summer of 1959 was in part, if not mainly, responsible for aggravating the effects.

Arrangements have been made to record the results of dipping treatments in 1960 so that, if necessary, experimental work on this topic can be renewed.

The Pine Needle Midge, Cecidomyia baeri Prell

Although no studies were made on this insect, it is worth recording that heavy infestations occurred in 1959 in Scots pine crops in eastern and central England. The minute larvae of this Cecidomyid live at the needle bases and their feeding activities cause defoliation which, because it is concentrated on the current year's needles and particularly on the upper parts of the crown, is very noticeable.

Advisory Work and Visits

One hundred and thirty-four enquiries were dealt with during the year, eighty-five originating from Forestry Commission and forty-nine from private sources.

Dr. M. Crooke visited Denmark in June 1959, to study the spruce bark beetle *Dendroctonus micans* Klug.

GREY SQUIRREL RESEARCH

By H. G. LLOYD and K. D. TAYLOR

The Straits Enclosure population study at Alice Holt Forest has continued through the year, with an all-out effort to recover as many marked animals as possible. Over 1,600 squirrels have been either shot or trapped and among them were 310 marked in previous years. This is quite a satisfactory proportion since some of the 1,600 were this year's young and had therefore been born too late to be marked. Similarly, in some parts of the 12½ sq. miles of experimental area, live-trapping had not been carried out since before the 1959 breeding season, and there were therefore two years' young which had escaped marking. The work of analysing data and tabulating results will be in progress during the autumn of this year and a report available by 1961.

Bait preference trials of high protein content calf-food and ground nuts have shown the former to be definitely unpalatable to wild squirrels while the latter appears to be as least as attractive as acorns. Cage tests of "Warfarin" on ground nuts have given promising results and field trials will be carried out this summer.

FOREST MANAGEMENT

By Dr. F. C. HUMMEL

The main weight of our effort during the year was directed towards economics, which is dealt with in the following section of this *Report*, and towards working plans. Mensurational and census work was confined mainly to the continuation or completion of projects begun in previous years.

There was also work in connection with international organisations. The writer was absent from the section during the greater part of the year working for F.A.O. in Rome. The assignment was to prepare, for publication, a report on Timber Trends and Prospects in the Asia Pacific Region. He also undertook some work for the International Union of Forest Research Organisations, Section 25, and attended, as Forestry Commission representative, the meeting of the F.A.O./E.C.E. Working Party on Forest and Forest Products Statistics in Geneva in December 1959.

Working Plans

Field Work

The principal development of this year has been the organisation of Conservancy working plan teams. Each team comprises two or three Conservancy assistant foresters and one or two Management Section foresters or assistant foresters, one of whom acts as their leader. Such teams are now working in most Conservancies.

Surveys were completed at the Forest of Dean, Thetford and Loch Ard, and are in progress at Ebbw and Cynwyd. The enumeration data for Thetford were processed by a digital computer with a considerable saving in time.

Training

A six-week course in ground survey and working plan survey techniques was held at Winchester. This was organised in conjunction with the Education Branch, and we were fortunate enough to have the services of an Ordnance Survey instructor for the ground survey course.

Census of Woodlands

The field work on the census revision of Northamptonshire was completed. This involved the assessment of about 16,000 acres out of a total woodland area of about 30,000 acres, the balance having been surveyed in the previous year.

As foreshadowed in last year's report, no further counties have been surveyed. Future surveys will be carried out by means of a sampling system and will provide figures of area, volume and increment for groups of counties and for conservancies. The method and intensity of sampling to be employed on these surveys have been investigated and a workable scheme evolved. The date of the first of these sampling surveys has been provisionally fixed for 1965.

The section has continued to deal with a wide variety of enquiries relating to estimates of woodland area, production forecasts, etc.

Mensuration

Yield Tables

Some progress was made with extending the age-ranges of the yield tables for the more important coniferous species, and in preparing multiple yield tables showing the effects of different thinning treatments. A preliminary investigation into the growth of lodgepole pine showed that the trend of height growth was very similar to that of Scots pine, and therefore the height/age curves for Scots pine (Forest Record No. 24) can be used to determine the quality class for lodgepole pine. There are, however, indications that on sites which best suit it, lodgepole pine does grow faster than first quality Scots pine and that an additional quality class of 80 feet at 50 years may be possible.

Permanent Sample Plots

The replicated thinning experiment in Sitka spruce, mentioned in last year's annual report, was established at Loch Eck Forest, Argyll. Twenty-seven plots were laid down to compare both the degree and periodicity of thinning; the treatments range from 120 per cent to 40 per cent of the yield table basal area. Detailed measurements were taken on all trees of five sample plots at Bagshot which had to be clear-felled after having served as a thinning experiment for 39 years. The object of the final measurement was to compare the accuracy of various methods of measuring standing crops.

Other Work

The demand for lectures, courses and field demonstrations in mensuration has continued to increase.

FOREST ECONOMICS

By A. J. GRAYSON

The period under review has seen the consolidation of certain lines of work started in previous years, in particular the working up of results of the sawmill study (noted in the previous report) and the amplification of studies on profitability and roading, as well as the continuation of work in the major field of hardwood economics. One new project has been started, this being concerned with the methods and results of collecting statistics leading to assessments of overall payments and receipts in the national private forest estate.

In this report attention is concentrated on the subject of prospects for hardwood cultivation, and on the methods employed in the mill study.

Economics of Hardwoods

This study is centred on an analysis of the development of price of hardwoods (in the round or sawn form, and by species wherever practicable). This concentration on price follows from the consideration that the major uncertainty in planning arises in the field of prospective money returns. While volumes may be estimated fairly precisely, existing prices and developments in relative prices call for much fuller appraisal. In almost all fields of use, there are imported timbers in direct competition with a home timber either of the same species or of a species with analogous properties, and the volume of demand for a home-grown product is markedly affected by price. Moreover the developments in preserving softwoods, and the increased availability of metals and plastic materials, both combine to offer resistance to any increased use of hardwoods.

It follows that the question of the prospective supply of imported hardwoods relative to that of home-grown hardwoods requires especial study, while substitution by softwoods and materials other than wood also requires consideration. While no analysis of this fundamental question, which has an even more important bearing in the softwood sector itself, can ever hope to be complete, it appears clear that the increasing demand and rising factor (wages, rent and interest) and non-factor (machinery, transport, royalties, etc.) costs in tropical supplying countries are at least capable in the future of raising prices of imported hardwoods faster than those of home-grown. In consequence the competitive advantages of home-grown hardwoods could become relatively stronger. However, this view must be qualified by reference to the potential production from hitherto untapped sources; because of this possibility the future may well see as marked a swing away from the present West African and South East Asian timbers, as the post-war period has seen in the displacement of North American timbers.

More recent work on hardwoods has led to the following conclusions:

(a) Records of standing sales over the past century in this country show that beech, Norway spruce and Scots pine have all increased in value relative to oak and European larch. This development is clearly linked with the substitution of other materials in place of strong, durable timbers.

(b) Current relative prices for different species should not be taken as the sole guide to the recognition of the most profitable course of management at any one time. In planning the treatment of crops which are likely to remain on the ground for a half-century or more, attention must be paid to the changes in fashion, technologies of conversion and use, etc. which influence the strength of demand and hence the price that a species may be likely to command.

(c) Considering the post-war period, during which time more detailed statistics on average import prices have become available, it may be noted that, while imported and home-grown sawn hardwood prices have moved together, both have risen more slowly than the prices of imported sawn softwoods. While the supplies of both home-grown and imported hardwoods clearly jointly determine the level of hardwood prices, it is difficult to analyse price formation more completely. This is because the diversity of demands for the materials included under the description "hardwoods" is so very wide. There is also the point that the common linking of one consumer with one particular source of supply, as well as other institutional factors, may render the whole picture too complicated for further analysis, unless price comparisons for materials, or groups of materials, of similar utility are available. Accordingly, it is essential to recognise the need for statistics by species, or species' groups, on volumes and prices.

(d) The post-war supply of home-grown sawn hardwood has declined at about 4½ per cent per annum. Superimposed on this general trend, there have been other fluctuations, and it has proved possible to detect a relationship between these variations and the price received for products in the previous year. Specifically, it appears that the quantity produced in any year has been positively associated with the price of sawn goods in the previous year, deflated by the cost of roundwood in that year. The elasticity of supply (i.e. the effect of a change in this price/cost ratio on the change in quantity produced) is estimated at about ½.

Sawmill Study

A mill study was undertaken in the early part of the year, with the aim of assessing the value to a particular miller of the logs supplied. In the absence of an adequate market test of sawlog value, a direct appraisal by measurement is useful in two respects. Firstly, it enables one to assess the price changes that may be expected if a supplier provides longer or bigger-girthed logs, and this evidence is invaluable in building up a price-size curve for use in profitability studies. Secondly, it enables a check to be made on the fairness of existing prices, both in respect of their variation with size and shape of log, and their absolute levels. For any mill, the variation of cost of sawing with shape and size of log may be determined, as well as the change in value of the sawn-timber produced from different log sizes. Shape and size were defined in the mill study by top-diameter under-bark, and length. Figure 1 indicates the shapes of curves derived for sawn value and milling cost, while Figure 2 shows the curve of *residual* value obtained by subtracting cost from value at each top diameter.

Six batches of logs in the diameter classes 6-6·9 inch, 7-7·9 inch, etc. up to 11-12·9 inch, were sawn separately in order to estimate saleable volume recovery from the round log and the value of the sawn outturn. As a separate part of the study, five runs of measured logs were timed at the mill headsaw, the runs being representative of the normal flow of logs. After certain corrections had been applied for variations in the ratio of time absorbed on the resaw, compared with time at the headsaw, values of milling time per unit of log volume were calculated. The volume recovery estimates provided by the

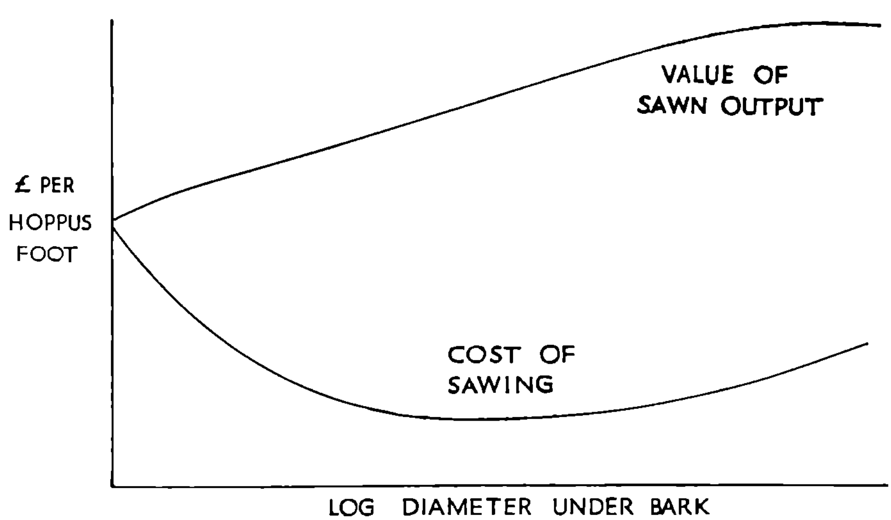

FIG. 1.—Diagrammatic representation of variation in value of sawn output and sawing cost for a given log length.

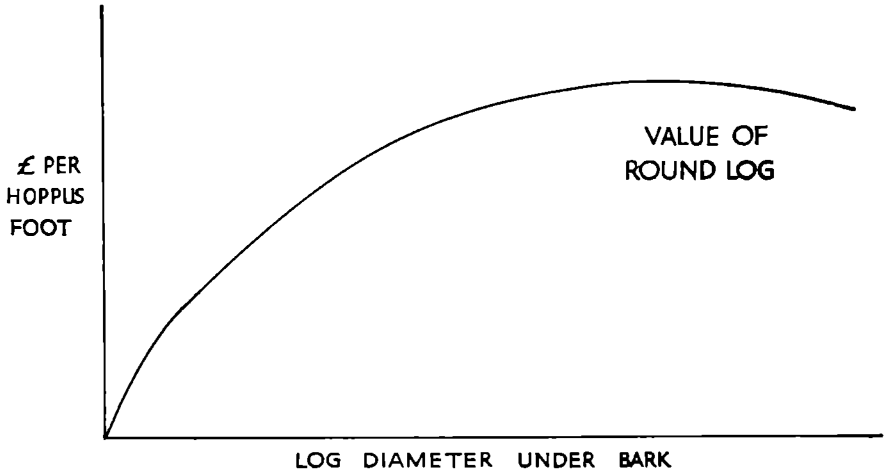

FIG. 2.—Variation in the residual value of round log, for a given log length, derived from the curves of Figure 1.

batch results were used to calculate the level of those variable costs which could reasonably be held to change in proportion to the volume of sawn outturn. With fixed charges added, total costs could thus be estimated, making the slightly artificial assumption of full capacity working on a continuing flow of logs of a stated top diameter and length. Unit costs of milling per hoppus foot of log were then computed. The residual log value (i.e. the price the miller could afford to pay for his logs and still cover all costs) was then derived by subtracting unit cost, at each combination of diameter and length, from the estimated sawn value per hoppus foot of log computed using the batch results.

The cost of milling was plotted against log diameter for different log lengths. The resulting family of curves exhibited the reversed J-shaped curve generally found in mill studies. Length was found to have the largest influence on cost per hoppus foot of log in the extremes of the range of log diameters. When value of sawn out-turn per hoppus foot of log was plotted against diameter for the various log lengths, it was seen that length had an even more important influence than in the family of cost curves, but this effect was in the opposite direction. For whereas a longer log of a given diameter cost less to saw, the value outturn from it was lower by a larger amount, and consequently residual value was reduced as length increased, within the range studied. Longer logs of a given top diameter clearly involve less "dead" time in handling, and hence costs per unit volume fall for the longer logs. But in rapidly tapering logs, and with the sawing patterns adopted, longer logs involve more resawing, higher waste and, because there is little differentiation between batten and board prices, lower value outturn per unit volume, compared with shorter logs.

Thus the net effect found in this particular mill study was that residual log value rose markedly with increasing top diameter, but declined with increasing log length at all values of top diameter. This result, in the specific instance studied, has important practical implications for both the miller and the supplier of round logs. Studies of the appropriate pattern of cross-cutting, and of the choice of place (in the forest stand, at road side, or in mill-yard) where the operation should best be undertaken, are clearly indicated.

DESIGN AND ANALYSIS OF EXPERIMENTS

By J. N. R. JEFFERS

As in previous years, advice on the design and analysis of experiments and surveys, and the analysis and interpretation of such investigations, has been undertaken by the Statistics Section. The most important factor in the provision of this service has been the completion of the transfer of all computing from electric desk calculating machines to an electronic digital computer. The main computer used has been a Ferranti Pegasus one at the nearby Royal Aircraft establishment, but some work has also been done on a Sirius computer at the Ferranti London Computer Centre, and on a Mercury computer at Oxford University. All types of statistical analysis can now be carried out quickly and economically, and the range and depth of the experimental work of the Research Branch has therefore been increased enormously.

Advisory work on the design and analysis of forest experiments has also been undertaken for the Colonial Forest Departments, and for other organisations and research stations interested in forest problems, particularly for the Forest Products Research Laboratory and the Tropical Products Institute.

A limited amount of research into the application of statistical methods to problems of forest research and management has also been undertaken, and this year there has been an increased emphasis on applications to problems of forest management. In particular, research into the methods of sampling for auditing, methods of conducting utilisation and accident surveys, and the use of the methods of operational research have all been investigated.

Experimental Design

Designs have been provided for more than one hundred experiments during the year, and there has been the usual diversity in the complexity and scope of these experiments. Stress has continued to be placed on the design of experiments in such a way that further treatments may be applied when the original objects of the experiment have been fulfilled, so that the effects of the two sets of treatments can be disentangled. The results from the earlier fertiliser experiments using fractional replication have also been satisfactory, and further trials on the same lines have been laid down.

Particular attention has been paid to the important subject of the design of thinning experiments, whether of the conventional plot type or of more unconventional forms. While it cannot be claimed that much real progress in the design of this important type of experiment has been achieved, the discussions and investigations of the past year have at least cleared the ground for more substantial progress in the future, and it is hoped that satisfactory solutions to these problems will be found.

Survey Design

The design of a wide variety of surveys continues to play an important part in the work of the Section. Notable subjects for surveys included the numbers and types of forest accidents, production and disposal of woodwaste, the moisture content and specific gravity of fresh-felled timber, the effects of the hot dry summer of 1959, and the physical, mechanical, and chemical properties of home-grown timber. The sampling problems of working plan enumerations have also been given special attention.

Analysis of Experiments and Surveys

As a result of the transfer of all computing to electronic digital computers, the number of analyses completed during the year has been trebled. Since the number of experiments and surveys analysed increased by only about twenty per cent, this increase in the number of actual analyses undertaken represents a far more complete investigation of each individual collection of experimental and survey data. Indeed, the main advantage in the use of digital computers has not been in the increased number of experiments analysed, but in the complete freedom to carry out any analysis that the research officer in charge of the experimental work desires. Greater care has therefore been necessary in specifying exactly those hypotheses which are required to be tested. Provided the data have been collected in a suitable manner, the research officer now has a free choice of hypotheses to be tested.

Particular emphasis has been given to multiple regression analysis of experimental data, and wider use of the analysis of covariance, since both of these forms of analysis are very much easier to perform with the aid of a computer than with electric desk machines. Methods of statistical genetics have also been applied to an increasing number of the experiments of the Genetics Section, with valuable results—again the barrier to the application of these methods in the past has always been the length of time required for the computations.

Research has continued into the problems of the analysis of perennial crops by methods which describe the growth of the trees by means of mathematical models, and this work has received some stimulus from work of other statisticians in this field, particularly in India. Multivariate analysis as a fundamental tool in the analysis of data of forest research and management has also received continuing attention, and has been applied to a wide range of problems. It is hoped to write up the results of some of this work in the coming year.

Programming of Computers

Although the several computers which are used by the Statistics Section have a considerable range of statistical programmes, a notable part of the time of the Section has been spent in the development of new programmes. The Pegasus computer, in particular, has a very full range of statistical programmes, and the extension of this range has taken the form of writing programmes for special kinds of experimental design, or, alternatively, in generalising existing programmes to cover the widest possible range of designs. As an example of the former, programmes have been written to cover all the most frequently occurring experimental designs, e.g. randomized blocks, latin squares, graeco-latin squares, split-plot and other factorial designs. One special programme which deserves particular mention, is that for the analysis of fractionally replicated 3^5 factorial designs, which have been used in recent work on the use of fertilizers on pole-stage crops.

The need to segregate analyses by types of design has, however, been found to be cumbersome and wasteful of machine time and effort, and a start has been made in the writing of generalized programmes capable of handling the analysis of any type of design. A programme for orthogonal designs has been started, but has not yet been completed, mainly because it was felt that a programme for non-orthogonal designs was of greater urgency. This latter programme, which has been written in co-operation with Dr. G. H. Freeman, of the East Malling Research Station, is now complete and provides the analysis of variance for any experimental design with up to three constraints, orthogonal or non-orthogonal, although in fact it would be wasteful to use the programme for the analysis of orthogonal designs.

The most important of the special programmes for forestry research and management is the programme written to simplify the computation of the volumes of enumeration plots in working plan and other surveys. This programme calculates the basal areas and volumes by species and diameter size classes for the plot from records of the numbers of trees of each species in each girth class, and the heights of a small number of sample trees, and it also builds up a record of the total distribution of volumes by species and size classes, and the essential data of the survey, in terms of the mean basal area, mean volume per acre, the standard deviation and the standard error of the mean volume per acre. The programme, which is now fully operational, can be applied to the large number of practical situations in which enumeration is required.

Other special problems for which programmes have been written include the evaluation of quantities of nutrients in the foliage of forest trees from laboratory measurements, the compiling and editing of lists of research branch experiments for a large number of purposes, and the compilation of long-term and short-term thinning and felling forecasts for Forestry Commission forests.

International Union of Forest Research Organisations

The Working Part of Section 25 of the International Union of Forest Research Organisations, which is studying the problems of standardisation of measurements in forest experiments, and of the collection and publication of information on instruments used in forestry, and of which the Statistician is Secretary, has continued its activities, and is preparing the final report for the next Congress of the Organisation. The Statistician is also a member of the Advisory Group of Forest Statisticians of the Organisation, and this Group has been actively considering the part that it can best play in the encouragement of the use of efficient statistical methods in forest research.

The International Union of Forest Research Organisations has also published the book prepared by J. N. R. Jeffers of this Statistics Section, describing the use of statistical methods in forest research. (See Appendix III).

MACHINERY RESEARCH

By R. G. SHAW

Drain Cleaning

The cleaning of forest drains at an economic price has been a long standing problem, and many ideas tried out over several recent years have proved to be no more than a partial solution. During the past year, however, a machine on entirely new lines has been developed and it has given encouraging results in prototype form on drains up to a depth of 18 inches. This machine consists of a rotor carrying a series of flails driven by the power take-off shaft of wheeled or tracked tractors (see Plate 14).

Transport

Work has continued on experiments directed towards increasing the cross-country capacity of wheeled vehicles. An example is the conversion of a Land Rover to giant wheel equipment (10 × 28).

Loading

With the steady increase in the size of individual logs, mechanical loading is becoming more important. Hydraulic jib type loaders, notably the Swedish H.I.A.B., continue to give excellent service in the Commission's forests, and a new British design of twin lifting-arms for side-loading is in the prototype stage.

Bark Peeling

A wide range of peeling machines exists and several types are already being used successfully for peeling straight poles. A recent demand has arisen for a machine capable of peeling rough and bent hardwoods for use as wood pulp, and an investigation is taking place on the design of a machine for this comparatively difficult operation.

Power Saws

A test rig based on the Provisional Schedule for the Testing of Power Saws issued by F.A.O. has now been installed at the Forest Products Research Laboratory. On this rig it is possible to measure the power being given by any individual saw when actually cutting.

Extraction and Conversion

The extraction of timber from the forest on steep slopes or on very soft ground continues to be a very expensive operation and much work has been done in recent years on various forms of ropeways, winches and chutes. The difficulty found with all this equipment is the disproportionate time required for erection and dismantling for the small output per acre yielded by the normal thinning operation. A new development is a light monorail railway which can be very quickly erected, operated and dismantled by a team of five men.

Conversion, limited to cross-cutting and peeling, on the line system with a powered conveyor, has been taken to the point where results suggest that a material saving in cost can be achieved by this method. The throughput must, however, be of the order of 6 tons per hour for a period of at least four working days to make it worth adoption and there are few areas at present yielding this output of thinnings within a radius of four miles (see Plate 15).

Mechanisation of Nursery Operations

Nurseries remain one of the most rewarding avenues of mechanisation in forestry and machines are in use for many nursery operations. Standardisation is, however, difficult owing to the variation in local conditions, and there are many locally-developed machines doing good work in their own areas. A recent development is a lining-out plough produced at York Forest in North-East England which has the advantage of maintaining very accurate spacing between the rows of transplants.

UTILIZATION DEVELOPMENT

By E. G. RICHARDS

Home Grown Pitprops

The investigation into the compressive strength of home-grown pitprops, mentioned in the *Research Report for 1958*, continued. The testing, at the Forest Products Research Laboratory, of pitprops from England and Scotland was completed, and the results demonstrated the suitability of properly prepared, seasoned, home-grown softwood pitprops for use as timber supports in the mines. A preliminary report on these tests has been forwarded to the National Coal Board. The testing of pitprops from Wales will shortly be completed.

Statistical examination of the experimental data continues, and a report on the various characteristics of the timber and their correlation with strength properties is being prepared.

The Use of Timber in Building

The survey into the types, dimensions and qualities of softwood used in domestic housing was completed. The results have been published as Forest Record No. 42, *Use of Home-Grown Softwood in House Construction.*

Yields of Hardwood Coppice

This survey, mentioned in the *Research Report for 1958*, was completed and an account of the methods used, and the results, is given in Part III of this *Report*, in the paper "Estimating Yield of Hardwood Coppice for Pulpwood Growing".

Determination of Specific Gravity and Moisture Content of Freshly Felled Conifers

Extensive sampling of 20 to 40 year-old crops of the major coniferous species, to determine their specific gravity and moisture content, is under way. The species comprise Scots and Corsican pine; European and Japanese larch; Norway and Sitka spruce; and Douglas fir. Studies are being undertaken on the correlations of various characteristics, including top diameter of log, with both moisture content and specific gravity.

Properties of Home-Grown Timber

A comprehensive programme of study on the properties of home-grown Sitka spruce and their relation to site factors began this year. This programme is being undertaken jointly with the Forest Products Research Laboratory at

Princes Risborough, where all the tests on the timber are carried out, except for those on pulping properties which have so far been undertaken by the Tropical Products Institute.

Fence Post Trials

Further assessments on these trials mentioned in the *Research Report for 1958* have been made. A small number of failures of *untreated* posts have already occurred.

Thinnings House

The timber house at Joyden's Wood, Kent, described in the last Annual Report, was completed during the year and is now occupied. Valuable practical experience has been gained in the sawing, kiln drying, pressure treating and machining of home-grown timber cut from the small diameter logs used on this work. A further bungalow made in home-grown timber from thinnings is now planned.

Extractives from Wood Bark

The work carried out by the British Leather Manufacturers' Research Association is reported on by Dr. D. E. Hathway in his paper "Utilisation of Tan Barks", in Part II of this Report.

A survey of the literature on bark has been prepared for the Forestry Commission by the Tropical Products Institute, and this, together with the work undertaken by the Forestry Commission, has shown that, at present, no very promising new large-scale developments in the use of home-grown bark can be expected.

THE LIBRARY AND PHOTOGRAPHIC COLLECTION

By G. D. KITCHINGMAN and I. A. ANDERSON

Library

The number of books in the library on the 31st March, 1960 was 3,485, an increase during the year of 220, of which 126 were bought and the remainder received by gift or exchange. 819 books are now on permanent loan to Sectional libraries. Other loans of books increased from 926 to 952. 285 publications were borrowed from outside libraries. Another 71 volumes of periodicals were bound, bringing the total to 1,426.

Archives

The files in this section form a valuable collection of typescript reports, separates, translations, etc. which has been carefully indexed and cross-referenced in the library card catalogue. This section will eventually be of great historical interest.

Documentation

Progress is slow, but the number of cards in the indices (card catalogue) is now about 92,500.

Bibliographies

Annotated bibliographies on Land Use, Fire Protection, Damage by Tree Roots and Elm Silviculture were issued during the year in the Library Quarterly. Besides these four, many were prepared on other subjects in response to requests. An index to bibliographies on forest subjects, which have been already prepared by forest institutions throughout the world, is urgently needed. Work was continued on the bibliography of British forest literature up to 1950.

Translation

The more important translations completed were noted in the Library Quarterly. These now total 110.

Aslib

Close contact was maintained with the Association of Special Libraries and Information Bureaux, of which the Library is a member.

Gift of Books

The Forestry Commission is particularly grateful for the gift of many valuable books and reprints from the library of the late Mr. William Dallimore, V.M.H.

Photographic Collection

The Photographic Records Section has had its busiest year.

The following figures for slides loaned for lecture purposes indicate the extent to which this collection is now being used:

1952/3	652	slides loaned
1953/4	1,216	„ „
1954/5	5,081	„ „
1955/6	5,458	„ „
1956/7	7,740	„ „
1957/8	8,640	„ „
1958/9	10,368	„ „
1959/60	13,421	„ „

The number of colour slides in the collection increased from 5,700 to 7,000.

1,718 photographs were loaned to exhibitions, agricultural shows, publishers, etc.

Film distribution amounted to 204 films loaned during the year, compared with 180 films last year and 166 in 1957/8.

A film on the Life history and Control of the Pine looper moth, *Bupalus piniarius* should be ready for issue in 1960, also a short record film on seed collection by means of a tree net and tree bicycle.

PART II

Research Undertaken for the Forestry Commission by Workers attached to Universities and other Institutions

RESEARCHES IN MYCORRHIZA

By Dr. IDA LEVISOHN
Bedford College, University of London

Differential Effects of Strains of Boletus scaber on the Growth of Birch Seedlings

From the practical as well as from the academic point of view it is of considerable interest to obtain information about the specificity of mycorrhiza-formers and their influence on tree growth. In the *Report on Forest Research, 1957*, results of experiments were recorded which demonstrated differential responses of certain tree seedlings to various mycorrhizal fungi. Later observations suggested that not only different species of fungi, but also different strains of the same fungal species, might be responsible for the dissimilar performance of young trees. This was confirmed in pot-culture experiments carried out during 1959.

For inoculation purposes, pure culture mycelia of three forms of *Boletus scaber*, differing in their ecological origin, were employed. One came from a heathland soil (Dorset), another from moorland (Yorkshire), and the third from a deciduous wood in Berkshire. As regards pure culture reactions, the form from Dorset had previously been found to behave differently from the two other forms (Levisohn, 1959).

Betula verrucosa was used as test plant, being grown in sterile sand and in two different soils, each "sterilized" and "not sterilized". One of these experimental soils had been brought in from Wareham (P.38), the other from Ringwood nursery. The average height of the 1-year-old seedlings is recorded in Table 7.

Table 7

Effect of Various Forms of Boletus scaber on the Development of Birch Seedlings in Different Growing Media

	Control medium	*B. scaber* Dorset	*B. scaber* Yorks	*B. scaber* Berks
Sand, sterilized	1·3	2·8	1·9	1·7
Wareham soil, unsterilized	1·5	3·4	2·8	2·9
Wareham soil, sterilized	2·5	2·9	2·8	2·6
Ringwood soil, unsterilized	2·4	2·6	3·1	3·4
Ringwood soil, sterilized	5·0	5·2	5·4	5·0

Table 7 shows that, in the sand-cultures, only the form from Dorset had a pronounced stimulating effect on the seedlings. In the unsterilized heathland soil, all three forms were beneficial, the Dorset form producing the best effect. On the other hand, the forms from Yorkshire and Berkshire were more effective in the unsterilized soil of the agricultural type (from Ringwood). Inoculation in sterilized soils has, so far, not been observed to influence growth of the young plants. Since root examination is still in progress, no information can yet be given as to whether the growth stimulation recorded is due to actual mycorrhizal infection or to the rhizosphere activity of the mycelia under observation.

Seedlings of Scots pine have not shown any response to the three different forms of *B. scaber* introduced into experimental soils. However, they have stimulated Scots pine plants growing in sand-cultures.

Preliminary Study of the Effects of Gibberellins on Root Infections of Forest Trees

Researches carried out during the last few years in the U.S.A., Australia, and Great Britain have demonstrated that gibberellins can decrease the nodulation of leguminous crops, and caution was therefore recommended in the application of gibberellic acid to legumes. This state of affairs suggested an enquiry into the effects of this substance on other root-associations, including fungal root-infections of forest trees.

In order to investigate whether gibberellins can interfere in the formation of mycorrhizal and non-mycorrhizal associations, certain test plants were selected which have shown differential growth response to gibberellic acid: Scots pine, Douglas fir, and beech. It was planned to include *Eucalyptus camaldulensis*, which has been reported to demonstrate remarkable stimulation from gibberellic acid treatment (Giordano, 1959) and which is one of the tree species in many environments free from mycorrhizal infection.

The experiments devised to assess the reaction of fungal root-associations involved applications of gibberellic acid (1) as soil treatment; (2) in the form of a foliar spray. Here only a preliminary account is given of some of the investigations carried out in 1959 on the effects of gibberellic acid as a soil treatment on the root-infections on Scots pine seedlings in their first year of growth.

Although it seems generally accepted that gibberellic acid is rapidly decomposed in the soil, it was considered of interest to test the activity of the substance in its natural environment (the soil), and to employ not only gibberellic acid as such but also *Gibberella fujikuroi*, the soil-borne fungus which produces the acid. A pure culture of the fungus was provided by the Butterwick Research Laboratory, Welwyn.

a. Effect of Gibberella fujikuroi

Scots pine seedlings were grown in 4½-inch pots with three different soils; two podsols and a soil of the agricultural type. The experimental soils exhibited a considerable contrast as regards their fungal population. In all, 72 pot-cultures were set up, 24 pots in each soil series (12 controls and 12 treated cultures). *G. fujikuroi* was inoculated at sowing and re-inoculated twice at monthly intervals. Three months from sowing, the inoculated pots showed slight light inhibition in growth and some discolouration of the foliage. These symptoms of decreased vigour were accompanied by a conspicuous shift in the proportion of the various root-associations affecting the experimental seedlings. In all three soils, the incidence of pseudomycorrhizal infection had increased at the cost of mycorrhizal infection. However, at a later stage, when the seedlings were about eight months old, the differences in shoot development had disappeared, and the drastic shift in root infections, observed earlier, was far less pronounced.

In mixed cultures on a nutrient agar medium, *G. fujikuroi* showed antagonistic effects on a number of mycorrhiza-formers tested, including several mycorrhizal mycelia active in the soils under observation. Pronounced inhibition was also recorded for a root parasite (*Rhizoctonia sylvestris*) attacking the roots in one of the soils, while the common pseudomycorrhiza-former *Mycelium radicis atrovirens*, present in the two podsols, was not affected by *G. fujikuroi.*

b. Effect of Gibberellic Acid

An aqueous solution was applied to cultures in the same soils as those used for testing the activity of *G. fujikuroi.* There were also 24 pots (12 controls and 12 treated cultures) in each soil series. One month from sowing, the regular watering of the pots was interrupted by applying, once weekly for 7 weeks, 100 ml. of gibberellic acid solution at a concentration of 100 p.p.m. to each of the pot-cultures reserved for this treatment. At the time of the last application, i.e. towards the end of June, 1959, the soil in the treated pots showed a markedly higher water-holding capacity than the control soils, a phenomenon which was particularly noticeable in the soil of the agricultural type. Ten months from the last treatment, this effect of gibberellic acid is still conspicuous. The "field-capacity" of the treated soils is much higher than that of the control soils. It was also observed that a soil cover of algae and mosses, present in the untreated cultures, is absent from the pots which have received giberellic acid.

In an effort to determine whether the greater ability to retain water was a direct effect on the physical properties of the soil, or brought about, at least to some degree, by changes induced in the treated seedlings and/or by changes in the soil microflora, experiments with unplanted pots, using both sterilized and unsterilized soils, were carried out. In both sets, the application of gibberellic acid produced a noticeable increase in the water-holding capacity. From the results of these experiments, and additional investigations which will be reported later, it would appear that the influence of gibberellic acid on the soil is essentially a direct one. It seems likely, although this has not been established yet, that the change in the soil is of a colloidal nature, as in the case of soil changes produced by certain soil-conditioners.

As to the seedlings themselves, no differences in shoot development between controls and treated cultures have been observed. Examination of the roots showed identical effects of gibberellic acid application to the experimental soils: considerably reduced root systems of lighter colour, with total absence of any root-associations, and the presence of root hairs. Unusual metabolic poducts, some of them oily in nature, were abundantly distributed throughout the cortical cells. Recently a number of seedlings were transferred from treated to untreated soil, and vice-versa, but it is too early to say anything here about the conditions of their root system after transfer.

On a nutrient agar medium, incorporation of gibberellic acid in a concentration of 100 p.p.m., affected the growth rate of mycorrhizal mycelia adversely. After 4 weeks' growth, the average colony diameter was as follows:—

	Control medium	+ 100 p.p.m. gibberellic acid
Boletus granulatus	4 cm	2 cm
Boletus scaber	15 „	10 „
Rhizopogon luteolus	11 „	6 „

The parasite *Rhizoctonia sylvestris* reacted with profuse formation of sclerotia to the addition of gibberellic acid while no effect on *Mycelium radicis atrovirens* was recorded.

The next step in the present gibberellic work will be an investigation concerned with the influence of foliar spray on the fungal root associations of the experimental plants. Should treatment of the plant *per se* affect mycorrhizal and pseudo-mycorrhizal infections in the same way that soil application does, the warning about caution in the use of gibberellic acid would not only refer to treatment of leguminous crops.

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STUDIES IN SOIL MYCOLOGY

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Mycostasis in Soils

Germination Assay

Monthly germination tests with *Mucor ramannianus* on twelve woodland soils, as described in the *Research Reports* for 1958 and 1959, have been continued for a third year. Despite the unusually wide difference between the wet summer of 1958 and the dry one of 1959, a seasonal variation has been found to persist in the germination level, with a maximum in the winter months and a minimum during the summer, when the soils are normally strongly mycostatic. Although, during each winter, there has been a wide variation between the different soils, nevertheless the average germination level for all soils during the 36 months of the assay to date has exceeded 50 per cent of the control level during only two months: December 1957 and January 1958. Out of the 390 soil samples tested up to March 1960, only 35 showed germination equal to or exceeding the controls. It may therefore be taken as confirmed that the mycostatic factor is generally present in these forest soils throughout the year.

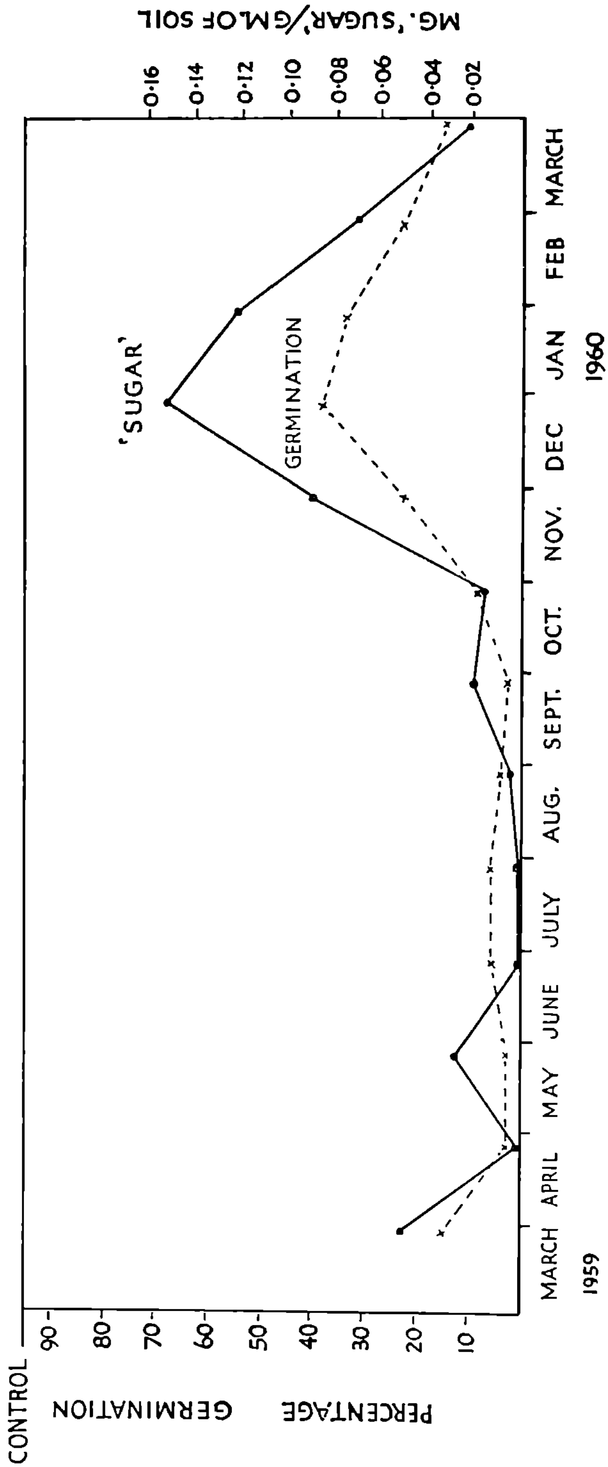

FIG. 3.—Percentage Germination (broken line) in relation to "Sugar" Concentration (full line), by time of year.

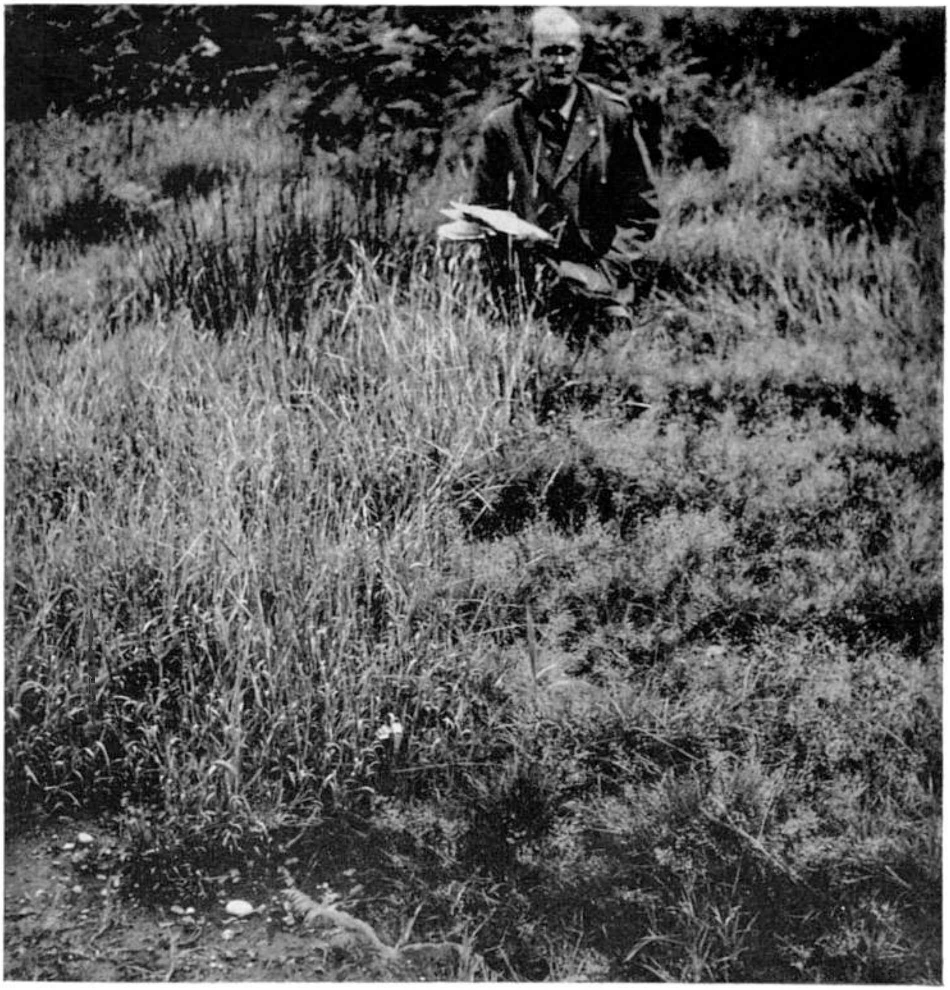

PLATE 1. Holmes and Fourt: Herbicides for Controlling Vegetation.

Bramshill Forest: Herbicides on Forest Firebreaks

Right: Crude Sodium Borate at 9 cwt. (active) per acre applied to a ploughed sandy soil, formerly a mixture of *Holcus mollis*, *Agrostis tenuis* and a few herbs. The rhizomatous *Holcus* proved susceptible, and the development of a dense flowering mass of pure *Agrostus tenuis* strongly suggests some degree of tolerance.

Left: Diuron at 12 lbs. (active) per acre has prevented re-establishment of *Agrostis tenuis*, but has left the *Holcus mollis* practically unscathed.

Photo: Second Summer after treatment.

PLATE 2. Holmes and Fourt: Herbicides for Controlling Vegetation.

Bruton Forest, Somerset: Herbicides On Forest Firebreaks.

These plots show the effects of Crude Sodium Borate, applied to a ploughed ride, on heavy soil, formerly densely covered with several species of grass, *Juncus*, *Carex* and herbs. *In the foreground*, 21 cwt. (active) per acre, maintained sterility for two seasons observed. *Behind it* the 9 cwt. (active) per acre plot supports a little *Deschampsia caespitosa* only. The third plot at 15 cwt. (active) per acre. has a very few surviving plants of *Juncus acutiflorus*, from rhizomes. Other Borate plots on this site were colonised by the apparently tolerant *Chenopodium polyspermum*.

Photo: Second summer after treatment.

PLATE 3. Holmes and Fourt: Herbicides for Controlling Vegetation.

Blandford Forest, Dorset: Herbicides On Forest Firebreaks.

Right foreground: Diuron at 48 lb. (active) per acre applied to a wood-edge community on a chalk-heath soil. From a mixture of grasses, herbs, and low woody shrubs, an even sward of *Glechoma hederacea* has developed.

Left background: Borate-Chlorate mixture at 4 cwt. (active). Borate plus 4 cwt. (active). Borate plus 2 cwt. (active) Chlorate, all per acre. A vigorous grass cover has developed, predominantly of *Holcus lanatus* seedlings, with some *Dactylis glomerata* and *Rubus* species.

Photo: Second Summer after treatment.

PLATE 4. Henman: Pruning Conifers by Disbudding: Disbudded Scots pine at Mabie Forest which was unable to support a crown above the 16½ ft. length of disbudded stem. Photographed in April, 1960, with two seasons' growth of crown.

PLATE 5. Henman: Pruning Conifers by Disbudding: Disbudded Scots pine at Mabie Forest on which disbudding is continuing in the hope of obtaining a clear length of 16 ft. Photographed in April, 1960.

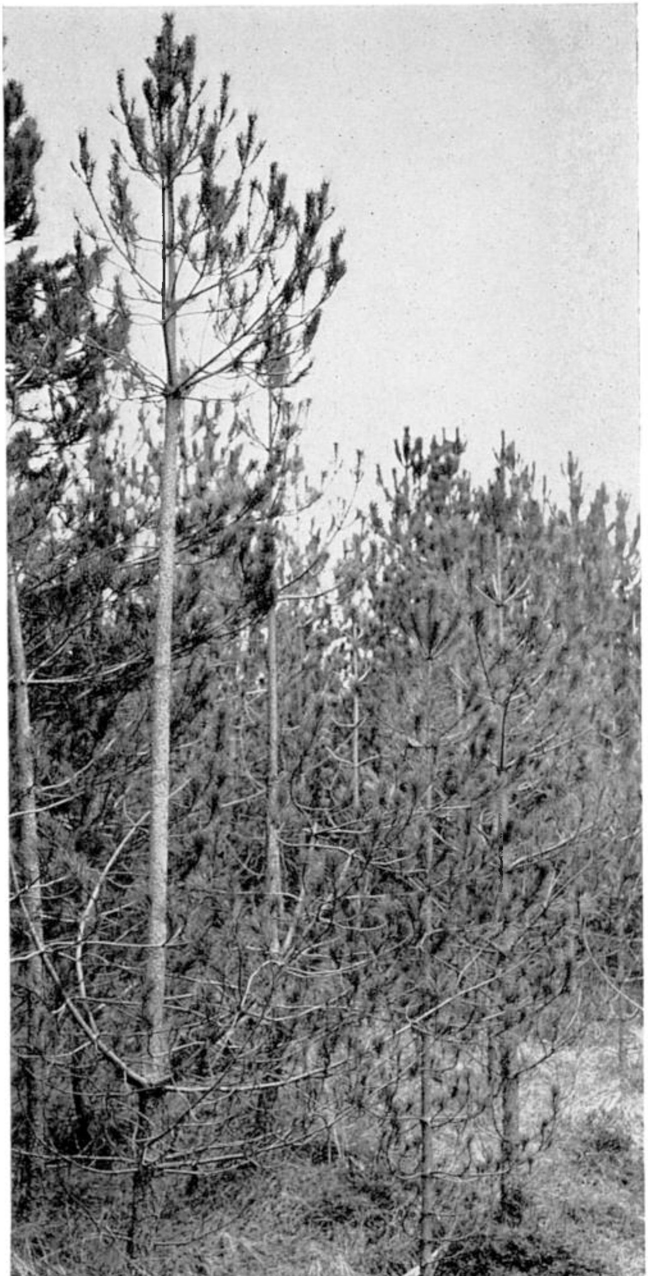

PLATE 6. Henman: Pruning Conifers by Disbudding: Disbudded Corsican pine at Lossie Forest, with 8½ ft. of clear stem and five whorls of branches in the crown. An example of successful disbudding.

Photographed in April, 1960.

PLATE 7. Stewart: Experimental Introductions: Advance crop of Scots pine 7 ft. tall, with single furrow ploughed for introductions. A row of checked *Sitka* spruce between the pines has been "ploughed in" (Langdale Forest Broxa Exp. 88).

PLATE 8. Stewart: Experimental Introductions: 9-year-old birch in advance crop of Norway spruce (Kielder Exp. 59). Winter Aspect.

PLATE 9. Stewart: Experimental Introductions: 9-year-old birch in advance crop of Norway spruce (Kielder Exp. 59) Summer Aspect.

PLATE 10. Stewart: Experimental Introductions: Strips 2 rows wide, cut in 5 ft. tall Norway spruce. One line of plants introduced in each strip. Photo taken 3 years after planting of introductions (Kielder Exp. 59)

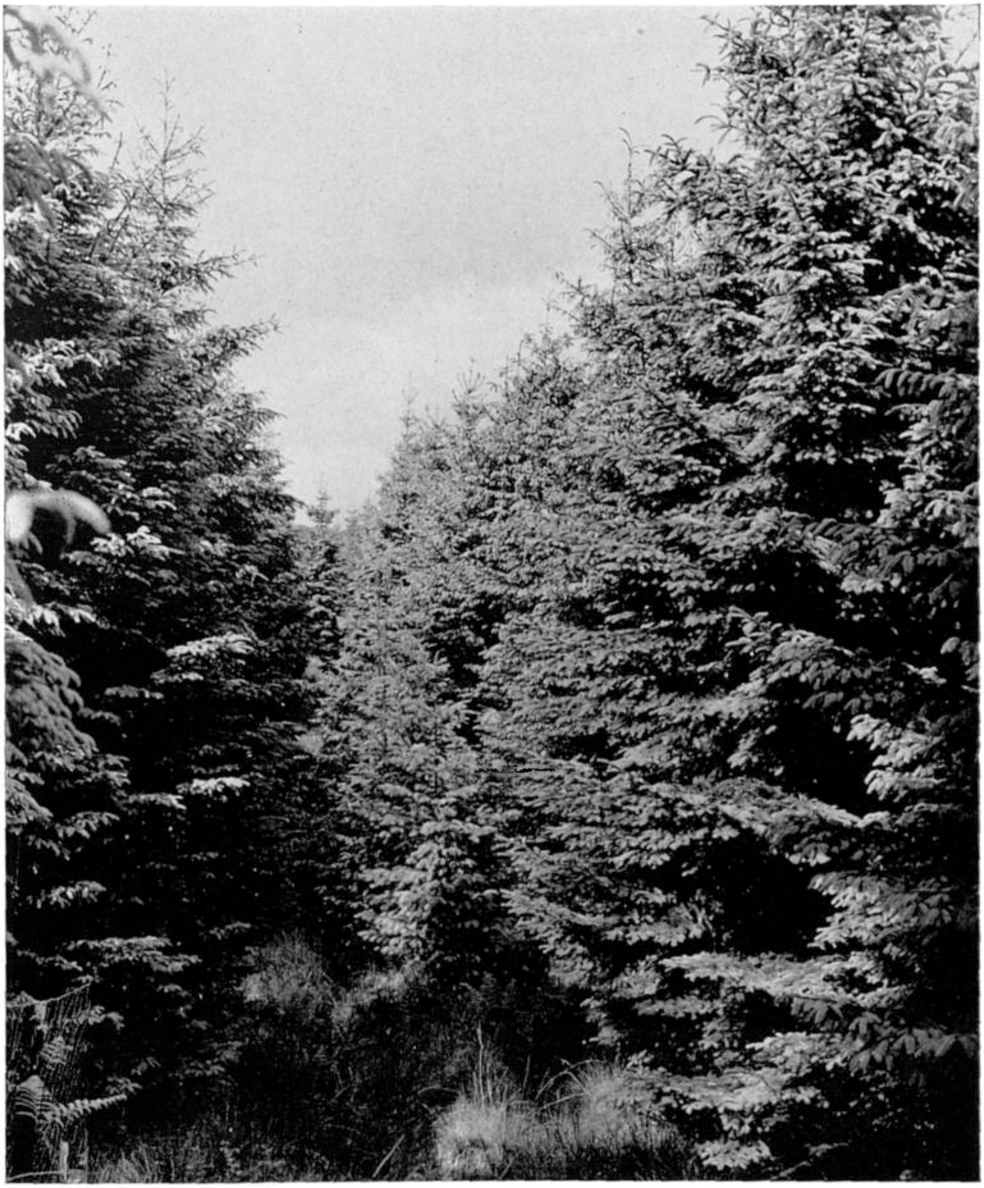

PLATE 11. Stewart: Experimental Introductions: 9-year-old Douglas fir in Norway spruce advance crop (Kielder Exp. 58).

PLATE 12. Stewart: Experimental Introductions: 13 year old hemlock and Grey alder in advance crop of Lodgepole pine (Teindland Exp. 41).

PLATE 13. Stewart: Experimental Introductions: 15 year old hemlock in Japanese larch (Allerston Forest, Wykeham Exp. 76).

PLATE 14. Shaw: Machinery Research: A prototype of the new flail type drain cleaning machine developed by the Forestry Commission for cleaning surface drains to a depth of 18 inches.

PLATE 15. Shaw: Machinery Research: Timber conversion on the line system. A power-driven conveyor feeds to a pendulum saw which, in turn feeds direct to peeling machines. Output is 6 tons per hour. The equipment can be moved and re-erected in half a day.

PLATE 16. Matthews and Jobling: Propagation of Elms and Poplars: Summer softwood cuttings of various clones of poplar raised under mist.

For the twelve months March 1959-60 the germination graph (see Figure 3) more nearly resembled that for 1957-1958 than that for 1958-1959, although the average remained higher in summer and lower in winter, and the period during which some stimulation of growth occurred (November to January only) was shorter than in either of the previous winters. As in 1958-1959, but not in 1957-1958, this condition was restricted to some of the litter samples.

Attempts to relate these variations with the weather records at a local station have been hindered by the discontinuance of certain readings, so that the records at another local weather station have had to be substituted over the whole period; but in general it can now be said that, over the three years, there is no pronounced or consistent pattern of relationship between the level of germination and the weather, except for the broad seasonal variation corresponding inversely with the average temperature. On some occasions a rise in germination has been preceded by sharp ground-frosts, in others not. The only marked correspondence with rainfall, in September, 1958, was largely limited to the beech-oak sites.

The main differences observed between the coniferous and broadleaved forest soils was that, in the summer of 1958 and 1959, mycostasis was more complete under the conifers than under the broadleaved trees. This was due to the persistence of considerable germination on the beech-oak litter samples in those summers, whereas in the late summer of 1957 inhibition was complete on all twelve soils.

Comparison of the Three Soil Layers

Figure 4 shows that a marked superiority in germination level over the humus and mineral layers was a continuous feature of the litter-assays from February 1958 onwards, and that only in 1957 was the seasonal variation strongly shown by all three layers. In 1958 and 1959 the pronounced winter rise in germination was attributable mainly to the litter samples—indeed, in 1958 almost entirely to these. It is particularly noteworthy that between February 1958 and November 1959, a period of twenty months, the four humus layers showed scarcely any departure from complete inhibition, with the sole exception of a marked rise in March 1959. This was due to the total lack of inhibition in one sample only (Church Island pine humus) which might have been caused by some local factor. The rise in the winter of 1959-60 was more broadly based and unlikely to be casual. The mineral samples also showed no midwinter maximum in 1958, and only a slight one in 1959.

It seems, therefore, that the relatively mild and rather dry winter of 1958-1959 was exceptional in that the mycostatic activity of the lower soil layers was scarcely affected. Of the three summers, the wet summer of 1958 resembled the dry one of 1959 in that some germination persisted in the litter layers, and the complete mycostasis of all twelve soils found in 1957 has not been repeated until the current season.

The over-all average percentage germination during the three years for the three soil layers, up to March 1960, stands at: litter 37·9 per cent; humus 10·3 per cent; mineral 9·2 per cent. Some 13 per cent of the litter samples showed stimulated germination, as against 1 per cent of the humus and 3 per cent of the mineral soil samples. This difference was more marked under the beech-oak than under the coniferous trees, and at the sea-level Church

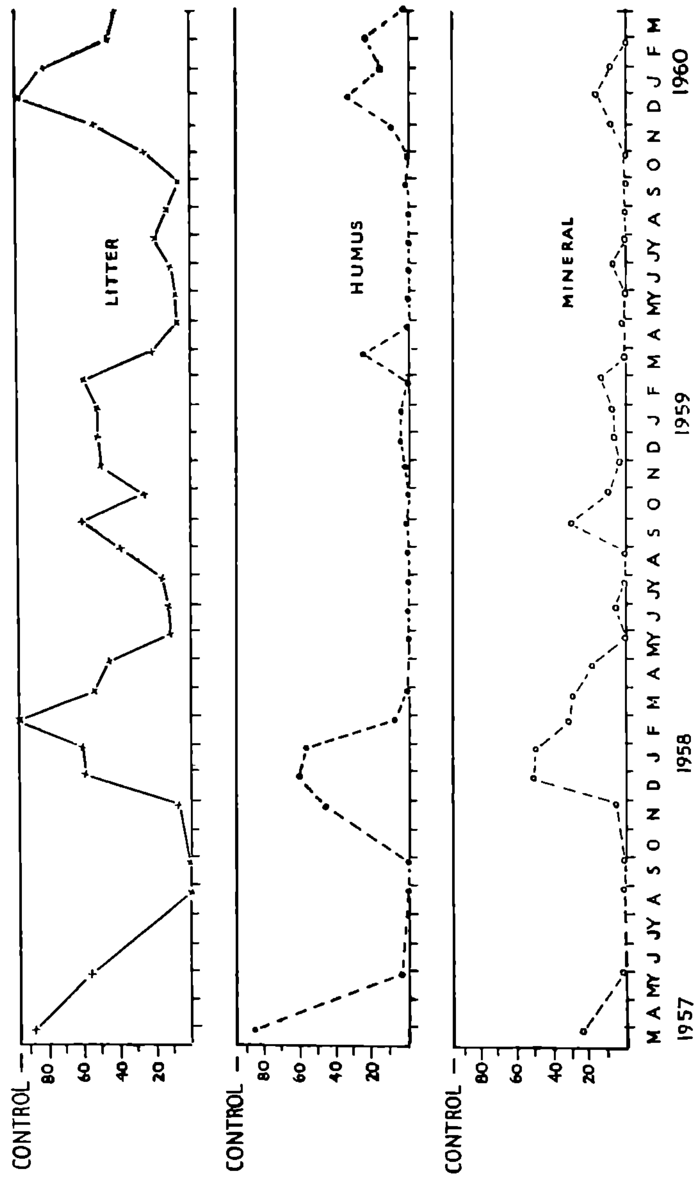

FIG. 4.—Percentage Germination on the three soil layers, by time of year.

Island site than on the hillside at Marian y Winllan. A comparison of the litter layers is shown in Table 8.

Table 8

Percentage of Litter Samples Showing:—

	Total Inhibition	*Partial Inhibition*	*No Inhibition*	*Stimulated Growth*
Beech-Oak ..	15·3	58·4	26·0	21·4
Conifers	38·4	52·3	9·2	7·7
Church Island	22·7	51·5	25·6	18·1
Marian y Winllan	31·7	57·1	11·0	7 9

It is proposed to terminate the germination assay during the summer of 1960. A considerable bulk of data now awaits analysis.

Reducing Substances in Soils

Preliminary results reported in 1959 showed that there is a close correspondence between germination percentage and estimations of the reducing power of the soil samples. This has now been fully confirmed by further work. Correlation, based upon 156 soil samples spread over the thirteen months, March 1959-60, is highly significant ($r = \cdot 41$, $p < \cdot 001$).

Figure 3 shows total reducing power (as estimated by a modification of the Shaffer-Hartman method, see 1959 *Report*) plotted with average germination percentage, for the twelve soils previously used, monthly from April 1959 to March 1960. It can be seen that there is parallel variation between the two curves during the winter period when germination is high, but none during the summer when it is low. In particular, minor rises in both May and September are not followed by the germination curve. This seems compatible with the idea that the sugar content of the soil is the main determining factor during the winter, but that during the summer the mycostatic factor itself is the more important.

Although in the estimation of reducing material in the soil samples, tannins and protein material are precipitated with lead acetate, so that the main reducing material left should consist of sugars, it was felt advisable to run chromatograms with a view to confirming this point, and determining which sugars are present. Hitherto one method only has been used: the butanol/pyridine/water method of Trevelyan, Proctor and Harrison (1950). For extraction, both sodium hydroxide and water have been used, with similar results.

The "fulvic acid method" of Forsyth (1947) which involves extraction with 0·5 Normal sodium hydroxide, precipitation of the humic acid fractions with hydrochloric acid, followed by filtration, evaporation, and further extraction with alcohol, showed the presence of ribose, sorbose, and galactose in the extracts of pine humus soil, together with an unidentified spot of high molecular weight. Similar chromatograms from the extract after hydrolysis with Normal sulphuric acid showed a decrease in this spot, with an increase in the size and intensity of the spots for ribose and galactose.

The same spots were obtained with a water-extract made by bubbling nitrogen gas through a soil+water mixture, followed by Seitz-filtration and precipitation with neutral lead acetate. The presence of sugars in the soil-extract is therefore confirmed. Freezing the soil before extraction to $-20°C$ gave the same spots, but somewhat larger. Autoclaved soil gave much larger spots for the same three sugars, with the addition of another representing xylose. The high-molecular-weight spot was much reduced, indicating probable hydrolysis of a polysaccharide.

The presence of a polysaccharide fraction in soils has been demonstrated by Forsyth (1950), who suggests that it is a synthetic microbial product. He also showed that such polysaccharides are capable of autohydrolysis in aqueous soil solution, giving rise to simple reducing sugars. Bernier (1958) has more recently extracted polysaccharide material from a range of forest soils and has shown that they are complex heteropolysaccharides, yielding a range of sugars, including galactose and xylose, on hydrolysis. It seems probable therefore that the high level of reducing sugars found in our forest soils during the winter months may in part be accounted for by the gradual hydrolysis of the soil polysaccharides.

Soil Extracts

Satisfactory extracts of the inhibitor, not partially masked by sugars in solution, can be obtained with any certainty only during the summer period. Other difficulties arise from the ability of the inhibitor in aqueous solution, especially when exposed to the air.

During the summer of 1959, crude extracts of a number of forest soils were made by mixing the soil with freshly boiled distilled water and filtering through four thicknesses of Whatman's No. 52 filter paper in a sealed evacuated pressure vessel, under 10 lb. pressure of nitrogen gas applied from a cylinder. The extract was then either siphoned off and assayed directly against the test spores, or concentrated under reduced pressure using a nitrogen gas leak before assaying. Both direct and concentrated extracts could be stored in sealed vessels under nitrogen for up to 48 hours without loss of activity. When exposed to the air they lost activity completely in, at most, 18 hours.

Various methods of assay were attempted: in hanging drops of the extract, and by the cylinder cup method of agar seeded with the test spores, but were found unsatisfactory. The first gave erratic results depending upon the position of the spores in relation to the air-water meniscus; the second gave inhibitory zones with certain bacterial broth filtrates, but not with soil extracts. It was suspected that impurities in the agar were having a masking effect. Finally a satisfactory method was found which may be called the Washed Agar-Disc Method.

A stiff, about 2·5 per cent, agar was made up with powdered agar which had been washed five times in ion-exchanged water. After autoclaving, this was poured into small, carefully cleaned, shallow dishes of 2 cm. diameter, forming discs containing about 3 ml. of water agar. These were seeded with a drop of suspension of the test spores of *Mucor ramannianus* in ion-exchanged water, the firm agar rapidly absorbing the excess water. Drops of the extract, prepared and kept under nitrogen, were quickly placed on the surface of the agar discs, which were immediately placed in a pressure vessel, and this was evacuated and filled with nitrogen, sealed, and placed in the incubator. Under these conditions control discs with only drops of ion-exchanged water added, showed 96 per cent germination in 24 hours, while soil extracts from humus and mineral layers of forest soils showed a range of greatly reduced germination levels from 10 to 20 per cent. Concentrated extracts, and also extracts made from soil which had been incubated under nitrogen, have produced a germination level as low as 2 per cent. A method is therefore now available for testing the activity of soil extracts, and this is being used during the current season.

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FOREST SOILS RESEARCH IN SCOTLAND

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Fertilizer Trials on Sand Dunes

At Culbin Forest, Morayshire, measurement of height growth and analysis of the foliage of Corsican pine, treated with inorganic fertilizers, has continued.

The slight but significant increase in height growth in trees treated with ground mineral phosphate (G.M.P.) in 1954, first observed in 1956, has been maintained, and needle phosphorus contents were significantly higher in treated trees, as they were in 1958. In the N.K.Mg. trial, laid down in 1956, the significant increase in height growth due to nitrogen was maintained for a third year, and a small but significant increase due to potassium was seen for the first time. The nitrogen treatment increased needle potassium content; the N.Mg. interaction was significant for needle phosphorus content, either factor decreasing it in the absence, and increasing it in the presence, of the other.

Fertilizer Trials on Deep Peat

Analysis of peat and foliage from a 31-year-old stand of lodgepole pine on the Lon Mor, Inchnacardoch Forest, Inverness-shire (Experiment 47, P.28) suggested exhaustion of the ground mineral phosphate applied at 11 years of age and also an induced potassium deficiency (see *Research Report* for 1959). An unreplicated factorial P.K. trial was superimposed in May 1959, and foliage analysis at the end of the year showed a considerable uptake of potash, but no uptake of phosphorus (from insoluble G.M.P.), and there was a considerably greater increase in girth increment, as measured by dendrometer, in the two potash plots. A similar, replicated, trial is being laid down in 1960 on a larger stand of the same species nearby in collaboration with the Research Branch.

Measurement of growth in the N.K.Mg. fertilizer trials at the Lon Mor, laid down on 29-year-old Sitka spruce and 12-year-old lodgepole pine in 1957, has continued. Girth increment in the Sitka spruce in 1959, as measured by dendrometer, showed a highly significant increase due to potassium and a significant increase due to nitrogen; height increment in the lodgepole pine has been significantly increased by potassium. The application of aqueous ammonia and granite dust to 13-year-old lodgepole pine in 1958 has had no effect on height growth so far; calcium cyanamide significantly reduced height growth in 1958 and 1959, while lime significantly increased height growth in 1958, but not in 1959. Foliage samples for 1959 from these experiments have not yet been analysed.

Analysis of foliage from an unsuccessful trial, on checked Sitka spruce, of two rates of ground mineral phosphate, top-dressing, and of mulching and heather pulling at Inchnacardoch, showed that all trees were suffering from extreme nitrogen deficiency, presumably due to competition from heather, and that trees in the mulching, pulling and control plots were also suffering from phosphorus deficiency; potassium levels were generally marginal. Accordingly a new extension, using basal G.M.P. and a factorial combination of two rates of potassium and three of nitrogen, is being laid down in 1960 in collaboration with the Research Branch. In another part of the area, where Sitka spruce was planted in mixture with lodgepole pine, the spruce showed a significant regression of height growth on needle nitrogen content, which appeared to be correlated with the degree of suppression of the heather by the pine; this shows the direct nutritional effect of nursing.

Analysis of foliage from P.56 Sitka spruce, which was showing severe yellowing, on a deep peat area in Blairadam Forest, Fife, suggested an extreme potassium deficiency, and a fertilizer trial is to be laid down in 1960 by the Research Branch to test this.

Tree Growth on Deep Peat

As a result of the intensive study of changes in peat following afforestation (*Research Report* 1959), and the demonstration of induced potassium deficiency described above, a survey of deep peat areas recently afforested, or proposed for afforestation, has been started. It is hoped that analysis of the top twelve inches of the peat in two-inch layers, and also of the natural vegetation, will make comparisons of fertility possible, and may help to explain differences in tree growth on apparently similar areas. Preliminary results suggest that appreciable differences exist in inorganic phosphorus and potassium contents, and have confirmed the rapid decrease in the content of these two nutrients with depth. Sampling is being done in such a way that nutrient content of the vegetation and of the peat can be expressed in lb. per acre.

The thesis "The physical and chemical properties of deep peat in relation to afforestation" has been accepted for the degree of Doctor of Philosophy by the University of Aberdeen.

SOIL FAUNAL INVESTIGATIONS

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Changes in weight per unit of leaf lamina of beech and oak, from leaf fall to eventual disappearance, are being studied. The beech leaves were collected from an 18-year-old planted stand and were graded for uniformity before being labelled. Two types of leaf were selected from these grades, one type having a higher initial weight (at leaf fall) than the other. The leaves were labelled, and at fortnightly intervals discs have been punched out and weighed. The differences in weight between the two grades of leaf have been maintained and no net loss in weight has occurred during the first 5 months of the experiment.

The oak leaves were collected from two different sites, one an 18-year old planted stand, the other a 50-year-old naturally regenerated oak-dominant woodland. Leaves from the former site had a higher initial weight than those from the latter. Whilst dry weight of both samples of oak has varied rather more than that of beech, there has been little net reduction in weight, except that there is no difference in weight between leaves from the two sites after 5 months.

Both the beech and oak leaves have been on the surface of the litter and subject to alternate wetting and drying, yet show no net loss in weight. Observations indicate that breakdown of the lamina occurs in leaves at the bottom of the litter layer, and this is more marked in oak than in beech. These observations are being more closely investigated in further experiments.

By means of a leaf trap it has been estimated that in the autumn, the dry weight of leaf material falling on the floor of the beech stand is in the region of 2,000 lb/acre.

In culture experiments, the mite *Steganacarus magnus* was fed on discs of freshly fallen water-saturated oak leaves. 0·022 mg. of leaf lamina were consumed in 100 mite/days. During the three months of the experiment the moisture content of control leaf discs fell from 27 per cent to 6·5 per cent but there was no decrease in weight of dry matter. These experiments will be extended and continued.

To study respiration rates, two types of apparatus are being developed. One large enough to accommodate undisturbed cores of litter and soil, and the other much smaller and suitable for cultures of mites. The larger apparatus is developed from a commonly used type of respirometer which generates oxygen electrolytically on demand. An important modification has been the inclusion of an agar KCl bridge to join two half-cells and thus make the apparatus independent of variation due to changes in atmospheric pressure.

THE JUVENILITY PROBLEM IN WOODY PLANTS

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An investigation is being made into the physiological basis of juvenility in woody species, with special reference to factors determining the transition from the juvenile to the adult state. For this purpose, the criterion of juvenility is taken to be primarily the inability of seedling trees to produce flowers, and the transition to the adult condition is indicated by the onset of the flowering condition.

Experiments with seedling birch (*Report on Forest Research for 1957-8*, p. 108) seems to suggest that the attainment of a certain minimum *size*, rather than chronological age, is the important factor in determining the transition to the adult condition. As the young tree increases in size its shoot-system increases in complexity and there is a gradual reduction in the annual growth increment, which apparently indicates a loss of vigour in the shoot-system, and which has been referred to as 'aging'. There is thus a possibility that this 'aging' may be important in determining the transition from the juvenile (non-flowering) to the adult (flowering) condition, as the tree increases in size. The present experimental programme is designed to test this possibility, and to get further information on the nature of the changes involved in the transition from the juvenile to the adult condition.

The experiments are being carried out primarily with birch and larch, but additional experiments are being conducted with ivy and blackcurrant, since these latter species have certain advantages as experimental material.

Juvenile scions of birch, larch, etc. have been grafted on to mature flowering trees of these species to ascertain whether flowering will be hastened in these grafts, as compared with that of corresponding 'control' shoots allowed to remain on the parent seedling trees. Scions have been taken from trees of various ages in order to ascertain whether flowering is more easily induced in scions which are approaching the adult condition, than in very young scion material. The effect of grafting on to precociously-flowering birch seedlings is also being studied.

Following the successful experiments of Dr. Longman with seedling birch, referred to above, similar experiments are being carried out with larch to ascertain whether seedlings can be brought rapidly to the flowering condition by growing them to a large-size as rapidly as possible, by maintaining continuous growth under controlled conditions of daylength and temperature. The 'size-factor' is also being studied in seedling ivy and blackcurrant.

The effect of environmental conditions, particularly daylength and temperature, on flower-initiation in mature birch, beech and larch is being studied by using grafts of mature wood on to seedling stocks grown in pots.

Experiments are being conducted to ascertain whether the 'aging' of the shoot-system in mature trees arises from the increased distances over which nutrients have to be transported between the shoot-tips and the roots.

RELATIONSHIP BETWEEN LARCH CANKER AND TRICHOSCYPHELLA WILLKOMMII

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Freezing and Inoculation Experiments

The remaining trees of the 1955 and 1956 experiments were harvested in December, 1959. These were potted plants of European larch which had been frozen locally, with or without subsequent inoculation with *Trichoscyphella willkommii.* The inoculated trees had been placed under cankers with active fruit bodies, or sprayed with a spore suspension of *T. willkommii.* During the summer of 1958, all these trees were frozen for 6 hours at $-5°C$ in a refrigerator. After harvesting, cultures were made from cankers on certain plants, and a fungus, closely resembling, in culture, *T. willkommii,* was isolated from most of the cankers from inoculated plants. Anatomical investigation confirmed that healing of the original frost wound had been delayed by the fungus in those of the inoculated plants which had become infected, but that in most cases healing was well advanced by the summer of 1958, when the plants were again frozen. The frost treatment then given, though not affecting the cambium as a whole, had caused cambial damage around the partly healed cankers, resulting in a check to healing, and in some cases an enlargement of the canker and renewed fungal activity, resulting in one or two cases in the production of fruit bodies. The uninoculated plants had completely healed by the summer of 1958, and the frost treatment then given caused no damage in them.

These results, which will be published more fully elsewhere, suggest that both periodical frost damage, and the presence of *Trichoscyphella willkommii* are necessary for the perpetuation of cankers, as well as for their initiation.

Spore Trapping

The Hirst spore trap in a heavily cankered European larch plantation in the New Forest was converted to electrical operation during the summer of 1959. The new arrangement proved completely reliable, and the troubles associated with petrol operation no longer occurred. Owing to the unreliability of the petrol motor then in use, the run made in the spring of 1959 yielded results too discontinuous to be of use, but satisfactory runs were made from November 5th until December 1st, 1959, and from March 18th until May 18th, 1960. The slides exposed on the first of these two runs have been analysed; spores of the *Trichoscyphella* type are not at all abundant, but do occur. Owing to the dry summer of 1959, fruit bodies were sparse the following autumn, and this may account for the small numbers of spores trapped. The spore numbers were too small to permit any detailed correlation with weather conditions to be made, but spores appear to be liberated following periods of high humidity; temperature appears to be less important. On several dates, spores were found either during or immediately after periods of air frost.

Following consultations with Dr. Hirst, it is proposed to set up traps in close proximity to cankers with active fruit bodies, so as to follow the pattern of spore discharge more closely, and to attempt to catch spores on agar, not vaseline, so that they may be grown on for identification purposes.

SHELTERBELT RESEARCH

By R. BALTAXE

Department of Forestry, University of Edinburgh

In the field of air flow in relation to shelterbelts, work is concerned with investigating changes in the shelter effect of certain types of belts as a result of changing wind speed and of seasonal changes in their permeability to wind.

With the co-operation and assistance of members of the Department of Natural Philosophy at Edinburgh University, some preliminary wind-tunnel experiments were carried out. Thin, i.e. virtually 2-dimensional, metal screens of known geometrical permeability were used as model windbreaks. The leeward windfields of these were probed with a freely revolving vane to a distance of $16h$ and a height of $1{\cdot}2h$ (h equals height of the model), enabling the direction of air flow and the location of turbulence to be mapped. This has not previously been done with screens of known permeability, and is of some interest in relating this factor quantitatively to the pattern of air flow. Another feature of these experiments was the indication they gave of the limits of the zones in which air flow was sufficiently close to the horizontal for velocity measurements, made with horizontally orientated pitot-static tubes, to be of reasonable accuracy.

For full-scale investigations a number of suitable shelterbelts have been selected, the necessary preparations made, and a few wind studies carried out. A necessary preliminary to this was the estimation of the relative accuracy of the nine cup anemometers which comprise the available measuring equipment. After exposing the anemometers on a variety of apparently open upland sites and revolving them on a specially constructed turntable, it was found that the only air flow (outside a wind-tunnel) sufficiently smooth for its own irregularities not to mask those of the instruments was a wind coming off the sea.

It was also found that irregularities in the wind structure could completely mask the relatively small shelter effect to windward of a belt, when the measurement period was less than some figure which is presumably a function of the duration of the gusts, their absolute velocity and the lengths of the measurement line. As these conditions change from day to day it will be advisable to find the minimum measurement period giving a constant shelter curve, by trial and error for each wind study.

The main preoccupation in the past twelve months has been with instrumentation, with the aim of making it feasible for a single operator to collect sufficient data, detailed and accurate enough to serve the investigation. To this end the anemometers have been fitted with solenoid-operated levers, enabling them to be operated remotely and simultaneously from a single switch, using a 120-volt high tension battery as the power source.

This set-up involves cumbersome equipment in the way of electric cable and still requires the whole measurement line to be traversed twice for each run. By making the control anemometer, located ten times the height of the belt to windward, independent of the other instruments, the necessary equipment can be almost halved, and the distance to be covered reduced even more, not to mention virtually eliminating the need constantly to cross well fenced shelterbelts. This has recently been achieved by converting one of the counter-pattern anemometers to a contact type, and attaching to it a continuous recording device, the entire apparatus having been designed and made by the Department of Physiology at Edinburgh University. For the first time single-handed wind studies are beginning to look like a practical proposition.

The continuous record of wind-speed, which can be obtained from contact anemometers, is of particular interest in the type of investigation at present being pursued, as well as facilitating operation of the anemometers, for example when they are out of sight and reach in the course of measuring the vertical velocity gradient. Accordingly the simple conversion to contact-pattern of all the anemometers and their connexion to a single recording apparatus is currently being investigated.

SOIL FAUNAL RESEARCH

By D. R. GIFFORD,

Department of Forestry, University of Edinburgh

Experiments on implantation of sterile and baited cores of Sitka spruce litter into the litter of Compartment 12 at the Forest of Ae were continued during the early summer, but the early sampling was on too small a scale to give any good figures on movement of the slower *Oribatids* present. It was found that there was a rapid colonisation by the mites of the uppermost litter horizon, with no discernible variation in the species composition into cores that were sterile; this was also true of cores inoculated with *Trichoderma viride* and a *Penicillium*, but the numbers present were rather low in all three types of core. The very great fluctuation in numbers and species composition exhibited by ordinary core sampling makes it necessary to implant large numbers of the baited cores before any valid conclusion can be drawn, and this experiment was temporarily abandoned due to the inadequacy of present facilities.

The ecological study was continued throughout the year and is now more or less complete. Preliminary study of the data obtained indicates that the active fauna, at least among the mites, is much the same in the Aoo horizon of both unplanted moorland and Sitka spruce, but the *Trombidiform* mites are either much more populous in the *Molinia*, or more easily extracted from its litter. The hardy *Mesostigmatid* mites were more abundant in the spruce litter and more species were collected in this than in moorland samples. The F horizons of the two types showed marked differences in numbers and species composition, particularly among the *Oribatids*. These differences, together with an evaluation of some of the site factors which may influence them, are now being worked out.

STUDIES ON THE MORPHOLOGICAL VARIATION OF CONIFERS

By Dr. E. V. LAING
Department of Forestry, University of Aberdeen

Picea omorika Seedlings

During the year the investigation into the morphology and identification of *Picea omorika* seedlings, with a view particularly of elucidating the problem of hybridisation of this species with *Picea abies* and *P. sitchensis*, was continued. It is suggested that the natural regeneration that sometimes appears is not that of true *P. omorika*, but of hybrids.

Seedling *P. omorika* is found to be quite unlike adult *P. omorika*.

The characters of the adult plant are as follows:—

Buds—brown, broadly ovoid with a ring of drawn-out, subulate scales at the base.

Leaves—flat, with stomata only on one side.

Twigs—yellow-brown clothed with hairs.

The seedlings on the other hand give the following characters:—

Buds—traces of ring of subulate scales at base.

Leaves—tending to be flattened, with stomata well developed below, but with a few traces of stomata above as well.

Twigs—completely devoid of hairs.

In most respects the seedling *P. omorika* is very like that of *P. sitchensis*. *P. omorika*, however, shows quicker growth than Sitka.

Without a detailed examination, *P. omorika* seedlings might also be mistaken for Norway spruce. This species, however, is quite distinct in that the needles are rounded and show stomatal lines on all surfaces. Both the cotyledons and the primary leaves have serrations on the margins.

Observations, so far, indicate that the adult characters of *Picea omorika* may not appear until the plants are at least four years old.

Pseudotsuga

Previous reports had noted some of the variations in Douglas fir to be found in our woodlands. An attempt has been made to formulate these into keys—one for vegetative shoots and the other for cones and vegetative shoots as follows:—

Pseudotsuga taxifolia

Vegetative Shoots

1.	Leaf tips broad sometimes bifid or tending to bifid....	2
	Leaf tips narrow, entire	3
2.	Buds very pointed, hypodermis continuous	*P. vancouveriensis*
	Buds conical, very broad at base	*P. glauca*
3.	Leaves pectinate	*P. douglasii*
	Leaves in two ranks with V shaped depression between	7
	Leaves more imbricate, covering twigs	4
4.	Twigs glabrous....	*P. merrilli*
	Twigs hairy	5
5.	Leaves more sharply pointed....	6
	Leaves blunt, or slightly pointed	*P. globulosa*
6.	Hypodermis continuous	*P. macrocarpa*
	Hypodermis discontinuous	*P. californica*
7.	Hypodermis very reduced	*P. caesia*
	Hypodermis discontinuous	*P. rehderi*
	Hypodermis continuous	*P. flahaulti*

Cones and Vegetative Shoots

1.	Cones with reflexed bracts	2
	Cones with long straight bracts	3
	Cones with short straight bracts	5

2.	Needle tips broad tending to bifid	*P. glauca*
	Needle tips narrowly rounded	*P. flahaulti*
	Needle tips more sharply pointed	*P. californica*
3.	Twigs glabrous....	*P. merrilli*
	Twigs pubescent	4
4.	Leaves pectinate	*P. douglasii*
	Leaves more imbricate, hypodermis continuous	*P. vancouveriensis*
	Leaves intermediate, bracts very long	*P. caesia*
5.	Lateral points of bract hidden by scale	6
	Lateral points of bract just beyond scale cone large	*P. macrocarpa*
6.	Leaves covering twig	*P. globulosa*
	Leaves more in two lateral sets	*P. rehderi*

HYDROLOGICAL RELATIONS OF FOREST STANDS

By Dr. L. LEYTON and Dr. E. R. C. REYNOLDS

Imperial Forestry Institute, Oxford University

With the assistance of Mr. B. J. Kemp, investigations have begun on various phases of the hydrological cycle in forest stands. As an approach to the measurement of precipitation incident on the canopy, standard rain gauges, with and without shields (Nipher and Alter types) have been erected at both canopy level and 10 feet above, in a seventeen-year-old plantation of Norway spruce in Bagley Woods near Oxford. Over the period March to November, 1959, measurements of throughfall (precipitation not intercepted by the canopy) have been made, comparing the accuracy of estimates using standard rain gauges and troughs (3 feet × 2 feet). A random distribution of 20 gauges over approximately ½ acre of plantation gave rather high standard errors, ranging from 9 to 14 per cent of the means, according to the particular interval concerned; moving these gauges to new random positions after approximately each inch of precipitation, reduced the error to between 6 and 13 per cent. No appreciable increase in the accuracy of the estimates was obtained by covariance analysis or stratification based on the position of the gauge below the crown, though position had been shown to influence the catch significantly. By contrast, 20 troughs, located at random over the same area, gave errors varying from 5 to 6 per cent of the mean; this was considered to be an acceptable standard of accuracy.

Stem-flow gauges installed on 20 randomly selected trees revealed considerable variations in catch, the standard errors amounting to 17 to 20 per cent of the mean values; however, since stem-flow in this stand contributed relatively little to the total throughfall, such large errors can probably be tolerated for total throughfall estimates.

Over the period concerned, interception by the canopy was generally of the order of 30 per cent. of the incident precipitation, though occasionally as low as 18 per cent. Full details of this investigation will be published elsewhere.

TRACHEID LENGTH IN YOUNG CONIFERS

By Dr. L. CHALK and J. LADELL
Imperial Forestry Institute, Oxford University

The main purpose of this work is to facilitate the prediction of tracheid length in the mature wood from the type of material used in tree breeding, e.g. the scions used for grafting and for seedlings.

The new technique developed for measuring tracheid length from tangential sections (*Forestry* 32, No. 2, 1959) has proved very satisfactory and, by enabling a more accurate location of samples, has made it possible to study changes in length in small stems that cannot be investigated by the standard maceration techniques.

The pattern of variation in leading shoots of young Corsican pine plants has been shown by this method to be more complex than is generally realised, owing to the presence of strands of shorter cells below the leaf traces. The extent of these strands appears to be related to the lengths of the leaf traces and so to the elongation of the shoot. Another factor involved in this complex is the size of the pith. Preliminary studies have shown that the diameter of the pith varies with needle density—and so with shoot elongation—but that the ratio of pith to xylem diameter tends to be constant. The same ratio of about 0·40 has been observed in two sets of Corsican pine material, one of Scots pine and one of Japanese larch. The possibility that the ratio of pith and xylem diamater may be a constant, associated with needle arrangement, is of considerable interest and may have several useful applications.

The relation between these features and tracheid length is now being studied on 80 Scots pine plants, and in addition attention is being given to the possibility of predicting tracheid length from the primary elements in lateral buds.

The results obtained so far suggest that the genetic "possibility" as regards length may be measurable in the terminal bud, the actual lengths reached in the first year shoot being modified by its elongation.

PROTEIN-FIXING CONSTITUENTS OF PLANTS
PART II

By B. R. BROWN and C. W. LOVE
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Introduction

The properties of *Calluna* tannin are such that isolation of sufficient quantities in a pure state for chemical investigations is not easy and has not yet been satisfactorily achieved. Part I of this report (*Report on Forest Research for 1959*, p. 104) described attempts to isolate the tannin, none wholly successful, by (a) precipitation with gelatine; (b) salting out; (c) solvent extraction; (d) precipitation with ethanol; (e) precipitation with heavy metal salts; (f) column chromatography.

The difficulty involved in isolation and purification of the tannin arises from three main factors: (1) The insolubility of the tannin in organic solvents, but its very high solubility in water; (2) the instability of the crude tannin in the presence of air or acid and its thermal instability; (3) the occurrence of other polyphenolic substances of similar properties in extracts of *Calluna*, which are difficult to remove without also removing or in some way altering the *Calluna* tannin.

The first factor necessitates the use of aqueous solvents for extraction of the tannin from *Calluna* shoots. Experiments on extraction of *Calluna* shoots with aqueous acetone or aqueous methanol of various strengths has shown that 50 per cent aqueous acetone is the most efficient solvent for extraction of the tannin. Exposure of an aqueous-acetone extract of *Calluna* shoots to air, or warming it, causes darkening in colour followed by deposition of a solid which cannot be redissolved in water. Attempted isolation of the tannin by adsorption on cellulose, perlon, or hide powder has resulted in irreversible adsorption and complete loss of tannin.

Attempted Isolation of Tannin

(a) Adsorption on Hide Powder

When an aqueous solution of a tannin is allowed to stand in contact with hide powder, the tannin is adsorbed on to the hide powder. In the case of *Calluna* tannin the adsorption appears to be irreversible.

Standard hide powder (50 g.) was allowed to stand in contact with aqueous *Calluna* extract (500 ml., obtained by extracting *Calluna* shoots with water at room temperature for 14 days, 1 g. solid to 2 ml. water) for 24 hours at room temperature. The hide powder was separated from the aqueous phase by filtration and it was found that the filtrate gave a negative gelatine test. The hide powder was allowed to stand in contact with further 500 ml. portions of *Calluna* extract; complete saturation of the powder occurred after a total of 2,000 ml. of extract had been used.

The hide powder was divided into two parts, the first being allowed to stand in contact with 50 per cent aqueous acetone and the second with 70 per cent aqueous formamide, both at room temperature. The solutions rapidly became dark coloured but gave negative gelatine tests even after several weeks of attempted extraction.

(b) (i) Column Chromatography on Perlon

A column of perlon (26 g.) was packed dry and saturated with water. Aqueous *Calluna* extract (50 ml., obtained as in (a) above) was injected and the column eluted with water. The eluate fractions were examined by paper chromatography using 2 per cent acetic acid as irrigant. Chromatograms were examined under ultraviolet light for fluorescent substances and were then sprayed with diazotised sulphanilic acid.

After 600 ml. of eluate had been collected, elution was continued with 50 per cent aqueous acetone. Two compounds were then eluted from the column, referred to below as compounds 1 and 2, having the following properties:

(1) $Rf = 0{\cdot}28$; blue fluorescence under ultra-violet light; no colour with diazotised sulphanilic acid.

(2) $Rf = 0{\cdot}47$; non-fluorescent; orange colour with diazotised sulphanilic acid.

Substance 1 appeared after 50 ml. of aqueous acetone had been collected, followed by a mixture of substances 1 and 2. Elution of these compounds was complete after collection of 250 ml. of eluate. No tannin had appeared after 400 ml. of eluate had been collected.

(ii) Chromax Column Chromatography

Continuous ether extraction of aqueous *Calluna* extract (2½ l.) at room temperature for 24 hours gave a mixture of ten substances, examined by paper chromatography and detected by fluorescence under ultra-violet light or by colour reactions with diazotised sulphanilic acid. The mixture was split by extraction of the ethereal solution with 10 per cent sodium carbonate into carbonate-soluble, and insoluble fractions.

The carbonate-insoluble fraction (0·98 g.) was chromatographed on a Chromax column, eluting with 2 per cent aqueous acetic acid. The eluate was run on paper using 2 per cent acetic acid as irrigant and the chromatograms sprayed with diazotised sulphanilic acid. The fractions containing Compound 2 (see (b) (i)) were combined, extracted with ether, and the extract washed with sodium carbonate, dilute hydrochloric acid and water, dried and evaporated to yield a brown gum (70 mg.).

Infra-red Spectrum (Nujol) peaks at 3,330 $cm.^{-1}$ (hydroxyl)
1,704 $cm.^{-1}$ (saturated carbonyl)

Ultra-violet Spectrum in ethanol

$\lambda_{max.}$ 277, 309, 330, 346 $m\mu$
$\lambda_{min.}$ 255, 302, 312, 338 $m\mu$

An attempt to prepare the oxime was unsuccessful.

The carbonate soluble fraction was obtained by acidifying the sodium carbonate extract obtained above, extracting with ether and evaporating to dryness. Yield 0·97 g. This was chromatographed on a Chromax column, eluting with 2 per cent acetic acid. The eluate fractions were run on paper and examined under ultra-violet light. The fractions containing compound 1 (see (b) (i)) were combined, extracted with ether and the ether evaporated to dryness, giving a yellowish flaky solid (0·1 g.) which, after several crystallisations from water gave orange-yellow prisms, m.p. 180·5-182° dec. (Found: C, 56·55; H, 4·95, M.W. (Rast), 159: $C_8H_8O_4$ requires C, 57·1; H, 4·8 per cent, M.W., 168). The value obtained for the molecular weight is not regarded as reliable in view of the low decomposition temperature of the substance.

Infra-red Spectrum (Nujol mull)

Peaks at 3367 and 3205 $cm.^{-1}$ (hydroxyl)
1634 and 1610 $cm.^{-1}$ (conjugated carbonyl)

Ultra-violet Spectrum in ethanol

$\lambda_{max.}$ 218, 234, 303 (inflexion) 326 $m\mu$
$E^{1\,cm.}_{1\%}$ 714, 513, 607 750

$\lambda_{min.}$ 230, 264 $m\mu$
$E^{1\,cm.}_{1\%}$ 497, 208

Compound 1 was hydrolysed by boiling either with dilute acid or dilute sodium hydroxide, the same products being obtained in each case. These were detected on paper, one being a horse-shoe shaped streak (product A) having a yellow fluorescence in ultra-violet light and the other a spot giving a black colouration with ammoniacal silver nitrate in the cold (product B). The hydrolyseate showed the following behaviour on paper:

	Compound 1	*Product A*	*Product B*
R*f* value in B.A.W.* ..	0·81	0·50—0·61	0·91
R*f* value in 2% acetic acid	0·28	0·0	0·50
Under ultra-violet light	violet fluorescence	yellow fluorescence	—

* B.A.W. refers to the solvent system n-butanol/acetic acid/water (4:1:5 v/v) upper phase.

Sprays

	Compound 1	*Product A*	*Product B*
Vanillin/hydrochloric acid	—	—	—
p-toluene sulphonic acid, heat to 105°C	—	—	—
Sucrose/hydrochloric acid, heat to 95°C	—	—	—
Aniline hydrogen phthalate	—	—	—
Diazotised sulphanilic acid	—	—	—
Silver nitrate/ammonia	weak black colouration	—	intense black colouration
Ferric chloride-potassium ferricyanide	blue	—	blue

The above results suggest that compound 1 is an ester, hydrolysed to give a phenol (product B) and an acid (product A). Since a phenol necessarily contains at least six carbon atoms, product A would contain a maximum of two carbon atoms if the observed molecular weight quoted above were correct. This is unlikely since fluorescence is usually associated with complex and extensively conjugated molecules and product A does not appear to correspond in properties with any derivative of formic and acetic acid. Bearing in mind also the low decomposition temperature of compound 1, the observed molecular weight is probably wrong. Compound 1 does not, from its empirical formula, appear to be a flavanoid and is therefore unlikely to be relevant to the study of the tannin present in *Calluna.*

Chemistry of the Leucoanthocyanidins

The leucoanthocyanidins are characterised by their reaction with acid, when the corresponding anthocyanidin is formed. The normal procedure is to boil the leuco-compound with *iso*-propanol/hydrochloric acid either in the presence or absence of air. This reaction invariably gives poor yields, usually below 10 per cent, although Roux (*Biochem, J.*, 70, 344, 1958) claims up to 20 per cent conversion. By-products which are assumed to be polymeric are also formed in the reaction.

Calluna tannin is based on a leucoanthocyanidin structure since it gives cyanidin on hydrolysis with methanol-hydrochloric acid, and a monomeric leucocyanidin is also present in extracts of *Calluna.* These are converted to cyanidin in poor yield on hydrolysis with boiling methanol/hydrochloric acid with the simultaneous generation of phlobaphene and other unidentified products. No systematic study of this reaction has yet been carried out and it was regarded as necessary to fill this gap because of the recognition of the leucoanthocyanidins as a structural unit of the condensed tannins in many plant species. (See e.g. Roux and Evelyn, *Biochem.J.*, 69, 531, 1958). Work on the synthesis of flavan 3:4 diols, as model compounds of the leucoanthocyanidin type is being carried out with the aim of discovering optimum reaction conditions for the conversion of leucoanthocyanidins to anthocyanidins and to investigate the influence of structural and stereochemical factors on the reaction.

FURTHER STUDIES ON FOMES ANNOSUS

By Dr. J. RISHBETH
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Much of the research into stump treatments against *Fomes annosus* has been taken over by Mr. D. Punter. A wide range of potential protectants is being screened in the laboratory and promising ones will be given forest trials. The mode of operation of such protectants is being investigated further.

The possibility of using natural competitors for stump protection, at least on a small scale, is being re-examined. Of several potential antagonists tested in pine stumps, *Peniophora gigantea* was found to be the most promising. This species often competes with *F. annosus* in stumps under natural conditions, but its control over air-borne infection by the parasite is erratic. The aims of stump inoculation with *P. gigantea* are (1) to prevent *F. annosus* colonizing the freshly cut surface, (2) to restrict the growth of *Fomes annosus* in any stump roots already infected, and (3) later, by formation of sporophores, to increase spore production by *Peniophora gigantea* in the forests.

A technique has been devised for inoculating stumps with accessory spores (oidia) of the fungus on a moderately large scale. By this means aims (1) and (3) are achieved, and preliminary results suggest that aim (2) is at least partially fulfilled. *P. gigantea* apparently does not colonize stumps of some other conifers as effectively as it does those of pines.

Studies have been continued on the spore dispersal of various forest fungi. Spores of wood-rotting species often constitute the bulk of the air spora in forests during winter, whereas mould spores greatly predominate in summer. In East Anglia the number of *F. annosus* spores in the air does not vary greatly with season, and commonly ranges from 1-10 per five litres. Deposition on horizontal surfaces is rapid in almost still air, and is relatively slow at air speeds above 2m./sec. Estimations of forest air spora carried out for the Forestry Commission confirm that *F. annosus* is widespread in central and western Scotland. At Lael forest, Wester Ross, *F. annosus* spores were found to be far more abundant in second-rotation crops than in nearby first-rotation ones.

Observations on dispersal of *Fomes annosus* and *Peniophora gigantea* have been published in *Trans. Brit. mycol. Soc.*, 42, 1959. Two papers on stump protection against *Fomes annosus* have appeared in *Ann. appl. Biol.*, 47, 1959. D. S. Meredith has published a first paper on *Fomes annosus* and other stump-colonizing fungi in *Ann. Bot.*, 23, 1959.

UTILISATION OF TAN BARKS

By Dr. D. E. HATHWAY
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European Larch Tannin

The barks of the European larch, *Larix decidua*, and the Siberian larch, *L. sibirica*, are used in Russia for tanning, but in Western Europe, European larch bark is not now used in this way.

In recent investigations, the butt and crown regions of the stembark of eight trees from two forests contained 4·5-19·0 per cent tannin and 3·5-16·0 per cent non-tannin extractives on a moisture-free bark basis. Such extracts are considered unsuitable for commercial tanning in Britain since, in addition to the variable tannin content and unfavourable tannin/non-tannin ratio, the extract has a pronounced red colour (10 Lovibond units).

The fact that there is appreciably more tannin in the bark from the crowns than the butts, does not conform with a downward movement of tannin or of the phenolic precursors, but strongly suggests that in this tree, aromatic biosynthesis can occur away from the leaves.

Extraction of Sitka Spruce Bark

A one-hundredweight sample of Sitka spruce bark from Alice Holt Forest, which contained 17·3 per cent water-soluble tannin, and 14·3 per cent non-tannin extractives on a moisture-free bark basis, and which gave an extract with a colour of 2 red units and 6·5 yellow units (Lovibond scale), was extracted (Soxhlet) with water, methanol and N: N-dimethylformamide (DMF) respectively. The two solvent extracts were transferred to water, and the solvent evaporated in N_2 under reduced pressure. The three aqueous solutions obtained were separated from spruce-bark resin either by decantation or by extraction with benzene, and from insoluble phlobaphene by filtration. The tannin, non-tannin extractives, acids and salts contents, and colour of the extracts are shown in Table 9.

Table 9

Extracts Prepared from Sitka Spruce Bark

	Aqueous	*Methanolic*	*DMF*	
Water-soluble Tannin ..	14·7	17·9	23·4	% on moisture-free bark basis
Insoluble Phlobaphene ..	3·9	2·0	3·6	
Benzene-sol. Resin	0·2	5·3	6·5	
Other non-tannin extractives	10·6	9·2	8·1	
Total extractives	29·4	34·4	41·6	
Acids ..	31	34	38	mg. equiv./100 g. extractives
Salts ..	84	22	52	
Colour: Yellow	15	2·5	10	Lovibond units
Red ..	2·5	1·0	4	

The methanolic extract contains as much tannin as the water leach, has a considerably lower salts content, and is easier to work up than the aqueous extract, since less colloidal phlobaphene is extracted from the bark with methanol. The colour of the methanolic extract is good, and comparable with that of commercial myrobalans extract, which is in commercial use for tanning.

The colour of the DMF extract is slightly inferior to that of the aqueous extract, but the tannin content of this extract is greater by 60 per cent, and the improvement in tannin/non-tannin ratio from 3:2 to 7:2 favours tannery practice. DMF, therefore, appears to be a promising solvent for the extraction of spruce and other tanbarks. It is well-known that water does not extract all the tannin available from tanbarks, and dry bark which has previously been extracted with water, when ground in liquid ammonia, affords more tannin on further extraction with water. In a search for a more efficient solvent than water for the extraction of tannins from bark tissue, this new property of the highly polar DMF was discovered.

For laboratory tanning trials, Sitka spruce (5 kg.) was percolated at 20°C with several changes of methanol. Partial evaporation (cyclone evaporator) gave 2 litres of viscous liquid which was transferred to water, decanted from spruce-bark resin, and evaporated (cyclone evaporator) to 2 litres. There was no phlobaphene, and this solution was diluted to 8 litres to afford an aqueous solution of 45° Bk., suitable for tannage. This solution contained 8·1 per cent tannin and 4·9 per cent non-tannin extractives. The tightly bound bark from which this extract was prepared, had been detached in small pieces under winter conditions and, as a result of the severe injury sustained, the extract had a pronounced red colour (17 Lovibond units). Some depickled sheepskins were rapidly tanned with this solution into very reasonable leather. There was a tendency for this very pale leather to become pink on exposure to sunlight.

These two experiments, which are typical of several which have been made, indicate the scope and limitation of Sitka spruce-bark extract for tannage.

In collaboration with a member firm, some Sitka spruce-bark extract was prepared, in quantity sufficient for the tannage of some split hides which had been lightly pretanned with chromium. The leather, which was of excellent quality, was curried and finished by another member firm for upholstery purposes.

NUTRITION OF TREES IN FOREST NURSERIES

By Miss B. BENZIAN

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A number of long-term experiments on nursery nutrition are still in being, but the main task during the year has been the writing up of the main series of experiments. Most of the tables have been completed and a start has been made on the text.

During the year an interesting case of phosphorus toxicity to yellow lupins was investigated.

Conifers and green crops are grown in a rotation experiment at a nursery on very acid heathland soil near Wareham (Dorset). The older leaves of yellow lupins, *Lupinus luteus*, grown with fertilizer often die, as sometimes do whole plants. The most severely affected plants contain 2·2 per cent P, and pot experiments at Rothamsted using Wareham soil, confirmed that the damage increased with the amounts of monocalcium phosphate applied and with the P contents of the plants. At another nursery near Oxford, on less acid sandy loam, yellow lupins grew normally with the same fertilizer treatment as caused damage at Wareham. (R. G. Warren and B. Benzian, *Annual Report, Rothamsted Research Station*, 1959, p. 54).

PART III

Results of Individual Investigations

A SUMMARY OF TEN YEARS SEED TESTING EXPERIENCE WITH WESTERN HEMLOCK, TSUGA HETEROPHYLLA

by G. BUSZEWICZ and G. D. HOLMES

Western Hemlock has been planted on an increasing scale since 1950. The number of plants used in Forestry Commission plantations from 1950-59 are given below:—

Year	1950	1951	1952	1953	1954	1955	1956	1957	1958
Plants Used (Thousands)	80	539	567	296	245	1,543	2,469	1,744	1,174

Seed imports were increased to meet this expanding planting programme, and during the period 1950-60 over 3,000 lb. of seed, made up of over 100 separate collections, were sown. More than 90 per cent of this seed was imported from Western North America, mainly from British Columbia, but seed was also obtained from many other areas over the natural range of the species, from Alaska in the north to Oregon in the south.

Throughout this period, all seed lots have been regularly sampled for seed purity and weight, and germination analyses have been carried out. Examination of these tests, which were completed on more than 120 samples, provides useful evidence on the variation in seed quality, and on the germination requirements of the species. The main points arising from these tests are summarised and discussed below.

Seed Purity

In the period 1950-60, over 200 purity tests were carried out on samples representing 122 separate seed lots. Several of these lots were large enough to be represented by more than one sample, which accounts for the discrepancy between the number of lots and the number of samples. The results of replicated samples have been averaged for each lot to facilitate comparisons between lots. The results of all purity tests have been divided into four arbitrary quality classes, according to the pure seed percentage in the sample, and are summarised below:—

Table 10

See Purity—Summary of Results by Purity Classes

Quality Class (Purity %)	Imported Seed			Home Collected Seed		
	No. of Samples	% of Total Samples	Av. Purity %	No. of Samples	% of Total Samples	Av. Purity %
Over 90	70	93	95·5	29	62	95·8
81-90	5	7	87·5	11	23	87·9
71-80	—	—	—	4	9	75·4
Below 70	—	—	—	3	6	52·2
Total	75	100	94·9	47	100	89·3

Home-collected seed was generally less pure than imported seed, the percentage of first quality lots (over 90 per cent purity) being 62 per cent and 93 per cent respectively. The main reason for this is that home-collected lots contained a high proportion of empty seeds, many of which had been damaged and broken during dewinging and cleaning so that they were classed as impurities.

Seed Weight (Size)

This determination is usually made on completion of the purity analysis by weighing 4 replicate samples of 100 pure seeds from the pure seed fraction, and expressing the result as the weight of 1,000 pure seeds. The empty seeds are not excluded from the pure seed fraction unless they are damaged and visibly recognised as empty. (This test is a routine determination, which, together with seed purity and germination assessments, permits the calculation of the number of viable seeds per lb.) The results of the weight tests to date for Western hemlock can be summarised as follows:—

Table 11

Seed Weight—Average and Range of Seed Weight for Imported and Home-Collected Seed

Origin	No. of Samples	Wt. of 1,000 Pure Seed (Gms.)			No. Pure Seeds per lb. of Pure Seeds (Thous.)		
		Lowest	Average	Highest	Lowest	Average	Highest
Imported	75	1·32	1·847	2·400	189	246	343
Home-Collected	47	0·83	1·294	1·835	247	351	541

It will be noted that over this period, imported lots contained a lower number of seeds per lb. than home-collected lots. It is interesting to note that the *average* number of seeds per lb. for imported lots is almost the same as the lowest number per lb. recorded for home-collected seed. As with the lesser purity of home-collected seed, the difference is largely accounted for by the high proportion of empty seed in home-collected lots. Thus the average percentage of empty seeds in imported lots was about 10 per cent, while for home-collected seed only 5 samples out of 47 contained less than 20 per cent of empty seeds.

The seed lots tested originated from a large number of points throughout the natural distribution of the species, and an attempt was made to relate variations in seed weight to geographical origin of the seed. This enquiry was confined to those seed lots for which the origin was precisely known, and on which the percentage of empty seed was not important. A significant relationship between seed weight and latitude of origin was found, increases in the latitude of origin being accompanied by increases in the number of seeds per lb. (See Figure 5). To take an extreme example, collections in Alaska can be expected to have over 50,000 more seeds per lb. than lots collected in Oregon.

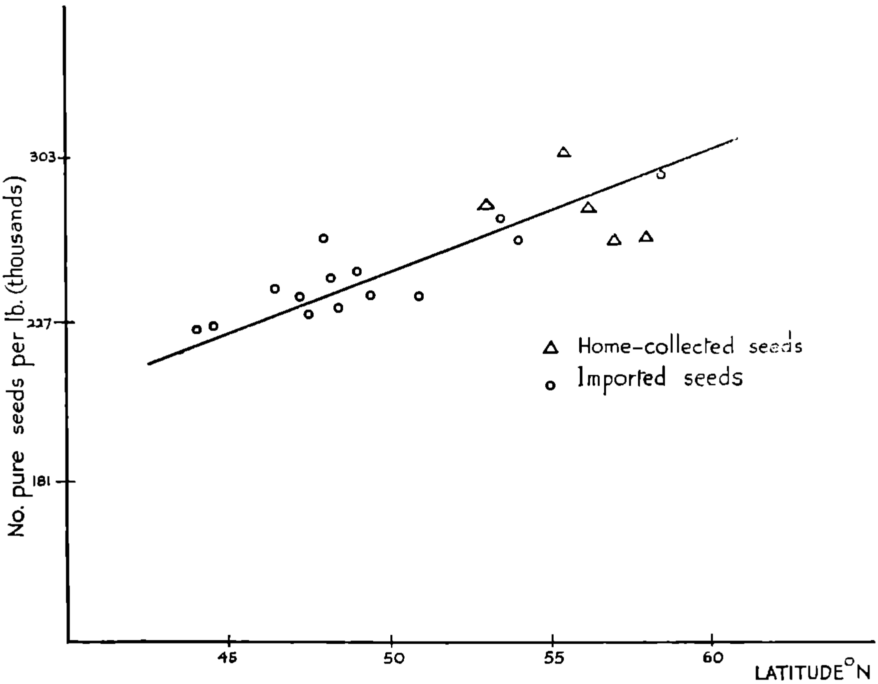

FIG. 5. *Tsuga heterophylla* Seed weight expressed as number of seeds per pound and latitude of collecting area.

Germination

Western hemlock is not an easy germination subject, and there are considerable differences of opinion amongst seed analysts regarding the optimum germination substrata and temperatures, and the appropriate methods of seed pre-treatment. It has been suggested (Anon 1948) that the seed has variable degrees of dormancy, many lots being non-dormant and able to germinate without pretreatment. However, as the degree of dormancy cannot be assessed in advance, it was recommended that all lots should be stratified for 90 days at 5°C before sowing. Later, in 1954, Allen and Bientjes recommended the so-called "naked stratification", the seeds being soaked for 36 hours, excess water drained off and the moist seed being stored at 0-2°C for 8 weeks. Thereafter germination can be completed in 21 days at 20° C. Bientjes (1954), provided more supporting evidence, and confirmed that for germination a constant temperature of 20°C is near the optimum, and superior to higher or to alternating temperatures. Barton (1954) reached similar conclusions, but recommended a shorter period of pretreatment, the seeds being mixed in wet peat for 2 weeks at 5°C.

In 1958, Te May Ching reported the results of an intensive study of germination requirements, and concluded that seed pretreatment by moist chilling is unnecessary. Further, he showed that the most rapid germination was obtained at a constant 20°C, at which temperatures germination was normally completed within 4-8 weeks. His tests were carried out in river-washed sand with 8 hours illumination each day. He preferred sand to filter paper as the germination substratum, a view shared by many American seed analysts. In Europe, filter paper substrata are generally favoured for small seeded conifers, because of the difficulty of standardising the moisture conditions in sand. It is unfortunate that there are no detailed comparative studies of the substrata for Western hemlock seed.

Allen (1958) points out that seed ripeness influences seed germination, and immature seeds appear to suffer somewhat from stratification. Mature seeds store better and germinate quicker than immature. Stratification may help in estimating the amount of immature seed present if the seed analyst employs two simultaneous methods, with and without pretreatment. The International Seed Testing Rules (1953) prescribed that the seed be prechilled for 4-8 weeks at 5-10°C, and germinated at an alternating temperature of 20-30°C for 42 days. This rule was revised in 1959, shortening the prechilling period to 3 weeks at 3-5°C and the germination period to 4 weeks at 20-30°C.

The main object of the laboratory test is to discover the maximum possible number of seeds capable of germination. However, in the case of Western hemlock it has proved difficult to meet this object, owing to the uncertainty about the optimum germination conditions. Accordingly, in 1950, it was decided to employ several contrasting test methods in the course of routine germination tests on this species, in order to provide data which might assist defining the optimum conditions more closely. The germination test methods examined included those shown in Table 12.

Table 12

Germination Test Methods Employed in Testing of Western Hemlock

Apparatus and Substratum	Temperature °C	Light	Duration of Test	Pretreatment
1. Jacobsen Tank (JA) (top of filter paper)	20-30	125 ft. candles 8 hrs.	35 days	None
2. Jacobsen Tank (JA) (top of filter paper)	20	„	35 „	None
3. Jacobsen Tank (JA) (top of filter paper)	20-30	„	28 „	Prechilled 21 days at 3°C
4. Incubators (INC) (between filter paper)	20-30	Dark	35 „	None
5. Incubators (INC) (between filter paper)	20-30	„	28 „	Prechilled 21 days at 3°C

Assessments of germination were carried out at weekly intervals, and at the end of the test the ungerminated seeds were examined by the tetrazolium biochemical method as a test of viability. Germination results are expressed as two figures, the first indicating the actual germination percentage and the second, or "plus" figure, (direct from the tetrazolium test), indicating viable seeds requiring a long period for germination.

Unfortunately, it was impossible to compare all test methods on all seed lots, and direct comparisons are restricted to several selected pairs of methods which were used together on the same samples in the course of routine testing. A total of 534 tests were completed on 267 separate seed lots, as shown in Table 13.

Table 13

The Average Germination Results of the Compared Test Methods

Test Method	No. of Samples	Test Conditions*	Germ. %	Plus Figure
(*See Table* 12)				
1	49	JA/20-30° C/L	48	4
2		JA/20°C/L	60	1
1	101	JA/20-30°C/L	49	5
3		JA/20-30°C/L/chilled	50	5
1	44	JA/20-30°C/L	54	5
4		Inc/20-20°C/D	62	2
3	51	JA/20-30°C/L/chilled	54	3
4		Inc/20-30°C/D	58	2
3	22	JA/20-30°C/L/chilled	36	5
5		Inc/20-30°C/D/chilled	34	Not tested

Total 267

*Note "JA"—Jacobsen Apparatus. "Inc"—Incubator.
"L"—Light. "D"—Darkness.

The rates of germination in these comparative tests are illustrated in the form of average germination curves for each method in Figure 6.

Inspection of these results (Table 13 and Fig. 6) shows that there were appreciable differences in the final results, and in the progress of germination, between methods 1 and 2 and methods 1 and 4 (see Figure 6 (A) and (C)). Method 2 (JA/20°/L) compared favourably with Method 1 (JA/20-20°C/L), the rate and final germination being appreciably higher at constant 20°C than at an alternating temperature 20-30°C.

Comparing Method 1 (JA/20-30/L) with Method 4 (INC/20-30/D), germination in darkness was found to be appreciably higher than in light.

Unfortunately, no direct comparison can be made between Methods 2 and 4 as the seed lots were quite different. However, both methods seem almost equally superior to Method 1. The superiority of germination in darkness as compared with light, at alternating temperatures of 20-30°C, (i.e. Methods 1 and 4), suggests that germination may be partially inhibited by light. Further, the superiority of a low constant temperature (20°C) over an alternating temperature (20-30°C), in the presence of light, (Methods 1 and 2), suggests that the inhibition is of more importance at higher temperatures.

Seed prechilling resulted in a slight increase in germination rates at 20-30°C in light (see Methods 1 and 3), the results being similar to germination in darkness at 20-30°C (Methods 1 and 4), suggesting that prechilling reduces the sensitivity of the seed to light. This idea is also supported by the compari-

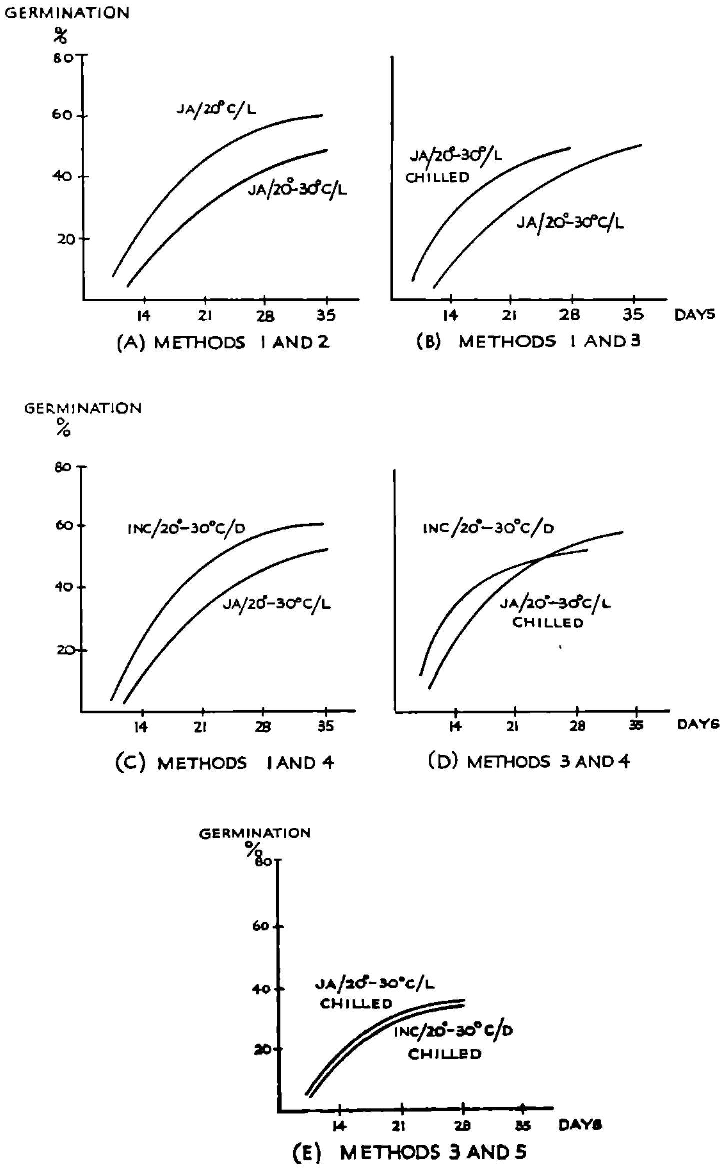

FIG. 6. Average Germination curves for the five pairs of test methods examined for *Tsuga heterophylla* seed, 1950-1960. J.A. = Jacobsen Apparatus. INC = Incubator.

son of chilled seed germinated in light (Method 3), and darkness (Method 5). Here the germination patterns were almost identical, again suggesting that pre-chilling reduces the sensitivity of the seed to light.

The pairs of test methods examined are of insufficient variety to permit precise conclusions on the role of individual environmental factors, but the following tentative conclusions can be drawn:—

(1) In the presence of light a constant temperature of 20°C is superior to an alternating temperature of 20-30°C.

(2) At 20-30°C germination was better in the dark than in light.

(3) Pre-chilling seeds at 3°C slightly increased the rate of germination of seeds under light, but not those germinated in darkness.

Unfortunately, no observations were made on the interaction of light and temperature factors during germinations, but it seems possible that a combination of darkness and low temperatures might be advantageous for this species.

Pending more detailed studies of the interaction of individual factors, it is concluded that the most satisfactory test conditions are given by Method 2, i.e. Jacobsen apparatus, constant temperature of 20°C; light; no prechilling. Under these conditions germination will be completed in 35 days. Moreover the low "plus figure" of this method gives additional evidence for its superiority over the other methods.

Quality of Home-Collected and Imported Seed

An examination of the results of germination tests reveals large differences between home-collected and imported seeds, as shown in Table 14.

Table 14

Germination Quality of Home Collected and Imported Seed

Quality Class (Germination %)	Home Collected Seed			Imported Seed		
	No. of Samples	% of Samples Total	Av. Germinative Capacity	No. of Samples	% of Total Samples	Av. Germinative Capacity
80 and over	4	6	80	19	10	84
61-79	9	14	66	107	53	70
60 and under	53	80	25	75	37	51
Totals and Mean	66	100	34	201	100	64

Germinative capacities were generally low, but imported seed was superior to home-collected seed, the average germinative capacities being 64 per cent and 34 per cent respectively. In considering seed quality one must include seed purity and seed weight as well as germinative capacity. The general averages for these values from 1950-60 were as shown in Table 15.

Table 15

Purity, Seed Weight, and Germinative Capacity

	Purity %	No. Pure Seeds per lb. (Thous.)	Germinative Capacity %	No. Viable Seeds per lb. (Thous.)
Home Collected Seed	89·3	313	34	106
Imported Seeds	94·9	233	64	142

In general, the home-collected seed has a lower purity and a higher number of pure seeds per lb. which is mainly attributable to the high proportion of empty seeds. It would, of course, be possible to obtain higher germinative capacities for home-collected lots by removing empty seed in the cleaning process.

Relationship of Laboratory Test Results to Germination in the Field

As stated earlier, the aim of the laboratory germination test is to provide a reproducible estimate of the maximum possible germination, which will serve as a quality index and a basis for control. Interpretation of the laboratory results to provide a forecast of seedling yields in the field is a difficult problem owing to the complexity and variability of factors affecting field germination and survival.

Laboratory germination values are almost invariably an overestimate of field germination, the discrepancy being smallest for rapidly germinating and high quality seed. Western hemlock seeds are relatively slow germinating, and field germination and survival tend to be low and erratic. The current seed sowing practice with this species is to sow 2,500 viable seeds per square yard of seedbed in order to produce a desired stocking of about 900 seedlings per square yard, i.e. about 35 per cent of viable seeds are expected to produce seedlings.

Actual production varies considerably from season to season and nursery to nursery. For example, the results of stock-sowings of Western hemlock in five different years in the same nursery at Wareham, Dorset, was as follows:—

Year:	1950	1954	1955	1956	1957	*Average*
Production of 1 year seedlings as % of viable seeds sown	17%	43%	60%	16%	17%	30%

Such variability does not permit accurate planning of sowing programmes, and there remains a need for research into the factors responsible for fluctuations in seedling yields.

In 1955, a series of test sowings were carried out to observe the relationship between laboratory estimates of germination quality and seedling yield over a wide range of nursery conditions. Seeds were sown in accurately weighed amounts in each of 8 nurseries, covering a wide range of climate and soil conditions. At each nursery the seed was sown in beds protected against mice and birds, and also in unprotected beds to provide a measure of the effects of birds and animals on yields. The results obtained during 1955 are summarised in Table 16.

These figures illustrate the great variation in seedling emergence and survival rates from one nursery to another, using the same seed lots. It is difficult to trace any consistent pattern. Some nurseries showed considerable higher numbers of seedlings emerging than others. For example, Nurseries 1 and 2 both showed relatively high seedling emergence rates, but Nursery 1 showed a disastrously low seedling survival compared with Nursery 2. There was also a considerable reduction in seedling survival at all centres in unprotected beds, indicating that birds and small mammals are important factors to consider.

Table 16

Western Hemlock Seedling Emergence and Yield as Percentage of the Number of Viable Seeds Sown

Nursery and County	Protected Beds				Unprotected Beds	
	Seedlings Emerging		Seedlings Surviving to End of Season		Seedlings Surviving to End of Season	
	Lot 1	Lot 2	Lot 1	Lot 2	Lot 1	Lot 2
1. Kennington, Oxford	36	68	8	8	4	8
2. Wareham, Dorset	56	79	54	75	31	50
3. Bramshill, Berks	6	4	4	2	4	2
4. Nagshead, Gloucester....	12	17	4	6	2	4
5. Benmore, Argyll	19	33	12	21	12	13
6. Fleet, Kirkcudbright	35	35	17	17	0	0
7. Inchnacardoch, Inverness	42	21	35	31	23	17
8. Newton, Moray	36	46	23	33	4	4
Average	30	38	20	25	10	12

Taken overall, these results indicate that a large proportion of losses of viable seeds occur before the seedlings emerge from the soil; on average, only about 30 to 40 per cent of viable seeds emerged as seedlings in protected beds. Losses after seedling emergence were also very variable from nursery to nursery. Some post-emergence losses were disastrous, e.g. Nursery 1, but by and large the losses were smaller than pre-emergence losses.

Total losses were greatest on unprotected beds, where an average of 10 to 12 per cent of viable seeds produced one-year seedlings compared with 20 to 25 per cent on protected beds. The magnitude of the losses of viable seed, particularly at the pre-emergence stage, represents a considerable financial loss, and the variability of yields from nursery to nursery necessitates application of large and sometimes wasteful safety factors in planning nursery sowings. These observations underline the necessity of further research into the factors responsible for losses, especially pre-emergence losses in the field.

Summary

(1) The report describes the results of purity, weight (size) and germination tests completed on seed lots of Western hemlock, *Tsuga heterophylla*, during the period 1950-60.

(2) Results are compared for home-collected and imported seed. The reasons for the difference in quality between home-collected and imported seed are discussed.

(3) A close relationship between seed weight (size) and latitude of origin was found.

(4) Five contrasting germination test conditions were examined, and it was concluded that, subject to further study of temperature/light

interactions, the most suitable method is the Jacobsen apparatus used with light as a constant temperature of 20°C.

(5) Variations in seedling yields from viable seeds sown in the field are discussed.

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THE USE OF HERBICIDES FOR CONTROLLING VEGETATION IN FOREST FIRE BREAKS AND UNCROPPED LAND

by G. D. HOLMES and D. F. FOURT

Introduction

A high proportion of forest fires originate from sources outside the forest area, and under most conditions an essential protective measure is the establishment of non-inflammable fire breaks or traces to cut off a fire before it reaches a plantation. In practice these breaks are either strips of bare soil maintained by mechanical or manual cultivation, or they may be green swards maintained by mowing, grazing or controlled burning. The width of such fire-breaks varies considerably according to circumstances, from 4-6 feet in the case of hand-screefed breaks to 20-30 feet for those which are mechanically cultivated or mown.

In general, a fireproof surface 20 feet wide is desirable, and where possible this should be firm enough to permit passage of wheeled vehicles, a feature of great practical importance in providing access for fire fighting purposes.

Bare fallow firebreaks fail to meet the latter requirements and they are also relatively costly to maintain, requiring two or more cultivations per year to maintain sterile fireproof conditions. Hence there is now a general preference for green firebreaks, formed by cultivation and grading, with repeated mowing to induce a short grassy sward. Graded green traces offer the advantages of both firm ground and cheap maintenance where gang-mowers can be used.

However, bare soil breaks still have an important role, notably where rough topography prevents the use of machinery, or where low rainfall and infertile soils will not support a green sward all the year round. Also, unlike green breaks, bare-soil does not present the risk of sward desiccation and increased fire hazard in times of extreme drought. If their disadvantages of relatively high cost and loose soil conditions could be overcome they would probably be used more widely. Herbicides provide a possible means of maintaining bare soil without cultivation, thus avoiding the drawbacks mentioned above. Accordingly, in 1956-59 a series of trials was carried out to assess the effectiveness, safety, persistence and probable cost of herbicides for the establishment and maintenance of bare soil fire breaks over a range of soil conditions. The herbicides of interest for this purpose can be grouped according to their mode of action and persistence as follows:—

(i) *Total* (*non-selective*) *Herbicides*—

(a) *Persistent*—low soluble, slow acting compounds, affecting plants largely through root absorption. These are not readily leached from the soil (e.g. monuron, simazine).

(*b*) *Non-persistent*—soluble, quick acting compounds, affecting plants through foliar contact and root absorption. They may be leached quite rapidly from the soil (e.g. sodium chlorate, sodium arsenite).

(c) *Mixtures*—combinations of persistent and non-persistent herbicides to combine rapid initial toxicity with persistence of effects.

(ii) *Selective Herbicides*—

Compounds which are usually absorbed and translocated via the foliage and roots differ in their toxicity to certain groups of plants. Common examples are 2,4-D (toxic to many broadleaved herbaceous species), 2,4,5-T (toxic to many woody species), and dalapon (toxic to grasses). These can be used in mixture to give a "non-selective" control of vegetative types, but they break down rapidly in soil and have little persistence.

The trials described were carried out under firebreak conditions, but the results have a direct bearing on the problems of total vegetation control in any uncropped area where weed growth is an obstacle, a fire hazard, a source of weed seed, or merely an eyesore, e.g. fence lines, roads (especially nursery roads and paths), and land around buildings, timber yards, etc.

Experimental

Trial Areas

The main trials were started in the spring of 1956, testing a range of herbicides for control of perennial and annual weeds of uncultivated and recently cultivated land, on three contrasting soil and vegetation types, viz:—

Site 1—"Sand" (Bramshill Forest, Berks, *see* Plate 1.).

The selected site was typical of fire breaks on sandy soils overlying Tertiary Bagshot Beds in Southern England, the soil being a structureless sandy podsol with a pH of 4·0-4·5. Vegetation was dominated by *Holcus mollis, Agrostis tenuis, Deschampsia flexuosa,* and *Pteridium,* with *Galium, Juncus effusus, Calluna vulgaris* and *Rumex acetosella.*

Tests were made on cultivated and uncultivated land at this centre, the cultivated areas being ploughed to 6 inches depth in January, preceding the first applications in February 1956.

Site 2—"Clay" (Bruton Forest, Wilts./Somerset Border, *see* Plate 2).

The soil, which is derived from Oxford Clay, is a surface-water gley of high base status, pH levels ranging from 5·5 near the surface to over pH 7·0 below. The vegetation was *Juncus* spp., (*J. acutiflorus*), *Carex pendula, Deschampsia caespitosa, Holcus mollis, H. lanatus,* and locally *Agropyron repens,* and *Agrostis stolonifera.* Herbs included *Angelica sylvestris, Chamaenerion angustifolium, Cirsium palustris, C. arvense,* and others.

The whole site was ploughed in February, 1956, shortly before herbicide treatment, exposing a mottled yellow/grey clay and completely burying the existing vegetation.

Site 3. "Chalky loam" (Blandford Forest, Dorset, *see* Plate 3).

The geology is Upper Chalk, and the soil a chalk-heath rendzina consisting of 2-3 inches of loam, sub-neutral in reaction, overlying loamy chalk rubble. The vegetation, as is commonly the case on wood fringes on calcareous soils, contained several woody species, notably *Ulex europaeus, Rubus fruticosus,* and *R. idaeus* in patches. Otherwise, the vegetation was predominantly grass, (*Festuca ovina, F. rubra, Holcus lanatus* and others), with the herbs *Urtica dioica, Teucrium scorodonia, Cirsium arvense* and *Glechoma hederacea.* The woody species were cut by hand, otherwise there was no site preparation before application of chemicals.

In addition, a fourth uncultivated site, consisting of a clay-loam overlying Gault clay at Alice Holt Forest, Hants., was utilised for trials of simazine in 1958-59.

Treatments

All treatments were applied to unit plots of 10 feet × 12 feet in a randomised block design. Compounds used dry in pellet or powder form were spread by hand, to quartered plots, while compounds used in solution or suspension were applied in water at 50 gallons per acre, using a knapsack sprayer. The chemicals tested are shown in Table 17.

Chlorate, Borate/Chlorate, Borate/2,4,-D, Borate/MCPA, and TCA were applied in late April 1956, and Simazine in April 1958. All other treatments were applied in February, 1956.

The compounds selected include most of the more promising herbicides now available for total weed control, and were applied at a wide range of rates per acre. In all cases, some of the rates were set deliberately high and possibly at an uneconomic level, in order to examine the extent of increased persistence at such rates.

Table 17

Herbicides and Application Rates Tested

Herbicide	Form Applied	Content of Active Ingredient	Rates of Application per Acre	
			Compound	Ingredient
1. Monuron	Water suspension	80% monuron	15-60 lb.	12-48 lb.
2. Diuron	„ „	80% diuron	15-60 lb.	12-48 lb.
3. Crude sodium borate	Dry powder	61·5% B_2O_3	15-35 cwt.	9·2-21·5 cwt. B_2O_3
4. Borate/monuron	Dry pellets	41·4% B_2O_3 +4% monuron	3-12 cwt.	1·25-5 cwts. B_2O_3 + 13·5-54 lb. Monuron
5. Sodium chlorate	Water solution	99% $NaClO_3$	1·5-6·0 cwt.	1·5-6·0 cwt.
6. Borate/chlorate	Dry powder	49% B_2O_3 +25% $NcClO_3$	4-16 cwt.	2-8 cwt. B_2O_3 + 1-4 cwt. $NaClO_3$
7. Simazine	Water suspension	50% Simazine	20-40 lb.	10-20 lb. Simazine
8. Sodium arsenite	Water solution	98% W/V As_2O_3	1·5-6 cwt.	1·5-6 cwt. As_2O_3
9. Sodium TCA	Water solution	94% TCA	40-160 lb.	38-150 lb. TCA
10. Borate/2,4-D	Dry pellets	39·2% B_2O_3 + 7·5% 2,4-D	4-16 cwt.	1·5-6 cwt. B_2O_3 + 34-136 lb. 2,4-D
11. Chlorate/MCPA	Water solution	95% $NaClO_3$ + 1% MCPA	85-340 lb.	0·7-3 cwt. $NaClo_3$ + 0·9-3·5 lb. MCPA

The objective was the establishment and maintenance of bare soil conditions, or to affect such a drastic vegetation change as to provide fire-proof conditions for as long as possible. In order to assess the treatment effects, all plots were examined at intervals up to 20 months afterwards, i.e. the end of the second season, recording the percentage of the area of each plot occupied by living vegetation. In addition, extensive notes were made of all the species occurring, their inflammability, and their relative susceptibilities to treatment.

Results

The details of results with each herbicide are summarised in Tables 18-28 showing the percentage cover of live vegetation in relation to soil type and cultivation treatment. The percentages quoted are the averages of two replications. Each table is accompanied by a note of the main species surviving or colonising at the time of the last assessment, and a short comment on the properties and observed performance of each herbicide.

Table 18

Monuron: (N-(p-chlorophenyl)-N¹N¹-dimethylurea)

Total Vegetation Cover (% of Total Ground Surface).
(Figures in brackets show the cover % on plots which were *additionally* cultivated immediately after chemical application).

Application Rate per Acre (Active Ingred.)	Interval after Treatment (months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky loam
12 lb.	4 months	5 (1)	5 (5)	15	50
	8 ,,	15 (5)	20 (10)	60	90
	19 ,,	40 (40)	80 (30)	85	100
	4 ,,	1 (1)	5 (5)	15	30
24 lb.	8 ,,	5 (5)	10 (15)	30	70
	19 ,,	20 (40)	50 (20)	60	100
	4 ,,	1 (1)	5 (5)	10	5
48 lb.	8 ,,	5 (5)	5 (10)	10	15
	19 ,,	5 (50)	20 (15)	60	100
Main species present 19 months after treatment		Holcus mollis, Agrostis tenuis, Calluna.	Juncus, Plantago, Rubus.	Holcus mollis, Calluna.	Glechoma, Cirsium, Holcus lanatus.

Monuron is a persistent total herbicide of low solubility (solubility 230 p.p.m.) and is used as a wettable powder containing 80 per cent of the active ingredient. It is of low mammalian toxicity and is non-inflammable.

Despite quite high initial toxicity, monuron failed to maintain bare soil conditions for more than one season, except on cultivated sand at 48 lb. per acre. However, the treatment is of interest from the fire protection standpoint owing to the smaller proportion of grasses amongst the re-colonising species. Thus, especially on the clay and chalk soils, most of the vegetation 19 months after treatment consisted of broadleaved herbs such as *Glechoma hederacea*, *Plantago media*, *Angelica*, etc., which present a low fire hazard.

In effect, this means that on clay and chalk, although the treatment may have failed to maintain bare soil, a useful fire retarding trace was produced as a result of the change in vegetation to predominantly broadleaved species.

In general, monuron was more toxic on sand than clay soils, and prior cultivation markedly improved its persistence on both types. The effect of additional cultivation after application was difficult to evaluate precisely, especially on sand, but on clay, improvements in persistence were noted at the higher dosage rates, (see Table 18).

Diuron is a substituted urea which is chemically closely related to monuron but it is less soluble (solubility 42 p.p.m.) and reputed to be more persistent. Like monuron, it is applied as a water suspension, (see Table 19).

Table 19

Diuron: (N- (3,4-dichlorophenyl)-N^1N^1-dimethylurea)

Total Vegetation Cover (% of Total Ground Surface).

Application Rate per Acre (Active Ingred.)	Interval after Treatment (Months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky loam
12 lb.	4 months	5	5	25	80
	8 ,,	40	30	40	100
	19 ,,	50	60	70	100
24 lb.	4 ,,	5	5	15	70
	8 ,,	15	20	20	95
	19 ,,	30	50	60	100
48 lb.	4 ,,	5	5	15	40
	8 ,,	5	15	15	70
	19 ,,	20	40	30	100
Main Species present 19 *months after treatment*		Pteridium, Deschampsia flexuosa, Holcus mollis.	Juncus, Plantago, Angelica, Cirsium.	Pteridium, Deschampsia, Calluna, Holcus mollis.	Rubus, Glechoma.

Diuron showed lower initial toxicity and persistence than monuron, and there were only small differences between the effects of the three dosage rates. Otherwise, results were similar to monuron, i.e. toxicity was most persistent on sandy soil, and with cultivation on both sand and clay. As

Table 20

Crude Sodium Borate

Total Vegetation Cover (% of Total Ground Surface)

Application Rate Per Acre (B_2O_3)	Interval After Treatment (months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky loam
9 cwt.	4 months	<1	<1	0	20
	8 ,,	1	<1	5	35
	19 ,,	60	5	60	100
15 cwt.	4 ,,	0	0	0	10
	8 ,,	1	0	0	25
	19 ,,	25	5	25	100
21 cwt.	4 ,,	0	0	0	5
	8 ,,	0	0	0	25
	19 ,,	10	5	30	100
Main species present 19 *months after treatment*		Agrostis tenuis, Senecio.	Deschampsia caespitosa, Juncus.	Agrostis, Deschampsia flexuosa.	Holcus lanatus.

with monuron, the most striking effect was the control of most grasses followed by rapid colonisation of the site by seedlings of other species, notably *Glechoma*, *Angelica* and *Plantago* on clay, and *Calluna* on sand, with some bracken from persistent rhizomes on sand, Despite its lower solubility vegetation control was rather less persistent with diuron than with monuron.

Crude sodium borate, (61·5 % B_2O_3), is a moderately soluble total herbicide acting mainly through its effect on roots. It is fairly readily leached but has the advantages of being of only moderate mammalian toxicity, and it is an efficient fire retardant, (See Table 20).

Initial control was excellent on all sites but the rate of re-establishment of vegetation varied greatly with soil conditions. On sand and clay there was negligible re-growth in the first year, but a 25 per cent cover of *Holcus* had developed on the uncultivated chalky loam.

In the second year, excellent control was maintained on cultivated clay even at the lowest rate, in contrast with cultivated sand where a well established grass cover, predominantly of *Agrostis tenuis*, appeared, though less densely at the higher rates. This species is apparently capable of tolerating high levels of Borate, as is *Chenopodium polyspermum* which appeared on the clay site. Results were not so good on uncultivated soils, particularly on the calcareous loam which had a 100 per cent cover of *Holcus* at all rates at the end of the second year. A wide variety of species were controlled, and the main colonisers after treatment were shallow rooting and tussocky grasses, notably *Agrostis tenuis*, *Holcus lanatus* and *Deschampsia* spp., all of which present a fairly high fire hazard.

Table 21

Borate/Monuron Mixture (Sodium Borate 41·3 per cent B_2O_3 + Monuron 4 per cent)

Total Vegetation Cover (% of Total Ground Surface)

Application Rate per Acre (B_2O_3 + Monuron)	Interval after Treatment (months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky loam
1·25 cwt. + 13 lb.	4 months	5	5	2	35
	8 ,,	20	25	30	90
	19 ,,	35	70	60	100
2·5 cwt. + 27 lb.	4 ,,	0	5	0	30
	8 ,,	1	20	10	70
	19 ,,	5	50	30	90
5 cwt. + 54lb.	4 ,,	1	1	0	10
	8 ,,	0	0	0	30
	19 ,,	5	5	10	80
Main species present 19 *months after treatment*		Molinia, Pteridium, Holcus mollis.	Rubus, Juncus, Angelica.	Pteridium, Senecio, Holcus mollis.	Glechoma, Rubus, Cirsium.

These observations suggest that good short-term control can be obtained at 9 cwt. B_2O_3 per acre, with or without advance cultivation on all except calcareous loams. Pre-cultivation, together with rates of 15-20 cwt. B_2O_3 per acre, is necessary for complete weed control for two seasons on non-calcareous sand or clay soils.

Mixture of sodium tetraborate and Monuron. This was prepared in pelleted form for dry application. The mixture is of low toxicity and non-inflammable.

This mixture gave an excellent initial kill of all species at the lowest rate of application on all except the calcareous loam. The effects were highly persistent, and almost complete sterilisation was achieved for two years at 2·5 cwt. B_2O_3 + 27 lb. monuron per acre on cultivated sand and at 5 cwt. + 54 lb. per acre on uncultivated sand and cultivated clay.

Judged from the practical fire-protection point of view, the results were acceptable on all 2·5 cwt. + 27 lb. per acre plots, as even where a high vegetation cover was present it was composed almost entirely of broadleaved species of low stature. This mixture is of some interest as it appears to successfully combine the properties of borax and monuron, i.e. efficient "knock-down" followed by persistence, (See Table 21).

Table 22

Sodium Chlorate—($NaClO_3$)

Total Vegetation Cover (% of Total Ground Surface)

Application Rate Per Acre ($NaClO_3$)	Interval After Treatment (months)	Cultivated	
		Sand	Clay
1·5 cwt.	6 months 18 „	10 60	25 100
3 cwt.	6 „ 18 „	5 60	5 80
6 cwt.	6 „ 18 „	5 50	5 80
Main species present 18 months after treatment		Holcus mollis, Deschampsia, Agrostis tenuis.	Holcus lanatus, Juncus, Cirsium.

Sodium chlorate is one of the most widely used non-selective herbicides. It is highly soluble, rapid in action through both foliar contact and root absorption. However, it has a very low persistence in the soil. Its main practical disadvantage is the greatly increased inflammability of herbage treated with chlorate. For this reason it must be excluded from practical consideration on firebreaks unless combined with a fire retardant such as sodium borate or calcium chloride.

This compound was restricted to cultivated soil on account of the high fire risk associated with application of chlorate to standing vegetation. There was a high initial kill of all species at the medium rate, (3 cwt. per acre) which persisted on both soils to the end of the first season. Thereafter recovery was rapid, and extensive re-growth and colonisation of several species occurred in the second season. Vegetation recovery was rather slower on sand than on clay, (See Table 22).

Table 23

Borate/Chlorate Mixture (Sodium borate 49 per cent B_2O_3 + $NaClO_3$ 25 per cent)

Total Vegetation Cover (% of Total Ground Surface)

Application Rate per Acre (B_2O_3 + $NaClO_3$)	Interval After Treatment (Months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky loam
2 cwt. + 1 cwt.	6 months 18 „	35 70	20 70	50 90	95 100
4 cwt. + 2 cwt.	6 „ 18 „	10 70	10 70	15 80	70 100
8 cwt. + 4 cwt.	6 „ 18 „	0 60	5 45	0 60	10 100
Main species present 18 months after treatment		Agrostis, Holcus, Deschampsia.	Holcus, Juncus, Plantago.	Agrostis, Holcus, Rumex.	Holcus, Rubus, Dactylis.

Borate Chlorate Mixture. This mixture of moderately soluble and highly soluble non-selective herbicides has the advantages that borate suppresses the fire hazard of chlorate, and also provides a valuable addition to the herbicidal action of the compound. The mixture is of low general toxicity and has a negligible fire risk. It can be applied in water solution or powder form, (See Table 23).

The general pattern of response was very similar to that described for sodium borate or sodium chlorate. The mixture gave a high degree of control of all species for one season on sand and cultivated clay at 4 cwt. + 2 cwt. per acre. However, 8 cwt. + 4 cwt. per acre was required to produce the same result on uncultivated calcareous loam. Persistence in the second season was poor on all soils even at the heaviest rate.

Table 24

Simazine (2-chloro-4, 6-bisethylamino- 1, 3, 5-triazine)

(The results reported were obtained in 1958-59 in supplementary trials outside the main 1956-57 series).

Total Vegetation Cover (% of Total Ground Surface)

Application Rate per Acre (active Simazine)	Interval after Treatment (months)	Uncultivated Clay-Loam
10 lb.	4 months 18 „	5 30
20 lb.	4 months 18 „	1 10

On available evidence, the mixture offers no advantages over borate or chlorate applied alone, other than the reduced fire hazard of chlorate when used in mixture with borate. Unlike the results with monuron or the borate/monuron mixture, the re-invading vegetation was predominantly grassy (*Holcus, Agrostis, Dactylis*) which is unacceptable in a fire-break unless mown.

Simazine is an extremely insoluble (solubility 3·5 p.p.m.) and persistent total herbicide, which is formulated for application as a suspension in water. It has a low mammalian toxicity and is non-inflammable, (See Table 24).

Like Monuron, the compound was very slow acting, and little effect was apparent until two months after application. However, by the end of the first season there was almost complete control of broadleaved and grass vegetation at both application rates. Some regeneration occurred in the second season, notably of broadleaved species (*Plantago*, *Taraxacum* with very little *Holcus*). Results were satisfactory for two seasons, the final cover having a very low fire hazard.

Table 25

Sodium Arsenite (90 per cent As_2O_3)

Total Vegetation Cover (% of Total Ground Surface)

Application Rate per Acre (As_2O_3)	Interval after Treatment (months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky Loam
1·5 cwt.	4 months	5	10	5	60
	8 „	50	70	50	90
	19 „	80	100	80	100
3 cwt.	4 „	5	15	5	30
	8 „	40	80	45	75
	19 „	70	90	75	100
6 cwt.	4 „	5	10	1	15
	8 „	30	60	15	45
	19 „	60	90	60	100
Main species present 19 *months after treatment*		Holcus mollis, Agrostis tenuis, Juncus.	Holcus lanatus, Rubus, Juncus.	Holcus mollis, Pteridium.	Rubus, Cirsium, Holcus lanatus.

Sodium arsenite is a highly soluble total herbicide which may be very persistent in certain soils. It is, of course, very toxic to man and animals, which imposes a severe limit on its practical use.

Initial toxicity was fairly high on all sites, but persistence was low, especially on the chalk and clay soils. There appeared to be little or no effect of cultivation on the control achieved on sand, (See Table 25).

The best results were achieved on coarse sand where very few plants appeared during the two seasons. On only slightly more fertile loamy sand results were less favourable, and over 50 per cent cover developed in the first year at the high rate, compared with 80 per cent for the adjacent cultivated controls, rising to 90 per cent at the end of the second year, irrespective of cultivation.

There were no marked changes in the species composition of the cover, and most of the species originally present began to re-colonise in the season of treatment.

Table 26

Sodium Trichloracetate (T.C.A.)

Total Vegetation Cover (% of Total Ground Surface)

Application Rate per Acre (TCA)	Interval After Treatment (months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky loam
38 lb.	6 months	75	80	50	100
	18 "	90	100	90	100
76 lb.	6 "	40	70	45	100
	18 "	80	100	80	100
150 lb.	6 "	5	20	15	100
	18 "	60	90	70	100
Main species present 18 *months after treatment*		Holcus mollis, Agrostis tenuis.	Juncus, Pulicaria, Rubus.	Holcus mollis, Calluna, Pteridium.	Holcus lanatus. Rubus.

Sodium TCA is a highly soluble and low persistence herbicide. It acts primarily through root absorption and was considered to be particularly toxic to annual and perennial grasses. It is of low mammalian toxicity and non-inflammable.

Results were disappointing, and even in the first season the heaviest rate of TCA failed to control the vegetation to an acceptable standard for fire-breaks. In the second season, recovery was complete on all soils, and by mid-summer the plots were almost indistinguishable from the adjacent control areas. (See Table 26).

Borate 2, 4-D Mixture. This mixture consists of moderately persistent and non-selective sodium borates and a low persistent, selective 2,4-D additive, with the object of increasing the initial effects and toxicity to a wider range of species.

There was an unsatisfactory initial kill of vegetation, and regeneration was rapid on all except the heaviest rate by the end of the first season. Persistence in the second season was poor, all plots being extensively colonised by predominantly grass vegetation, notably *Agrostis* and *Holcus* on sands, and *Holcus*, *Deschampsia*, *Dactylis* and *Juncus* on clays. *Agropyron repens* occurred on one of the clay plots and was unaffected by any of the dosage rates. The initial and long term results were inferior to those with borate or borate/chlorate at similar rates, and the addition of 2,4-D in this form has given no noticeable advantage. (See Table 27).

Table 27

Borate/2,4-D Mixture (Sodium borates 39·2 per cent B_2O_3 + 2,4-D 7·5 per cent)

Total Vegetation Cover (% of Total Ground Surface)

Application Rate per Acre (B_2O_3+2,4-D Acid)	Interval After Treatment (months)	Cultivated		Uncultivated	
		Sand	Clay	Sand	Chalky loam
1·5 cwt. + 34 lb.	6 months 18 ,,	60 75	75 100	60 85	85 100
3 cwt. + 68 lb.	6 ,, 18 ,,	35 70	45 90	35 80	75 100
6 cwt. + 136 lb.	6 ,, 18 ,,	5 60	20 70	5 70	15 100
Main species present 18 *months after treatment*		Holcus mollis, Agrostis tenuis.	Agropyron, Agrostis stolonifera.	Holcus mollis, Agrostis tenuis, Rumex.	Holcus lanatus, Dactylis.

Table 28

Chlorate/MCPA Mixture ($NaClO_3$ 95 per cent + MCPA 1 per cent)

Total Vegetation Cover (% of Total Ground Surface)

Application Rate per Acre ($NaClO_3$ + MCPA Acid)	Interval After Treatment (Months)	Cultivated	
		Sand	Clay
0·7 cwt. + 0·9 lb.	6 months 18 ,,	40 75	40 100
1·5 cwt. + 1·8 lb.	6 ,, 18 ,,	15 60	30 80
3 cwt. + 3·5 lb.	6 ,, 18 ,,	5 50	10 65
Main species present 18 months after treatment		Holcus, Agrostis, Deschampsia flexuosa.	Holcus, Deschampsia caespitosa, Rubus.

Chlorate MCPA Mixture

Results suggested that this mixed formulation had no advantage over sodium chlorate applied alone at similar rates. In general the effects were inadequate for firebreak weed control purposes, except possibly at the highest rate in the first year. Vigorous vegetation, consisting mainly of grasses, developed in the second year on all plots. (See Table 28).

Discussion

The notes on major species present at the time of the last assessment give some indication of the possible fire hazard of the surviving growth. However, these tables cannot give a detailed picture of the herbicide tolerance of the species encountered and an attempt has been made to summarise the available data in Table 29. Here the susceptibility of the main species found is indicated by a figure for each herbicide, showing the dosage rate required to achieve 90-100 per cent control for one-two seasons. This data must be regarded as tentative owing to the fact that few species occurred in all treatments at all sites.

It is difficult to generalise on the basis of these results, but there are several broad features deserving comment, thus—

(i) Advance cultivation by ploughing was beneficial in many cases. Application of herbicides to cultivated ground has the great advantage that control can be achieved without producing an inflammable mass of dead plant remains, which often follows a successful treatment of established vegetation. Apart from this, in several instances, notably with monuron and borate, advance cultivation appreciably increased the persistence of the herbicide and reduced the rate required for initial control by up to 50 per cent.

Cultivation, of course, has a considerable weed control effect, and it was found that ploughing alone seriously weakened plants of caespitose and rootstock habit, while annual and biennial species may succumb entirely. Rhizome or stolon-forming species are only temporarily checked and recover within a few weeks of ploughing.

(ii) There were wide differences in the degree of control and persistence achieved with each herbicide, according to the soil conditions concerned. The most striking result was the depression of herbicide effectiveness on the highly calcareous soil. Under these conditions the efficiency of borate, chlorate, arsenite and TCA salts appeared to be reduced, while monuron seemed less affected. It seems possible that reduced phytotoxicity on this soil is associated with the high level of free calcium carbonate, which may reduce the concentration of active anions, by forming compounds of lower solubility.

Comparison of herbicides on sand and clay soils showed that most commonly results were better on sand than on clay.

(iii) Among the species examined, the most resistant to herbicides were usually rhizomatous perennials, notably *Holcus mollis*, *Juncus acutiflorus*, *Pteridium aquilinum* and woody species such as *Rubus*.

Borate ore, at 9-15 cwt. B_2O_3 per acre, was the only compound to give a satisfactory control of *Pteridium aquilinum*.

The resistance of woody species was not unexpected, and in any case they are most efficiently dealt with by cutting and/or "spot" treatment by stump or foliage spraying with 2,4,5-T. Similarly, *Pteridium* or *Holcus mollis* can be controlled using the selective herbicides 4-CPA and dalapon respectively to supplement or follow-up a "non-selective" herbicide treatment.

(iv) The stated objective of bare soil conditions suitable for fire-control purposes was achieved with some herbicides, notably monuron, borate, borate/monuron and simazine on non-calcareous soils. However, an addi-

Table 29

Tentative Susceptibility Ratings for the Major Species Occurring in the Trial Areas

Species and Growth Habit	Rates of Herbicides for 90-100% Control (Lbs./Cwt. Active Ingredient(s) per Acre)							
	Monuron lb.	Diuron lb.	Sodium Borate Cwt.	Borate/ Monuron Cwt./Lb.	Sodium Chlorate Cwt.	Borate/ Chlorate Cwt./Cwt.	Sodium Arsenite Cwt.	Sodium TCA Lb.
Agrostis stolonifera (Stolons)	12 (R)	12	10 (R)	1·25/13	3	4/2	3 (R)	80 (R)
A. tenuis (Caepitose)	12	12	15 +		3		3	80
Ajuga reptans (Stolons)	24	12				4/2		80
Angelica sylvestris (Perennial root-stock)	48+ (R)	48+ (R)	10	2·5/27	3	4/2	6+ (R)	160
Arctium lappa (Perennial rootstock)				[2·5/27]				
Betula sp. (Perennial, woody)	24	12+	10	1·25/14	6	8/4 (R)		
Calluna vulgaris (Perennial, woody)	48 (R)	48	10	1·25/14		4/2		80 (R)
Carex sylvatica (Caespitose)	12	24	10	1·25/14			3	
C. pendula (Caespitose)	48	24	10		6		6	160
C. pillulifera (Caespitose)	12	12	10	1·25/14	3	2/1		40
Chamaenerion angustifolium (Rhizome)	12	24	15		3	4/2	6+ (R)	
Cirsium arvense (Rhizome)	[24] (R)	(R)	[15]	2·5/27	(R)	4/2	6+ (R)	[80] (R)
Conium maculatum (Rootstock)							[6]	[80]
Dactylis glomerata (Caespitose)	[12]	[12] 12	[15]	2·5/27		[4/2]	[6]	[80]
Deschampsia caespitosa (Caespitose)	24	24 (R)	10 (R)	1·25/13	1·5 (R)	4/2	6+ (R)	40
D. flexuosa (Caespitose)	24	24	10	1·25/13	1·5	4/2	6	40
Epilobium montanum (Perennial, rootstock)			10				1·5	80
Erica cinerea (Perennial, woody)	24	24	10	1·25/13		2/1		80
Festuca ovina (Caespitose)	[12]	[12]	[15]	[1·25/13]		[4/2]	[3]	[160+] (R)
F. rubra (Caespitose)	[12]	[12]	[15]	[1·25/13]		[4/2]	[3]	[160+] [R)
Glechoma hederacea (Stolons)	[48+] (R)	[48+] (R)	[15]	[5/54]		[4/2]	[6+] (R)	[160+] (R)

Table 29—*continued: Tentative Susceptibility Ratings*

Species and Growth Habit	Rates of Herbicides for 90-100% Control (Lbs./Cwt.) Active Ingredient(s) per Acre)							
	Monuron lb.	Diuron lb.	Sodium Borate Cwt.	Borate/ Monuron Cwt./Lb.	Sodium Chlorate Cwt.	Borate/ Chlorate Cwt./Cwt.	Sodium Arsenite Cwt.	Sodium TCA Lb.
Holcus lanatus (Caespitose)	[12]	[12]	[15] (R)	[1·25/13]		[8/4+] (R)		[160] (R)
H. mollis (Rhizome)	48 (R)	48	10		6+ (R)	8/4+ (R)	6+ (R)	160+ (R)
Juncus acutiflorus (Rhizome)	48 (R)	48 (R)	20 (R)	5/54 (R)	6+ (R)	8/4+ (R)	6+ (R)	160+ (R)
J. bulbosus (Caespitose)			10	1·25/13	1·5	4/2		
J. conglomeratus (Perennial, rootstock)		48	10		3			
J. effusus (Perennial, rootstock)	48	24	10	1·25/13		8/4 (R)		80
J. squarrosus (Caespitose)		12	10					
Luzula campestre (Caespitose)		12						
Lolium perenne (Caespitose)			10			8/4		
Molinia coerulea (Caespitose)	24	24	10	2·5/27		8/4		40
Prunella vulgaris (Rhizome)	24	24	10	2·5/27	3	4/2	3	
Plantago media (Caespitose)	48 (R)	(R)	10	2·5/27				80
Pteridium aquilinum (Rhizome)	48+ (R)	48+ (R)	15	5/54 (R)	6+ (R)	8/4 (R)	6+ (R)	160+ (R)
Rubus fruticosus (Stolons)..	[24] (R)	[48]	[15]	[5/54] 2·5/27 (R)		[4/2]	[6+] (R)	[160+] (R)
Rumex acetosella (Rhizome)	12	12	10		3		3	160
Ranunculus repens (Stolons)			10					160
Senecio sp. (Annual)		12	10 (R)			4/2		
Stellaria arvense (Caespitose)		12	10			4/2		
Teucrium scorodonia (Rhizome)	[24]	[48]		[2·5/27]		[4/2]	[6+] (R)	[160+] (R)
Urtica dioica (Rhizome)	[24]	[24]	[15]	[2·5/27]		[4/2]	[1·5]	
Viola sp. (Rootstock)	24		10	2·5/27				

* (1) Borate/2,4-D and Chlorate/MCPA mixtures are omitted as results were closely similar to those with corresponding rates of borate and chlorate alone.

(2) Values in square brackets, [ ] indicate ratings on calcareous loam. All other figures are a general assessment of results on the widely contrasting sand and sub-neutral clay soils.

(3) (R) = principal re-colonisers within 12-18th months of treatment.

tional most interesting point to emerge has been the dramatic change of the species composition with certain herbicides. Judged in terms of total vegetation cover, such treatments might be said to have failed, but in actual fact they have succeeded in the essential requirement, a fire proof area, through a change of species from tall grass to a short succulent broadleaved flora. Monuron and simazine were notable in this respect, and in many cases reduced the species to two or three herbs (e.g. *Glechoma, Plantago, Taraxacum*), which quickly rampaged over the whole plot surface, effectively slowing down recolonisation by more inflammable species.

(v) With regard to the herbicides themselves the following general remarks can be made:—

Borate Compounds: These herbicides, including borate ore, borate/monuron and borate/chlorate, were effective total herbicides and it is possible to achieve complete soil sterilisation for two seasons at high rates on soils which are not calcareous. On the whole results were better on light than on heavy soils but the differences were not great. Borates generally were least effective against perennial grasses, and high rates, or admixture with monuron, were necessary to control this group.

Monuron and Diuron Compounds: These proved effective and persistent especially against perennial grasses. At medium rates the compounds were successful in producing fireproof breaks by alteration of the species composition to broadleaved herbs. These compounds were less affected by high soil-base-status than borate and chlorate, and there was little to choose between monuron and diuron in persistence on sand and clay.

Simazine: This was not tested in strict comparison with other herbicides, but results suggest that its effects are similar to monuron and rather more persistent.

Sodium Arsenite, Sodium Chlorate, Sodium TCA: All these compounds were rather disappointing, mainly on account of their limited persistence even at high rates.

(vi) It will be apparent from the foregoing that total weed control under fire-break conditions places heavy demands on any herbicide on account of the wide range of species and soils encountered, coupled with the narrowness of the treated areas and the close proximity of sources of re-invasion by seed and vegetative means. Under these conditions, no herbicide is likely to remain effective in maintaining a fireproof trace for longer than two seasons, thereafter re-treatment at reduced rates, or "spot" treatment of particular weeds with a *selective* herbicide, will be necessary.

Costs and Conclusions

So far no reference has been made to the costs of herbicide treatments compared with those of conventional methods of fire-break maintenance. These must obviously be considered in evaluating the possible role of herbicides in this work.

To consider existing mechanical and manual methods, there are basically three practices which may be adopted according to local conditions, viz:

(i) Breaks formed by ploughing and maintained by discing or harrowing.

(ii) Breaks formed by bulldozing or ploughing, followed by grading, and maintained by gang-mowing to produce a short green sward.

(iii) Breaks formed by manual screefing of vegetation, and maintained by screefing or hand trimming. (Such breaks are restricted to steep or rocky land where machinery cannot be used, and they are rarely more than 6 feet wide).

The cost of these methods vary considerably, but recent actual costs incurred, including direct overheads and local supervision are of the following order:—

Type	*Cost per Acre of Firebreak* (a) *Formation*	(b) *Annual Maintenance*
(i) Ploughed and disced bare-soil breaks	£5—£15	£0·5—£5
(ii) Graded and mown breaks ..	Bulldozing—£10—£100 (depending on need)	£0·5—£3
(iii) Manual screefing and handling..	£50—£150	£10—£20

For purposes of comparison, the material costs only, for herbicide treatments, are summarised in Table 30. The herbicides and rates listed are restricted to those which gave a satisfactory firebreak for periods of one or two years. In addition a provisional estimate is made of the rates probably required as maintenance treatments in each case.

Table 30

A Summary of Estimated Rates (Active Ingredient) and Material Costs of Herbicides for Firebreak Formation and Maintenance

	Rates and Costs of Herbicides per Acre						
	(a) Formation				(b) Maintenance		
	Duration of Effect				Estimated Rate		
	One-Year		Two-Years				
	Rate	Cost	Rate	Cost	Rate	Cost	
Monuron ..	20 lb.	£37	32 lb.	£60	10 lb.	£18	
Borate Ore ..	7 cwt. B_2O_3	£30	15 cwt. B_2O_3	£60	5 cwt. B_2O_3	£20	Excludes Calcareous soil.
Borate/Monuron	2·5 cwt. B_2O_3 27 lb. Monuron	£78	2·5 cwt. B_2O_3 27 lb. Monuron	£78	—	—	
Sodium Chlorate	3 cwt. $NaClO_3$	£15	—	—	2 cwt. $NaClO_3$	£10	
Borate/Chlorate	4 cwt. B_2O_3 2 cwt. $NaClO_3$	£48	—	—	—	—	Excludes Calcareous soil.
Simazine ..	10 lb. Simazine	£30	20 lb. Simazine	£60	5 lb. Simazine	£15	
Sodium Arsenite	3 cwt. As_2O_3	£40	—	—			Sand only.

Thus at the rates found necessary for weed control in firebreaks, the cost of herbicides is quite high, costs of initial control ranging from £15-£80 per acre for one-year persistence, and £60-£80 per acre for two-year persistence. Thereafter it seems likely that fireproof conditions can be maintained for about £15 per acre.

In practice it is probable that maintenance cost could be reduced by localised "spot" treatment of regenerating weeds with the non-selective herbicide, using a selective herbicide on patches of resistant weeds such as woody species, bracken or certain rhizomatous perennial grasses. Discriminate use of selective material such as 4-CPA for bracken, 2,4-D/2,4,5-T mixtures for broadleaved and woody species and dalapon for persistent grasses could assist greatly in cheapening maintenance.

On a cost/efficiency basis the choice of non-selective herbicides would fall on one or more of chlorate, simazine, borate or monuron. Sodium chlorate remains the cheapest non-persistent general herbicide. However, it cannot be considered for control of established vegetation in firebreaks, unless mixed with a fire depressant which would bring the cost above £30 per acre, i.e. the same order of cost as the persistent herbicides. Borate was effective and relatively cheap, but like chlorate, it is sufficiently soluble to constitute a risk of damage to the roots of plantations which frequently adjoin firebreak areas. It also has the possible disadvantage that short grasses figure prominently among re-colonising species.

On the whole, the most satisfactory results were obtained with monuron or simazine, the indicated treatments being monuron at 20 lb. (active) per acre + annual maintenance treatments of 10 lb. per acre, or simazine at 10 lb. (active) per acre plus 5 lb. per acre maintenance treatment. For control of germinating annual weeds on bare land these rates could be reduced to one half. There is little to choose between these herbicides in cost, i.e. £30-£40 per acre formation and £15-£20 per acre maintenance costs. Advance cultivation is not essential with these compounds, although this is preferable for a reduced fire hazard and assistance in weed suppression. Both compounds have the advantage of low solubility, especially simazine, which can be applied with safety close to the edges of plantations and cultivated land without fear of lateral creep and crop injury.

It is apparent from the effects and cost figures given that herbicides must be considerably more expensive than mechanical methods of firebreak preparation and maintenance and they can only be of major practical importance on sites, such as steep or rocky ground, where machinery cannot be used. Also in other situations where there are difficulties in mechanical weed control, such as fence lines, roads, paths, and verges, especially in nurseries and building surrounds, some of the herbicides described can be of considerable practical value.

Summary

During 1956-9, experiments were carried out on a range of soil types to test the practical and economic aspects of using herbicides in the establishment and maintenance of efficient, non-inflammable firebreaks. Nine substances were applied, at 3 different rates, with and without prior cultivation.

It was concluded that:

(1) Weed-free firebreaks can be obtained using herbicides without much difficulty on non-calcareous soils; the most effective compounds being monuron, simazine and the borates.

(2) Many treatments failed to produce bare soil conditions, but resulted in a vegetative cover which was reasonably fireproof due to its succulence, stature, or the absence of inflammable debris.

(3) On calcareous soils, arsenites, chlorates, borates and trichloracetates of sodium showed much reduced toxicities.

(4) Efficient ploughing alone is capable of burying and killing much of the surface vegetation found on firebreaks. However, these studies show that if rhizomatous species such as *Holcus mollis*, *Pteridium aquilinum*, *Juncus acutiflorus* or *Pulicaria dysenterica*, are present in any quantity they soon recover.

(5) Herbicides are likely to be more costly than mechanical cultivation and mowing for formation and maintenance of firebreaks. However, they certainly have a place where ground conditions will not permit the use of mechanical methods. Thus for vegetation control on steep ground, banks, verges, paths, roads, etc. monuron or simazine deserve more extensive practical trial in conjunction where necessary with selective herbicides such as 4-CPA, 2,4,5-T or dalapon.

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THE DRAINAGE OF A HEAVY CLAY SITE

By D. F. FOURT

Introduction

The improvement of heavy clay sites by drainage has been the subject of much conjecture by foresters, and there is seldom any rational basis for the depth or spacing of drains adopted in practice. A trial of a range of drainage treatments was laid down in 1955 at Waterperry Wood, Oxfordshire, to throw some light on this question (Miller 1955). The plots were split for a variety of species, and assessments after 5 years show a mean height of 2 ft. 6 in. for oak on the most intensively drained plots, compared with 1 ft. 6 in. on the controls. The assessments will continue over many years to come, and should eventually provide a practical evaluation of treatment effects on the development of the

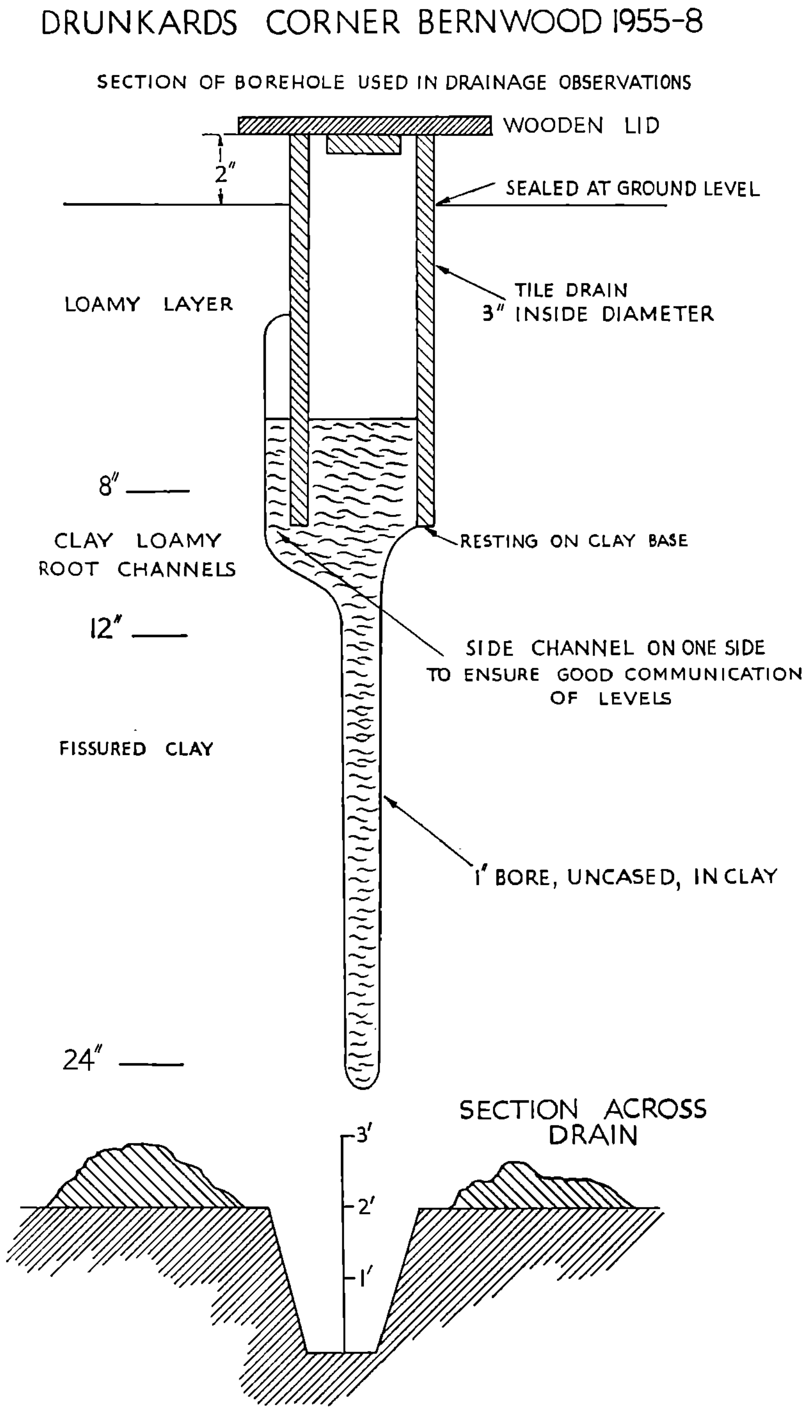

FIG. 7. Section of Borehole used in Drainage Observations at Drunkards Corner, Bernwood Forest, 1955-58. A section across a drain is shown below.

stand; however, owing to the long-term nature of such trials, an attempt has been made to study the direct effect of the treatments on the water regime of the plots by means of boreholes and observations on the profile. The present paper describes these studies and some preliminary results of the use of fluorescein to trace water movements in the soil.

The Site

The experimental site is at Drunkard's Corner, Waterperry Wood, part of Bernwood Forest, Oxfordshire, on a broad outcrop of Oxford clay to the east of Stanton St. John. It is fairly typical of extensive areas of heavy clay soils derived from clay deposits of Jurassic and Cretaceous age, such as the Lias, Kimmeridge and Gault. The area slopes very gently ($1\frac{1}{2}°$) S.S.E., lies between 200 and 230 ft. above sea level in a region of low relief and is subject to seasonal waterlogging.

The woodland was cut over about the years 1914-1918, and dense regrowth of birch, aspen, hazel and thorn, mainly of coppice origin, reclothed the ground. Most of the experimental area was cleared in 1953, the experiment laid out and the drains (Figure 7) cut the following year, and planting carried out in 1955. Four-acre plots of each drainage treatment and control are replicated three times in randomized blocks (Figure 8). The treatments are:—

(A) Control. (No new drains except surround).
(B) Drains 1 chain apart (24 in. depth).
(C) Drains $\frac{1}{3}$ chain apart (24 in. depth).

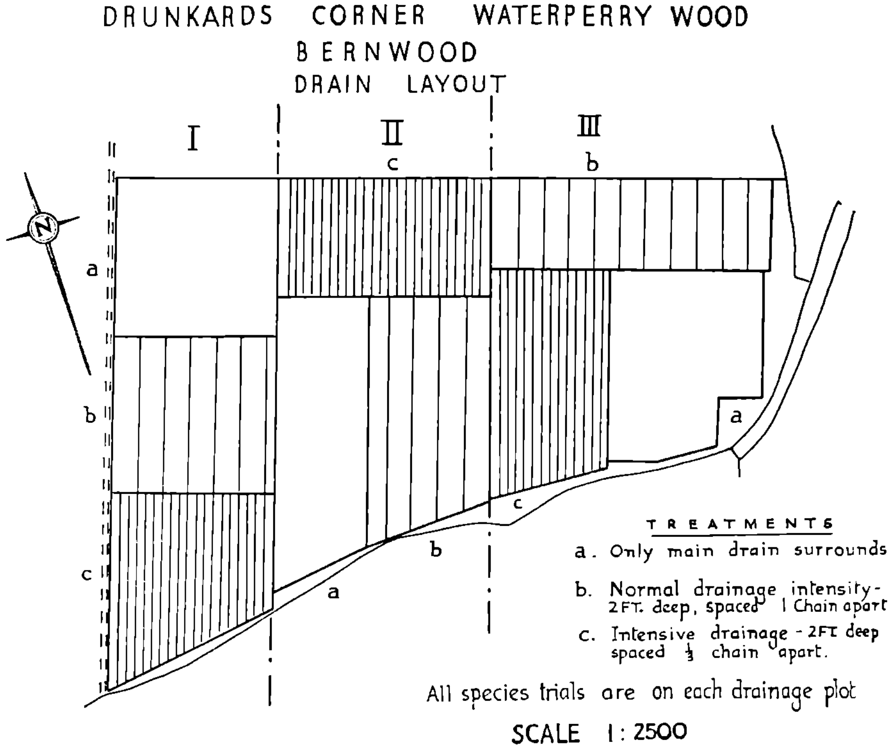

FIG. 8. Drain Layout at Drunkards Corner, Waterperry Wood, Bernwood Forest.

Land to the north-east of the plots, which has neither been drained nor had the forest cover removed, was used in this study to obtain comparative data. The whole area is intersected by an irregular pattern of old drains at average intervals of one chain, possibly cut about 100 years ago, and now nearly filled up. These may seldom be seen to carry water, but the porous structure of the surface soil descends to a greater depth in the old drain lines and allows some conduction below the surface. The control plots may be regarded as a drainage treatment of lower intensity than the grade B; the total length of old drain traces per plot is similar to that of the new drains at 1-chain spacing. There are also boundary drains which affect the control plots to a greater or lesser extent, according to their shape (Figure 8).

The Soil Profile

The essential features of the soil profile have been observed throughout the seasons. The following is a slightly generalised profile description, as small variations in the depth and texture of the upper layers are encountered. Some seasonal changes in structure and colour may also occur.

Inches	*Description*	*Clay %*	*pH*
0-1	Black-brown loam. Mull. Well rooted. Crumbly.	Not determined	6·0
1-6	Dull grey-brown loam/clay loam. Well rooted, fine blocky.	28	5·2
6-12	Grey and brown mottled clay loam. Coarse blocky to prismatic.	32	6·1
12-18	Grey-brown and orange-yellow mottled. Manganese nodules at base. Prismatic structure, polished interfaces.	50	6·5
18-30	Dull green and grey-brown mottle, rather plastic clay. *Gryphea* shells. Secondary calcium carbonate. Some columnar fissures.	54	8·8
30+	Grey-green clay. *Gryphea* shells. Occasional secondary calcium carbonate. Massive, dryer. Occasional fissures widely spaced (1 ft.-3 ft. apart) often oblique.	54	8·8

It must be stressed that the upper 6-8 inches of the profile is highly porous, even when waterlogged, due to the very well developed structure; below this and down to about 12 inches the porosity is much lower, water movement taking place in old root channels and fissures. Below about 12 inches the fissures are more or less vertical, dividing the clay into prisms. These fissures are readily seen when they open in dry seasons, but are inconspicuous under wet conditions; as the clay swells they close tightly and prevent further water movement. The fissures are less well marked below 18 inches and probably represent the shrinkage of the clay at an exceptional depth in unusually dry years, assisted by the transpiration of the former forest cover. Below 30 inches, fissures are virtually absent, the clay is more massive, firmer and apparently dryer. Free water never appeared at the face of the pit below 30 inches, and it is believed that water movement is entirely negligible at this depth. Indeed in the winter of 1957-8 several deep holes were dug in the bottom of the drains after obstructing flow from above, and no water seeped into these holes during the few dry days which followed. It is, therefore, assumed that no deep vertical percolation can take place; all the rainfall is either transpired, evaporated, runs off, or stored in the profile.

The Layout and Construction of the Boreholes

The construction of the boreholes used to indicate the soil water level is shown in Figure 7 above. The upper part of the bore was cut with a post-hole borer and the lower part with a 1 inch soil auger to a total depth of 24 inches. (This depth is the same as the drains). The bypass was designed to insure free communication with the soil in the upper part, despite the use of a tile drain liner. The liner supports the soil near the surface and was sealed with clay, as indicated, and fitted with a lid to prevent surface accession, and to exclude animals and leaves. As shown in the figure, the bore is reduced to 1 inch diameter in the lower part to minimise reservoir effects.

Such boreholes have often been used to assess the effect of treatments in drainage experiments. Provided that the presence of artesian water can be ruled out, as is evident on our site from consideration of the profile, the lined borehole or piezometer (Marshall 1959) is actually at a disadvantage compared with an unlined borehole; a series of piezometer tubes sunk to a range of depths would be required at each point, and tests showed that there was considerably greater practical difficulty in setting up the latter without bringing about permanent damage to the soil structure, resulting in sealing of the fissures at the bottom of the bore.

An important limitation of the usefulness of lined or unlined boreholes arises from the time taken for the equilibrium to be established between the water in the soil and the bore, where the soil is nearly impervious (Diebold, 1938). In this investigation it cannot be seriously doubted that the soil was waterlogged below the level indicated by the borehole, while this is within 13 inches of the surface, as the level was restored, on every occasion, within a few minutes after removing some of the water from the borehole. However, below this depth the indication may require some care in interpretation, especially during January, February and March, when the fissures were tightly closed. Below about 19 inches this is particularly important, and the absence of water near the bottom of the bores means that drainage of water from the profile has probably ceased; little can be inferred from the presence of water, when the fissures are closed, as very slow drainage may, or may not, be taking place.

In November, 1954, a preliminary series of boreholes was established in one of the three replications of the experimental plots. In the drained plots there were three transects between drains, each with a borehole at ¼, ½ and ¾ of the *land width* (that is, the width between the drains); on the control the lines were at right angles to the old drains in groups of 5, 4 and 4. After examination of the twelve months data from these boreholes, it was decided to lay out a comprehensive series in all the plots, in the hope that treatment effects could be established on a statistical basis. Accordingly, in January 1956, six new boreholes were made in each of the nine plots. The points selected were all on the midline between drains (or imaginary lines in the control plots), randomized within six sections to ensure a fairly even distribution. Buffer strips at the top and bottom of the plots were excluded.

An additional series of seven boreholes were set up in the uncleared woodland to the north-east of the experiment.

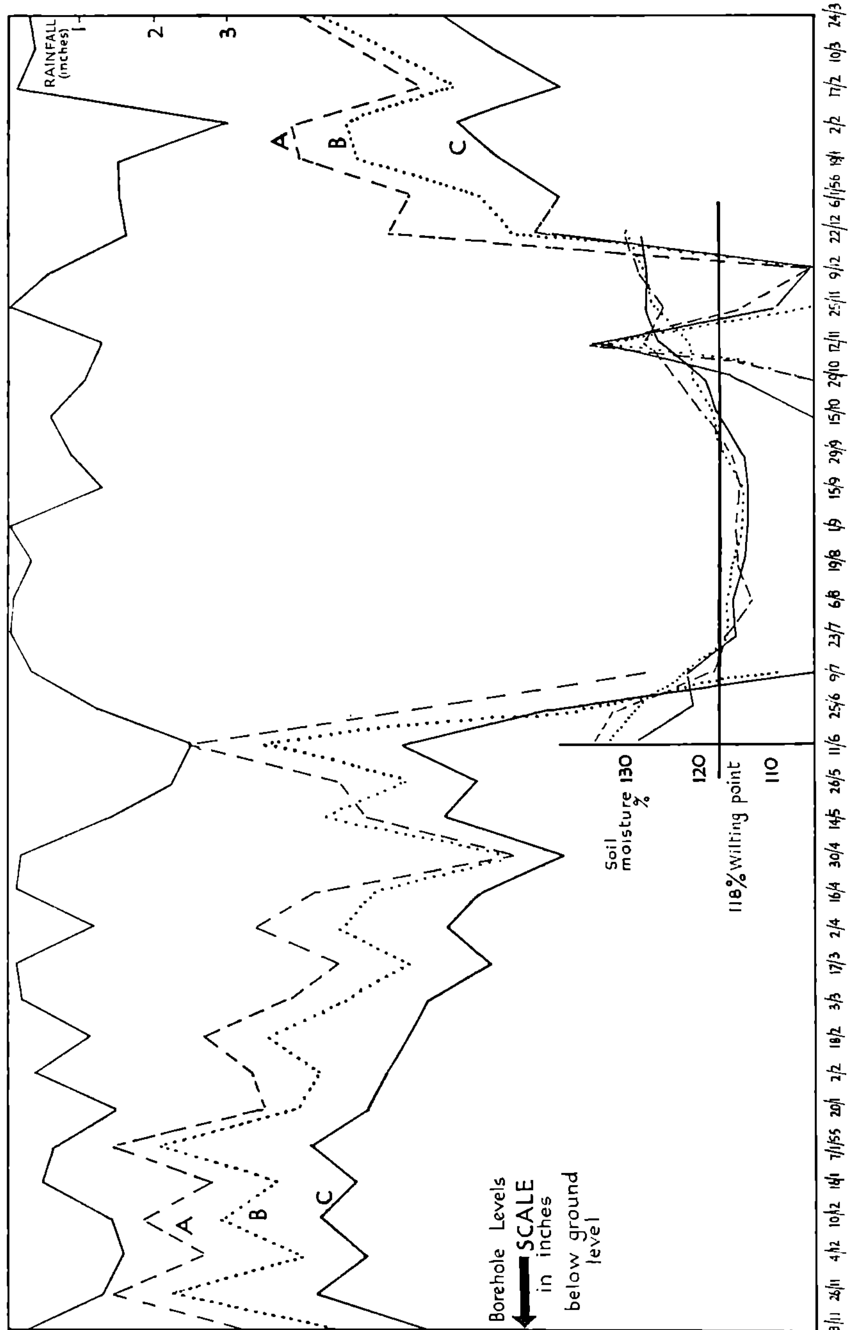

FIG. 9. Drunkard's Corner, Bernwood, 1954-6. Graph showing levels of standing water (left-hand scale) as reflected in boreholes from 18.11.54 to 24.3.56; readings taken at 14-16 day intervals. Rainfall from standard-type gauge at Kennington Nursery, Oxford, taken since last reading. Soil moisture content (central scale) as mean of 6 random samples, oven dried at 105°C, and calculated as Fresh weight per 100 gms. of oven dry soil.

KEY

- - - - - Treatment A. No new drains, except surrounds.

. . . . Treatment B. Drains at 1 chain (22 ft.) spacing, 2 ft. deep.

———— Treatment C. Drains at one-third chain (7·33 ft.), spacing 2 ft. deep.

The top curve, unlettered, shows rainfall, on right hand scale.

Results

The water levels in the preliminary series of boreholes were recorded at 14-16 day intervals for the first year. The holes at $\frac{1}{4}$ and $\frac{3}{4}$ land-width did not give any indication of "doming" of the water level between drains, but there were large random differences between holes which may have masked the characteristic shape of the water surface; supplementary sets of holes in each treatment, at closer intervals than the basic layout, were therefore added. These formed transects across the lands and were read on several occasions in the winter of 1957/8. The readings showed that in each treatment the water level at distances greater than 2 or 3 feet from the drain is virtually independent of the distance, as others have found on clay soils (Taylor and Goins 1957). Hence, the mean heights of the water in the wells may be taken to represent the conditions in each plot. (Figure 9 and Table 31.) The rainfall data are from a gauge at Kennington, $6\frac{3}{4}$ miles to the south-west.

Some soil-moisture records, based on six samples from each treatment and expressed as fresh weight per 100 gms. oven dry matter, are also given. The differences between the moisture contents in the intensive (C) treatment and control are significant at the 5 per cent level on the first two dates only.

Some wilting-point determinations were carried out to illustrate the physiological significance of these soil moisture levels. A large mixed sample of soil from the 2 to 6 inch layer was used to fill ten containers; following the practice of Briggs and Shantz (1912) sunflowers were selected as the test plant, and a mean value of 118 per cent was found for the permanent wilting point. The 2 to 6 inch layer was drier than this over much of the summer (Figure 9) and so played little or no part in supplying water to the crop.

Mean water levels for 1956 and 1957 are shown in Figure 10 (a + b) and Table 32; in this case the data is based on the comprehensive layout of boreholes set out after the first year. The levels for the uncleared area are also known. For several periods during the winter 1957-8, daily readings were taken after spells of heavy rain and an example of these results is given (Figure 9 and Table 33). At the 6th reading after five clear days, the borehole levels in the drained plots were down to 13 to 17 inches, corresponding to much less freely porous zones of the soil profile. Below this region the level in the bore could not be relied upon to follow the water in the soil, without considerable time lag. The water was, therefore, removed from the boreholes after the reading on the fifth and subsequent days.

The levels assumed in about half the bores continued the general trend, while the others collected very little water in 24 hrs., and these are believed to be in less effective communication with the fissure system. The dotted part of the curve is plotted from the mean levels after excluding the latter boreholes.

A delayed response of the borehole to the falling water level in the soil might give spuriously high readings up to the fifth day; thereafter as water was removed from the bores after taking the reading, errors due to a delay or lag effect would tend to give too low readings. As there is no marked break in the curve on the fifth day, errors due to lag may be neglected in the interpretation of these results.

These observations suggested that the drainage treatments had increased the depth of the permeable surface layers, and some further investigations were attempted to provide direct evidence on this point. When the water level in the control plots was at 6 to 8 inches from the surface, pairs of holes 10 inches deep and three feet apart were opened in a level, stump-free area. The water level in these pits was quickly established, and the level was raised 2 to 4 inches by pouring a fluorescein solution into one of each pair of holes. Fluorescein appeared in the other pit within 4 to 6 mins. A few weeks later when the water level was down to 12 inches, pairs of holes were again dug, this time to 18 inches depth. One was filled to 12 inches with fluorescein solution, and the other left empty. During several daily visits there was little fall of level in the dye-filled hole, and only a very little undyed water appeared in the empty hole. This indicated an abrupt change in lateral conductivity, from very freely conducting at 8 inches to virtually *nil* at and below 12 inches, at this time of year.

Tests with fluorescein solution, in both the drained plots, showed that movement of water could take place below 12 inches, presumably in the fissure

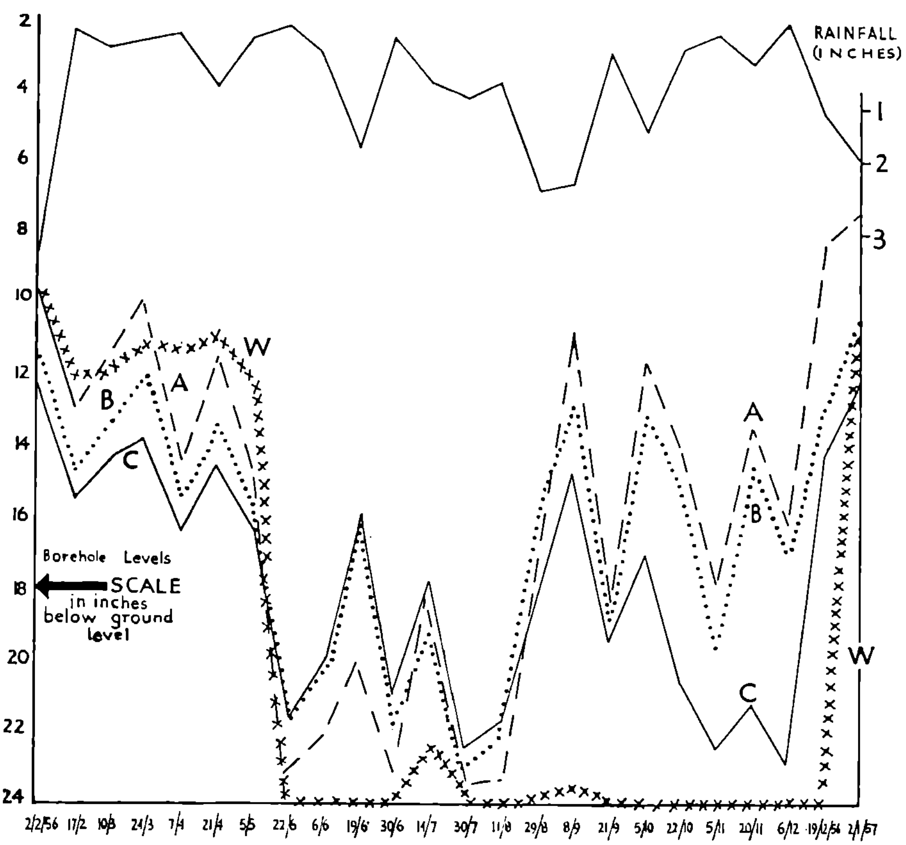

FIG. 10(a). Drunkard's Corner, Bernwood, 1956-7. Graph showing levels of standing water as reflected in boreholes (left-hand scale) from 2.2.56 to 6.12.57, readings taken at 14-16 day intervals. Rainfall (right-hand scale) from standard-type gauge at Kennington Nursery, Oxford, since last reading. (See 10(b) for key.) N.B. Figure continues on facing page.

system. The level dropped within a couple of days where holes were filled with the dye to the 12 inch level; moreover, the dye sometimes appeared in the drains, proving that the possible imbibition of water by the clay does not wholly account for the fall in level. Finally it was found by this technique that the surface layer buried beneath the spoil banks at either side of the drain had still retained its porous structure after about three years.

Discussion

It may be inferred from the profile description that deep vertical movement of water is impossible on the site, due to the nature of the clay subsoil; it is also clear that the uppermost 8 to 12 inches are very porous, and provide a route for lateral drainage. Though this might be held to be self-evident, the experiments with fluorescein provide a striking demonstration of these features of the profile. Superficial inspection of the borehole data indicates that closer spacing of the drains, than at one chain intervals, is required to produce a marked improvement compared with the controls. The main reason for this is the fact that the major fraction of the water movement is

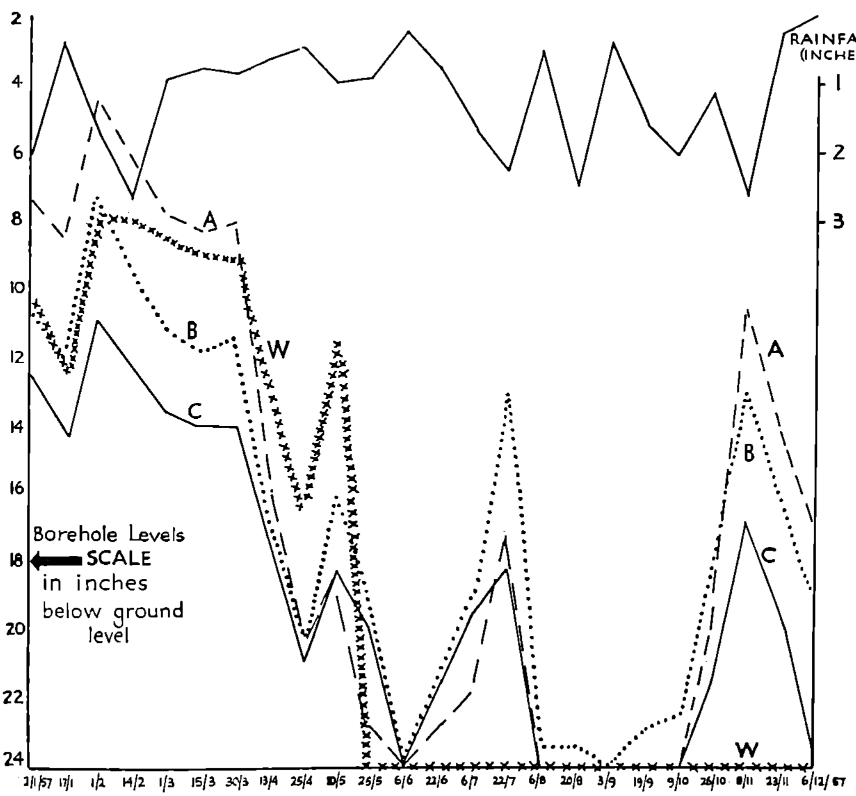

FIG. 10b

KEY

– – – – –	Treatment A. No new drains except surround.	Mean of 18 holes at random points on grid
. . . .	Treatment B. Drains at 1 chain (22 ft.) spacing 2 ft. deep	
————	Treatment C. Drains at one-third chain (7·33 ft.) spacing 2 ft. deep	
x x x x x	Adjacent woodland, undrained, mean of 7 holes in line.	

The top curve, unlettered, shows rainfall on right-hand scale.

restricted to the uppermost 12 inches, with increasing resistance below 8 inches. The observation that the camber of the water levels in the soil between the drains is very flat to within a few feet of the drains, is a natural consequence of the profile characteristics, and its recognition has an important practical application. Since the water-level gradient only extends a very short distance from the drains (unlike under some other soil conditions), the power of the drains to attract water may be regarded as negligible; the water flows mainly parallel to the surface down the slope of the ground at right angles to the contours. Hence the effective drain spacing must be measured in this direction, and drains making as small an angle as possible to the contour, will be most economical and efficient.

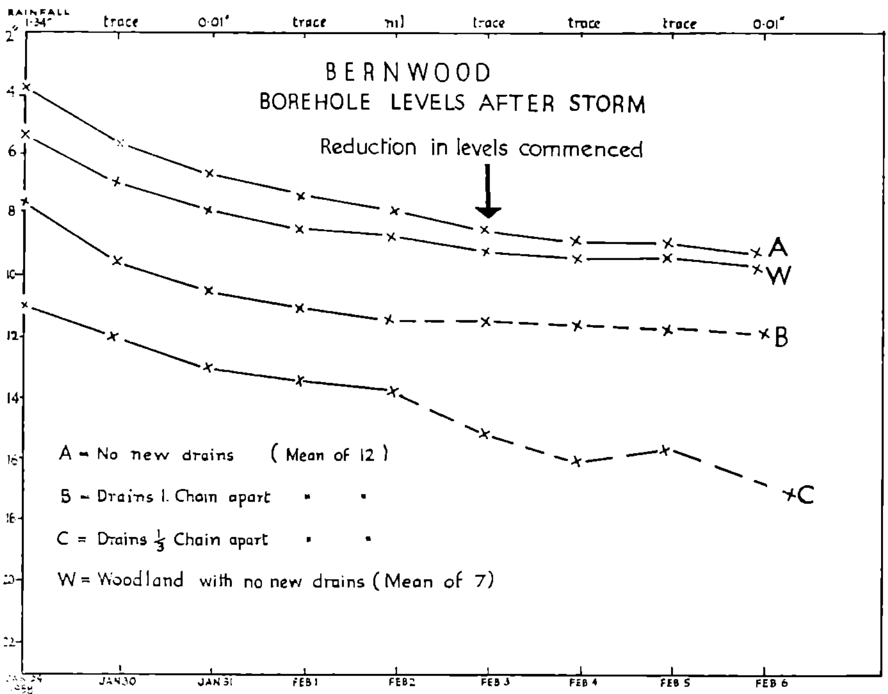

FIG. 11. Bernwood: Borehole levels after a storm. The vertical scale shows inches below ground level.

Further information on the question of drain spacing is given by the daily series of readings after wet spells, of which an example is given (Figure 11). With one-third chain intervals (curve C) the water clears the upper 12 inches in about 2 days, requires 4½ to 5 days with 1-chain spacing (curve B) and is falling below 9 inches very slowly after 9 days in the controls (curves A and W). Childs (1943) mentions 3 to 4 days to remove "surface water" as a desirable attribute of an agricultural drainage system. Little is known about the length of time for which tree roots will tolerate waterlogging, but there can be no doubt that there are complex relations with the rate of exhaustion of dissolved oxygen and the accumulation of possible toxic metabolic products of anaerobic soil micro-organisms. The structure of the surface layer of the undrained plots deteriorated soon after removal of the old crop; during winter it smells strongly of hydrogen sulphide, and there are colour changes suggesting strongly reducing conditions. In contrast the drained plots are friable at all times, with a strongly developed crumb structure and no indication of anaerobic conditions. The structure improvement accords well with Midgley's (1957) view that the most important factor causing structure development on heavy soils is the effect of frequent wetting and drying cycles on the clay colloids.

It is probable that qualitative differences of importance to the survival and efficient function of tree roots are associated with the contrasting soil structure, aeration and the microbiological complexes of the drained and relatively undrained plots; these differences may be much more important than a few inches difference in water level as such (Leyton and Yadav 1960). Nevertheless, if a small difference in winter water level only brought about a similar increase in the depth rooted, it would be significant in the summer when the top 2 to 6 inches of the profile becomes very dry, and is often below the wilting point (Figure 9).

Since trees are potentially able to exploit a much greater depth of soil than 12 inches, any improvement below this level is of the greatest interest. During the very dry summer of 1955, the boreholes remained empty until mid-September, and were again empty in December. The levels in late September, in the region of 17 to 25 inches, do not show marked treatment effects, but there is a tendency for the treatment order to be reversed. Marked reversal of the levels occurred in the early part of the following summer, and again to some extent in 1957. Some of these summer reversals are statistically significant, but they are not easy to interpret. Possibly, the drained profiles retain a greater volume of water at field capacity as a result of their better structure, and are slower to dry out. However, there is clear evidence in the succeeding periods, namely August-December 1956, and October-December 1957, that the normal treatment effects extend to the lower parts of the profile, below 17 inches at that time of year. Later in the season, after the level in the controls had been right up to 6 to 8 inches of the surface, and descended again to 12 inches, the use of fluorescein solution showed there was movement of water below 12 inches in the intensively drained treatment, but not in the controls. It is probable that the fissures open to a considerable depth in all the plots during the summer; as the water rises in the winter the fissures slowly close from the base upwards, behind the rising water. However, clay is very slow to resume its maximum volume even when under water; Emerson (1955) suggests that the process takes several months. As a result the fissures do not have time to close, in the drained treatment, to within 12 inches of the surface. During part of the year the lower levels due to drainage in the 17 to 24 inch region may be held, in part at least, to condition the treatment differences under the critical conditions from January to March. The depth to which it is desirable to cut drains on comparable sites should consequently be much greater than the depth of the crumb-structured surface layer, which is able to conduct water at all seasons; the depth of 24 inches seems fully justified at Bernwood. The borehole levels in the adjoining undrained woodland show that the transpiration of forest cover is a factor of major importance in delaying the onset of winter waterlogging (Figure 11). The transpiration draught of the coppice regrowth, which is the main woody component of the vegetation of the experimental plots, is also important.

This is evident from the sudden fall in borehole levels in the plots, during and after the time of flushing, even though rainfall may be considerable during this period. One would expect a rather greater effect on a drained area, due to greater depth of rooting. There is, therefore every reason to expect a progressive reduction in winter water levels as the new crop develops, and the effects due to deep and intensive drainage may well be greatly enhanced. It is tempting to suggest that a forest species selected for resistance to the ill effects of waterlogged conditions might give good results as a nurse in the establishment of economic crops on such areas, especially in the absence of coppice regrowth of a previous hardwood stand. Deterioration of soil structure in the undrained plots after removal of the old crop is marked; the current practice of the establishment of new crops under the cover of the old, both in the rehabilitation of such areas and their future management, seems justified on these grounds, irrespective of any other advantages.

Summary

The response of water levels in two types of borehole layouts to three drainage intensites, on a heavy clay soil recently cleared of derelict woodland, has been recorded. During periods of wet weather, especially in winter and early spring, the drainage treatments usually showed that these effects were significant at either the 1 per cent or 5 per cent level. Inversion of the winter order of the water levels took place occasionally in the summer, sometimes reaching significance, suggesting greater moisture availability on the treated plots. Daily readings after heavy falls of rain in winter show that the drained plots have 2 and 4½ days waterlogging (above the 12 inch level) for ⅓rd-chain and 1-chain spacing of drains respectively, compared with more than 10 days on the control. The comparison of the boreholes in the woodland with those in the cleared area implies greater water loss from the former with marked delay of the onset of winter waterlogging. It was shown, by using fluorescein as a tracer, that deeper movement of water takes place in the drained plots, at a time when lateral movement has ceased below 12 inches in the control. Drain spacing and depth are discussed and it is concluded that intensive and deep drains are necessary on heavy clay sites; there are indications that progressive improvement in soil conditions as the crop develops will result from this treatment.

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Table 31

Drunkards corner, Bernwood: 1954-6

Readings of water-levels, in inches below the surface, at 14-16 day intervals, in the Transect layout of boreholes in Block I. Rainfall data from a standard type raingauge at Kennington Nursery, Oxford, in inches. Soil moisture contents in samples from 2-6 inches, expressed as fresh weight per cent of oven dry weight.

Borehole data as average of 9 readings. Moisture as average of 6 determinations.

Date of Reading	Drainage Treatments			Rainfall		Soil moisture (Date 7 days after Water Level)		
	Control A	1 chain apart B	½ chain apart C	14 days previous	2 days previous	Control A	1 chain apart B	½ chain apart C
18.11.1954	8·27	11·00	13·28	0·35	0·08			
26.11	4·60	6·66	10·28	1·32	0·59			
4.12	7·46	9·94	11·77	1·58	0·07			
10.12	5·50	7·83	10·50	1·41	1·18			
16.12	7·70	9·40	11·50	0·48	0·04			
7.1.1955	4·65	6·11	10·39	0·66	0·23			
20.1	9·00	9·88	11·83	1·49	—			
2.2	8·65	10·50	12·39	0·33	0·01			
18.2	7·15	9·17	13·00	1·01	0·16			
3.3	9·65	11·22	13·44	0·16	—			
17.3	11·07	12·88	15·17	0·09	—			
2.4	8·73	11·06	14·06	1·18	—			
16.4	10·45	12·17	14·94	0·64	—			
30.4	15·88	16·17	17·22	0·16	0·12			
14.5	11·62	10·66	13·93	1·31	0·35			
26.5	11·04	13·00	14·88	2·25	—			
11.6	7·04	9·00	12·77	2·55	0·04	135·4	133·6	129·0
25.6	14·46	17·33	16·72	1·22	0·20	132·6	128·9	121·8
9.7	19·75	23·11	24·50	0·23	—	119·1	122·2	122·4
23.7	—	—	—	—	—	117·2	116·9	116·5
6.8	—	—	—	0·15	—	113·8	166·9	115·7
19.8	—	—	—	0·29	0·12	115·3	115·8	114·7
1.9	—	—	—	—	—	115·6	114·8	113·8
15.9	—	—	—	1·33	0·43	115·1	114·8	114·2
29.9	—	—	—	0·83	—	116·6	118·0	115·3
15.10	—	—	—	0·59	—	118·6	117·4	118·2
29.10	—	—	21·78	1·10	—	124·4	122·1	119·3
12.11	17·92	17·77	18·22	1·33	0·06	129·7	122·5	127·1
25.11	20·95	25·00	23·03	—	—	126·0	127·6	127·7
9.12	—	—	—	0·60	—	129·7	128·2	127·2
22.12	12·32	15·61	16·33	1·67	0·20	131·0	131·6	128·6
6.1.1956	13·0	14·8	17·05	1·52	—			
19.1	9·9	11·5	15·3	1·08	0·02			
2.2	9·7	11·2	14·2	3·02	0·92			
17.2	13·3	14·4	17·1	0·16	—			
10.3	11·4	12·3	15·2	0·42	—			
24.3	9·2	9·7	13·7	0·32	0·22			

Table 32

Drunkards Corner, Bernwood 1956-57

Date	Readings of Water Levels in Boreholes: Treatment: No. New Drains A	Drains at 1 ch. Spacing B	Drains at ½ ch. Spacing C	Standard Error	Exptl. Contrast	Blocks X Treatment Interaction	Woodland Undrained W	Rainfall: Previous 2 days	Since Last Reading
2.2.56	9·39	11·54	12·11	·893	—	X	9·57	0·92	3·02
17.2.56	13·09	14·54	15·64	·473	X	—	12·1	—	·16
10.3.56	11·51	13·32	14·39	·596	—	—	11·8	—	·42
24.3.56	9·73	11·91	13·72	·560	X	—	11·1	·22	·32
7.4.56	14·62 (2)	15·63 (1)	16·60 (0)	·448	X	—	11·43	·09	·24
21.4.56	11·45	13·54	14·69	·651	—	—	10·8	—	1·05
5.5.56	15·12	15·79	16·58	·420	—	—	12·3	—	·35
22.5.56	23·48 (14)	21·77 (9)	21·61 (8)	·557	—	—	24·1 (6)	—	·14
6.6.56	22·25 (11)	20·16 (5)	19·92 (6)	·708	—	—	25·0 (7)	—	·53
19.6.56	19·81 (7)	16·21 (3)	15·83 (5)	·829	—	—	24·4 (6)	—	1·90
30.6.56	23·42 (14)	21·92 (10)	21·25 (7)	·491	—	—	25·0 (7)	·11	·23
14.7.56	17·94 (6)	19·11 (4)	17·64 (2)	1·207	—	—	22·4 (4)	—	·90
30.7.56	23·42 (14)	23·00 (12)	22·69 (11)	·889	—	—	25·0 (7)	·35	1·12
11.8.56	23·31 (14)	22·39 (11)	21·58 (10)	·113	—	—	25·0 (7)	·06	·88
28.8.56	18·36 (7)	16·56 (1)	18·75 (4)	2·232	—	X	24·0 (6)	·65	2·49
8.9.56	9·89	11·82	14·83	·823	X	—	23·6 (6)	·45	2·83
21.9.56	18·50	19·62	20·45	·928	—	—	24·14 (6)	—	·30
5.10.56	11·33	12·92	17·03	·588	XX	—	24·71 (6)	·10	1·79
22.10.56	13·83 (1)	15·44 (0)	20·47 (2)	·620	XX	—	25·14 (7)	—	·48
5.11.56	18·10 (1)	19·58 (0)	22·98 (8)	·808	X	—	25·14 (7)	—	·26
20.11.56	13·25 (1)	14·28 (0)	21·25 (6)	·902	XX	—	25·21 (7)	—	·63
6.12.56	16·31 (1)	17·36 (0)	22·92 (8)	·832	XX	—	25·21 (7)	—	·07
19.12.56	8·36	11·72	14·39	·934	X	—	24·5 (6)	·02	1·49
2.1.57	7·27	10·00	12·31	·706	X	X	9·86	·47	2·10
17.1.57	8·53	11·75	14·94	·939	X	—	12·29	·12	·34
1.2.57	4·39	7·22	10·83	·982	X	—	7·64	·58	1·79
14.2.57	6·11	9·58	12·28	·716	XX	—	7·93	·10	2·72
1.3.57	7·81	11·25	13·50	·642	XX	—	9·64	—	·89
15.3.57	8·39	11·78	13·92	·647	XX	—	10·07	—	·79
30.3.57	8·14	11·42	14·00	·733	X	—	10·29	—	·80
13.4.57	15·36	16·86	17·78	·582	—	—	12·43	·06	·06
25.4.57	20·25	20·11	21·33	·429	—	—	16·64	—	·49
10.5.57	18·10 (2)	16·00 (1)	18·25 (0)	·865	—	—	11·79	·94	·96
25.5.57	22·44 (7)	19·17 (1)	20·17 (2)	·599	X	—	25·07 (6)	·03	·90
6.6.57	25·64 (14)	24·31 (11)	24·58 (10)	·597	—	—	26·21 (7)	·15	·25
22.6.57	23·06 (9)	21·11 (1)	21·78 (1)	·625	—	—	26·21 (7)	—	·76
6.7.57	21·86 (5)	19·03 (0)	19·53 (0)	·780	—	—	26·21 (7)	·03	1·64
22.7.57	17·19 (3)	13·19 (0)	18·08 (1)	·879	X	—	26·21 (7)	·10	2·31
6.8.57	25·36 (14)	23·42 (6)	25·17 (12)	·628	—	—	26·21 (7)	—	·46
20.8.57	25·36 (14)	23·39 (9)	25·14 (11)	·720	—	—	26·21 (7)	—	2·59
3.9.57	26·69 (18)	26·83 (18)	26·56 (16)	·277	—	—	26·21 (7)	·02	·37
19.9.57	24·36 (12)	22·89 (6)	24·47 (11)	·780	—	—	26·21 (7)	—	1·57
9.10.57	24·03 (11)	22·47 (5)	24·58 (11)	·972	—	—	26·21 (7)	—	2·13
26.10.57	19·47 (5)	18·67 (1)	21·64 (5)	1·400	—	—	26·21 (7)	—	1·16
8.11.57	10·56	12·94	16·69	·572	XX	—	26·21 (7)	—	2·72
23.11.57	14·31 (2)	16·17 (0)	21·08 (4)	·754	XX	—	26·21 (7)	·12	·20
6.12.57	17·06 (2)	19·33 (1)	23·58 (8)	·818	X	—	N.D.	·02	·02

Notes: In columns A, B and C, average water levels are shown for the boreholes in the Random series, measured in inches below the soil surface, at 14-16 day intervals. This data has been subjected to analysis of variance, the results of which are shown. A single "X" denotes significance at the 5 per cent level, while "XX" denotes significance at 1 per cent.

The figures in brackets under columns A, B, C and W denote the number of holes which were dry when readings were taken. In A, B, and C the maximum possible is 18, while in W, it is 7. The rainfall data was obtained from Kennington Nursery, Oxford, where a standard type rain gauge is installed and read daily.

When considering these results, it should be borne in mind that due to the random layout, the "control plots with no new drains" inevitably include some holes which are sufficiently near to old but functioning drains to enjoy a water-level regime comparable to that on the more intensive treatments.

Thus, the range of readings is found to be rather wide on the "A" plots, and is progressively reduced on the treatments with the increase in drain intensity. The effect of this on a layout offering only four degrees of freedom is to inflate the differences needed for significance, and but for the drains on the control plots, it is believed that significance would have been attained on many more occasions.

Table 33

Drunkards Corner, Bernwood: 1958

Borehole water-levels after heavy fall of rain, in inches below the surface.

Treatment	Jan. 29	Jan. 30	Jan. 31	Feb. 1	Feb. 2	Feb. 3	Feb. 4	Feb. 5	Feb. 6	Notes
No new drains A	3·87	5·59	6·67	7·30	7·79	8·50	8·83	8·84	9·21	
Drains at 1 ch. spacing B	7·63	9·50	10·46	10·96	11·42	11·3* 18·1	11·5* 19·8	11·6* 20·1	11·9* 20·8	Random
Drains at ½ ch. spacing C	11·00	12·04	13·00	13·38	13·7	15·1* 23·5	16·0* 23·8	15·5* 23·6	17·0* 23·8	Series in all 2
Woodland undrained W	5·29	6·87	7·79	8·43	8·64	9·14	9·36	9·29	9·57	Blocks
No new drains A	3·61	5·42	6·52	7·03	7·60	8·21	8·36	8·33	8·86	Transect
Drains at 1 ch. spacing B	6·10	8·12	9·55	10·15	10·65	12·85	13·52	12·92	13·25	Series
Drain at ½ ch. spacing C	11·33	12·73	13·73	14·07	14·33	17·33	18·20	18·17	18·67	in Block I
Rainfall since last reading	1·34	trace	0·01	trace	nil	trace	trace	trace	0·01	Raingauge on Experimental site

Notes

*After reading the borehole levels on February 2nd, some water was removed in order to test their equilibrium with the environment. The data on Feb. 3rd and subsequently shows the effect of this, in that 6 of the 12 holes sampled in the C treatment fell very rapidly to generally low levels. The average of each of these groups of 6 is shown. In the B treatment 3 of the 12 holes also fell rapidly and here again averages have been shown separately.

In the transect series, no separation of responsive and unresponsive holes has been made.

EXPERIMENTAL INTRODUCTIONS OF ALTERNATIVE SPECIES INTO PIONEER CROPS ON POOR SITES

By G. G. STEWART

In the early days of large-scale afforestation of difficult sites such as the upland heaths and the wet peat moorlands, it was soon found that only a small number of species could be grown with any degree of success. Thus, on these limiting sites, large areas carrying only a few hardy species were gradually built up. It was thought that although the more tender species did not thrive as afforestation species on these sites, it might be possible to introduce them into the successful species when these pioneers were safely established. If this were possible, not only might useful species too tender to be raised on the open moor be grown, but parts at least of the large blocks of pure crops —the few species which had been found successful in afforestation—could be converted into mixed woods, if this were desired.

From 1928 to 1952, thirty experiments were carried out with the general object of finding methods of introducing various species into young conifer crops, mainly Scots pine and Norway and Sitka spruce, on poor sites; this paper summarises these experiments and their results. Brief reference is made to them by Zehetmayr, 1960.

Upland Heaths

Sites

Four-fifths of the experiments have been concerned with the upland heaths. Most of these have been on the North Yorkshire moors (at Allerston and Langdale Forests). Other experiments have been made at Teindland and Newtyle Forests, Moray; Inchnacardoch Forest, Inverness-shire; Clashindarroch Forest, Aberdeenshire; and Devilla Forest, Fife. The sites used, although of differing geological origin and fertility, were all peaty podzols dominated by strong *Calluna*, and most of the sites were classed as exposed.

Pioneer Crops

Scots pine, as the most widely planted species on the upland heaths, was not unnaturally the commonest pioneer crop chosen for the experiments. Lodgepole pine, another common species on the heaths, was also used frequently, and Corsican pine, Mountain pine, Japanese larch, birch, alder and broom occasionally. All the pioneer crops chosen were small in size, varying, for all species except Japanese larch, from about 3 to 11 feet in height, with a mean of 5 feet. The three Japanese larch crops used were taller, being about 15 feet in height. The crops were mainly very young (10 years was the average age) and all had grown slowly but not abnormally for the particular sites and methods of establishment used. About half the sites had been ploughed and about half had received phosphate at the time of planting.

Introductions

From the first experiment up to 1949, Sitka spruce was the main species introduced. Many attempts had been made to grow Sitka spruce on the heaths as an afforestation species, but they had not been very successful. By using a pioneer species as an advance crop it was hoped to establish this valuable tree. The other species most frequently used have been Douglas fir, *Abies grandis* and Western hemlock; of the broadleaved trees, beech and alders have been the commonest. Since 1950 Sitka spruce has not been used, and the tendency has been to try many more species than before, in other words to make species trials similar to those on the open moor to see if the pioneer crop helped in their establishment. In these more recent experiments Douglas fir, *Abies grandis* and hemlock have always been included among the large number of species used. Introductions, in all experiments except two, received phosphate at planting.

The opening of the pioneer crops was done in three different ways, and the introductions into the pioneer crops followed two systems. The methods of opening the pioneer crops were as follows:

(1) Removal of single trees (or retention of pioneer crop unthinned).

(2) Removal of one line of trees. In some experiments an unplanted lane had been left for the purpose of making later introductions.

(3) Removal of trees by heavy low thinning.

In the first method, the introductions were made in groups of up to three plants using different spacings. In the second method, the introductions were made into the vacant lanes. In the third case the introductions were made by both the group and line methods.

Description of Experiments

Removal of Single Trees (or Retention of Pioneer Crop Unthinned)

Eleven experiments, including the earliest trials, fall in this group. These latter were at Inchnacardoch Forest in 1928 (Exp. 65 and 67) and consisted of the introduction of Sitka spruce into Scots pine 2 to 5 feet tall and into Lodgepole pine 2 to 7 feet tall, both species being on *Calluna* sites. In the Scots pine, the spruce grew slowly and occasional trees came into canopy before the experiment was destroyed by fire. The spruce in the Lodgepole pine was quickly suppressed by the latter's fast growth.

No further introductions experiments were begun until 1938, when two trials were started at Allerston Forest, and one at Teindland Forest. The latter experiment (Teindland Exp. 4), consisted of planting a number of broadleaved species—beech, sycamore, ash, birch, Grey alder, Oregon alder, *Nothofagus obliqua*, and *Sorbus intermedia*—in 5 feet tall Lodgepole pine. Only the alders were successful, with Oregon alder up to 23 feet and Grey alder up to 15 feet at 17 years (but at this age the latter were being suppressed and the former were dying back).

At Allerston (Wykeham Exp. 50) Sitka spruce was introduced in one experiment into 3 feet tall Scots pine, and into 2 feet tall Corsican pine. One tree in four of the pioneer crop was removed and replaced by one Sitka spruce. Pruning of interfering branches and "thinning" were carried out a number of times from the fourth to the twelfth year, including the release of groups of the spruce. The development of the crops is shown in the Table 34 below.

Table 34

Heights of Pioneer Crops and Introductions

Wykeham Exp. 50. Feet

	Mean height				Mean height of tallest pine adjacent to spruce group		
End of Forest Year	1937	1939	1942	1946	1949	1952	1955
Pioneer crops							
Age, years	5	7	10	14	17	20	23
Ht. Scots pine	2·8	5·6	7·7	13·0	19	25	29
Ht. Corsican pine	1·3	2·3	5·4	10·2	16	21	26
					Tallest spruce per group		
Introductions							
Age, years		2	5	9	12	15	18
Ht. Sitka spruce in Scots pine		1·3	2·9	6·5	12	18	25
Ht. Sitka spruce in Corsican pine		1·2	2·2	5·6	12	16	21

(This table is illustrated by Zehetmayr, 1960 (Figure 8).)

The success of this experiment in getting some of the spruce into the canopy was probably due to the heavy clearing made round selected groups of spruce. A mixed crop has resulted.

In the other experiment (Wykeham Exp. 52) the spruce were planted in rows between the pioneer crop Scots pine. After pruning and "thinning" the crop was converted to a strip mixture of 3 rows pine/4 rows spruce; the spruce beneath the pine was abandoned. At 18 years, the spruce (tallest trees in liberated rows) was 17 feet tall against a height of 27 feet for the pine. The result of this experiment is that the middle two rows of the spruce will reach the canopy; its success may be due not only to the drastic opening up of the spruce but to the adjacent pine strips which provided a heather-free area for the spruce to root in.

The next experiments in this group were laid down in 1942, also at Allerston Forest. The first (Wykeham Exp. 73) used a very wide spacing (18 feet by 18 feet) for the Sitka spruce introduced into Scots and into Lodgepole pine. The spruce went into check due to competition from the *Calluna* (and also possibly due to frost) and by the age of eight was completely suppressed. In the second 1942 experiment (Wykeham Exp. 74) eight species—Douglas fir, Norway spruce, Sitka spruce, *Abies grandis*, hemlock, *Thuja plicata*, Lawson cypress and beech—were introduced into 3 feet tall Scots pine. Two plants of each species were planted on dug-over patches at 16 feet by 20 feet after the removal of one pine. After early branch pruning, opening up of the pioneer crop was begun at eight years. The table below shows the development of the crops.

Table 35

Heights of Pioneer Crop and Introductions

Wykeham Exp. 74. Feet

	Mean height		Mean height of tallest pine immediately to south of introduced species		
End of Forest Year:	1941	1948	1951	1955	1957
Pioneer crop					
Age, years	7	14	17	21	23
Ht. of Scots pine	3	12·7	18·2	24·3	27·9
		Mean of tallest tree per group			
Introductions					
Age, years		7	10	14	16
Ht. Douglas fir		5·7	10·0	12·8	14·0
Norway spruce ..		3·5	5·5	8·6	10·9
Sitka spruce		4·2	5·4	7·3	7·8
Abies grandis		2·7	4·9	10·8	11·8
Western hemlock ..		5·2	11·5	20·4	25·0
Thuja plicata		2·9	4·4	6·8	7·6
Lawson cypress ..		3·5	5·3	8·2	9·0
Beech		3·7	6·2	9·9	12·2

(This table is illustrated by Zehetmayr, 1960 (Figure 10).)

This experiment was the first to use species other than Sitka spruce. Some of these, notably hemlock and to a lesser extent, *Abies grandis*, proved more tolerant of shade (and probably of heather too) and were thus relatively successful. This experiment is described in detail by Zehetmayr, 1960.

In another section of Allerston Forest, a number of species were specially planted in groups as pioneer crops, with gaps left between the groups for the later planting of other species. These pioneer crops, which were planted in 1932, consisted of 13-plant groups of Scots pine, Japanese larch, birch, Mountain pine, alder and broom. From 1938 to 1943, Scots and Corsican pine, and Sitka spruce, were introduced, not only in the specially-left gaps between the pioneer crop groups, but within the groups themselves (Harwood Dale Exp. 3). The only successful introduction has been Scots pine into the birch pioneer crop. It may well be that the introduced pine helped the pioneer crop to grow better, instead of the birch helping the pine. The growth of Sitka spruce has been very variable and is generally poor.

Further widely-spaced introductions of single plants of Sitka spruce into young Scots and Lodgepole pines were made at Allerston in 1943 (Harwood Dale Exp. 37 and 38). After 11 years the spruce was suppressed at 3 to 6 feet tall. Two years later, single Sitka spruce were introduced at a spacing of 9 feet by 9 feet into Corsican pine about 3 feet tall (Harwood Dale Exp. 39). Manuring treatments were introduced and the benefit given by 5 lb. of compost, compared with 2 oz. of basic slag, and by the latter compared with the control, was statistically highly significant at 10 years of age. At 15 years, although the spruce had grown quite well and was up to 11 feet tall, it was rapidly being suppressed by the pine.

The last experiment in this group was established at Clashindarroch Forest, (Exp. 12) in 1949. Single Sitka spruce were introduced at 8 feet by 8 feet into crops of Mountain pine 3 to 4 feet tall. The site was very exposed at an elevation of 1,250 feet and the pine was 17 years old; originally the crop was alternate pine/Sitka spruce, but the latter died, and these introduced spruce filled the gaps left. After 7 years, the spruce was still only 1 to 2 feet tall, and was being suppressed by the 6 to 10 feet tall pine.

Removal of One Line of Trees

Ten experiments are included in this group. The first two were laid down at Allerston Forest in 1938. In one experiment (Wykeham Exp. 51) Sitka spruce was introduced in single rows into 5 feet Scots pine and into 6 feet Lodgepole pine, after alternate rows of pine had been removed. Although early pruning was done, the spruce soon checked and was outgrown by the pine and suppressed. The other 1938 experiment (Wykeham Exp. 53) was the first to use ploughing for the introduced species. Sitka spruce was planted on one line of double-furrow ploughing made between spaced groups of mixed Scots pine and European larch 3 to 4 feet tall; (one plot of spruce was planted on ploughing away from the groups, as a control). All the spruce soon went into check and despite heavy pruning of the adjacent pine, was mainly suppressed. At 15 years, the height was 6 feet and few individuals could be expected to reach the canopy, since the pine and larch pioneer crop was 24 feet tall.

In 1939 at Teindland Forest, Morayshire, the following mixtures were introduced into a crop of Lodgepole pine 4 to 7 feet tall on a *Calluna* site

Table 36—*Dominant Heights of Pioneer Crop, and Heights and Losses of Introductions.*

Teindland Exp. 41

Heights in feet
Percentage losses over 10%
(in brackets)

End of Forest Year	1938		1944‡		1947		1953		1958	
Pioneer crop Age	9/10		15/16		18/19		24/25		29/30	
Ht. Lodgepole pine	4*	7*	11	15	19	21	24·3	27·6	29·9	31·5
Phosphate.. ..	Nil	2 oz.	Nil	2 oz.	Nil	2 oz.	Nil	2 oz.	Nil	2 oz.
Introductions Age			6		9		15		20	
Ht. LP in LP/SS			2·5	2·5	5·2	4·6	14·2	11·2	20·1	17·3
LP/Ts			2·4	2·3 (11)	4·9	4·1	14·0	9·9	19·7	15·3
Mean			2·5	2·4	5·0	4·4	14·1	10·5	19·9	16·3
Ht. Ts in LP/Ts			2·3	3·4	4·1	5·8	15·2	15·7	21·1	23·2
Ts/GA			2·2 (11)	3·2	3·9	5·6	14·3	16·3	20·5	23·2
Mean			2·3	3·3	4·6	5·7	14·8	16·0	20·8	23·2
Ht. SS in LP/SS ..			1·9	2·2	3·2	3·4	7·9	6·0	9·9	7·1
Ht. DF in DF/Be			3·3	3·1	5·5	5·3	10·7	9·3	12·6	11·1
Ht. Be in DF/Be..			—(100)	— (100)	—	—	—	—	—	—
Ht. GA in Ts/GA			7·1	6·7 (12)	9·6	8·7	16·0	13·1	15·3ϕ(50+)	15·8ϕ(50+)

Abbreviations:
LP .. Lodgepole pine
SS .. Sitka spruce
Ts .. Western hemlock
GA .. Grey alder
Be .. Beech

*Mean height; estimate only
‡Mean height
ϕConsiderable dieback
Method of assessment of dominant height—In 20 ft. by 20 ft. units (containing a 20 ft. long strip of pioneer crop lodgepole pine, and of introductions) tallest pioneer crop pine and tallest of each introduced species measured (—a rate of approx. 300 trees per acre).

Table 37—*Heights of Pioneer Crops, and Mean Heights and Losses of Introductions.*

Heights in feet
Percentage losses over 20% (in brackets)

End of Forest Year	1949			1955	1956	1955	1959		
Experiment	Wykeham 84	Newtyle 1	Devilla 1	Wykeham 84	Newtyle 1	Devilla 1	Wykeham 84	Newtyle 1	Devilla 1
Pioneer crops									
Age in years	21	9	13	27	16	19	31	19	23
Ht. Scots pine	9	5	10	17*	13‡	16‡	23*	21*	25*
Introductions									
Age in years				6	7	6	10	10	10
Ht. Pinus ponderosa				2·0	1·5 (37)	1·6 (30)	4	— (67+)	— (67+)
European larch				4·0	1·3 (50)	— (67+)	8	— (67+)	— (67+)
Japanese larch				3·3	2·3 (50)		8	— (67+)	
Hybrid larch				5·6	1·2(60)		13	— (67+)	
Douglas fir				3·4	1·5	1·6 (47)	5	2·3	2·7 (53)
Norway spruce					1·0			1·5	
Picea omorika				4·2	0·9	2·6 (34)	7	1·6	4·7 (34)
P. orientalis				2·9	1·9	1·8	6	3·0	2·7
Abies concolor				1·6	1·1 (53)	—(67+)	3	— (67+)	— (67+)
A. grandis				2·8	0·8 (40)	0·9 (60)	7	1·7 (40)	1·4 (63)
A. nordmanniana				0·7	0·6 (40)	— (67+)	1	1·4 (40)	— (67+)
A. nobilis				2·0	1·0	0·7 (60)	5	1·8	— (67+)
A. veitchii				3·8	1·4 (27)		7	2·1 (27)	
Western hemlock						1·4 (40)			3·8 (47)
Thuja plicata				3·2	1·9	— (67+)	5	3·1	— (67+)
Lawson cypress				3·3	1·2 (40)	— (67+)	6	2·0 (40)	— (67+)
Cupressus macrocarpa				— (100)	— (100)	— (67+)	— (100)	— (67+)	— (67+)
Cryptomeria japonica				3·4	— (67+)		5	— (67+)	
Sessile oak				1·7	— (67+)	— (67+)	4	— (67+)	— (67+)
Red oak				2·0	— (67+)	— (67+)	4	— (67+)	— (67+)
Beech				1·6	— (67+)	— (67+)	3	— (67+)	— (67+)
Sycamore				1·0	— (67+)	— (67+)	— (100)	— (67+)	— (67+)
Ash				0·6 (48)	— (67+)	— 67+)	— (100)	— (67+)	— (67+)
Birch				4·4	— (67+)	6·1	7	— (67+)	8·5
Betula lenta				2·1	— (67+)	— (67+)	5	— (67+)	— (67+)
B. lutea				3·8	— (67+)	— (67+)	7	— (67+)	— (67+)
Grey alder				7·7	— (67+)	— (67+)	13	— (67+)	— (67+)
Oregon alder				6·6	— (67+)		10	— (67+)	
Robinia				1·2 (63)	— (67+)	— (67+)	— (100)	— (67+)	— (67+)

*Mean of tallest Scots pine adjacent to introduced lines. ‡Mean height

Where losses are over 67% no height is given. A number of species were planted in 1951 and are thus one year younger than the ages shown.

(Exp. 41)—Lodgepole pine/Sitka spruce, Lodgepole pine/hemlock, Douglas fir/beech, and hemlock/Grey alder. The pioneer crop pine had been planted 9 and 10 years previously, as spaced groups on 10 feet wide strips of ploughing (with and without basic slag). The 10 feet wide strips which had been left unplanted, were ploughed in 1938 and planted the following year (an alternate plant mixture; two rows in each strip). (See Table 36).

The outstanding success of hemlock is obvious (see Plate 12), and Lodgepole pine is the next best species. Douglas fir has been heavily infested with *Adelges*, and Sitka spruce has suffered from *Neomyzaphis* attack. This is one of the most successful of the introductions experiments and the reasons for its success seem to be: good cultivation, a fairly wide strip, a pioneer crop the branches of which are not widely spreading, and the use of suitable species, (hemlock and Lodgepole pine).

No further work was done until 1950, when three experiments were established on the same plan. They were at three forests—Allerston (Wykeham Exp. 84), Newtyle (Exp. 1) and Devilla (Exp. 1). Each experiment involved the planting of a large number of species on a single line of ploughing in the gap made by the removal of two rows of the pioneer crop of Scots pine. The heights of the pine were as follows: Allerston 9 feet; Newtyle 10 ft., and Devilla 5 feet.

The experiments at Newtyle and Devilla have suffered severely from roe deer damage and thus the number of failures may be greater than they would otherwise have been; heights have also varied considerably. Table 37 gives the position at 10 years.

Extensions to the above experiments were established at Allerston (Wykeham Exp. 85) and Newtyle (Exp. 2) also in 1950 to test on a larger scale the introductions of Douglas fir, *Abies grandis* and hemlock into Scots pine, 5 feet tall at Newtyle, and 8 feet at Allerston. A similar experiment began at Langdale Forest two years later (Broxa Exp. 88 (see Plate 7).) The latter included Intermediate Douglas fir (*Pseudotsuga taxifolia* var. *caesia*) and Lawson cypress. Table 38 below shows the development of the crops.

Table 38

Mean Heights of Pioneer Crops and Introductions

Heights in feet

End of Forest Year	1949		1952	1955	1956	1957	1959	
Experiment	Wykeham 85	Newtyle 2	Broxa 88	Wykeham 85	Newtyle 2	Broxa 88	Wykeham 85	Newtyle 2
Pioneer crops								
Age in years	21	9	12	27	16	17	31	19
Ht. Scots pine	8	5	7	17*	11	18*	23*	19*
				Mean Height				
Introductions								
Age in years				6	7	6	10	10
Ht. Douglas fir				3·0	1·2	2·4	4	1·6
Douglas fir (var. caesia)						2·2		
Abies grandis				2·2	1·0		5	1·5
Western hemlock				4·9	1·6	5·8	12	2·8
Lawson cypress						2·8		

*Mean of tallest Scots pine adjacent to introduced lines.

Deer and frost have probably been the main causes of the poor growth at Newtyle. At Allerston and Langdale, hemlock has been the most successful species; at the former, this species appears to be coming through the pine and many plants should reach the canopy, but at Langdale the pioneer crop pine has grown faster and has closed firmly over the top of the introductions. Heavy opening up of the pine will allow groups of hemlock (and possibly Douglas fir) to reach the canopy. The great improvement at Allerston in the pioneer crop following the ploughing is of interest.

The last experiment in this group of line introductions was at Langdale Forest in 1952 (Broxa Exp. 86). A number of broadleaved trees were introduced (on one line of ploughing) into the gap made by removing a row of Scots pine. The pine was fast growing and the most which can be expected is that some species may form an understorey.

Removal of Trees by Heavy Low Thinning

There are only three experiments in this group, all established at Allerston Forest in 1944 and 1945, but they are important. In two (Wykeham Exp. 75 and 77) Douglas fir, Sitka spruce, *Abies grandis*, Lawson cypress and beech were introduced into Japanese larch about 15 feet tall. The larch, which had completely suppressed the ground vegetation, was heavily thinned before the introductions were made. In one experiment plants were set in single lines, and in the other they were placed in groups of four plants; in both cases, the effect was of underplanting at a spacing of 6 to 8 feet. The development of the crops is shown in the table below.

Table 39

Mean Heights of Pioneer Crops and Introductions

Feet

End of Forest Year	1941	1943		1945	1948	1950	1953		1958	
Wykeham Experiment No.	75	75	77	77	75	77	75	77	75	77
Pioneer Crops										
Age, years	9	11	12	14	16	19	21	22	26	27
Stems per acre	2,700	1,400	2,400	1,600	650	360	160	100	160	100†
Ht. Japanese larch		14½	16*		24				35	35
Introductions										
Age				2	5	7	10	10	15	15
Ht. Douglas fir					3·1	4·0	6·7	6·9	10·0	12·7
Sitka spruce					2·7	3·3	5·6	6·1	10·0	12·8
Abies grandis					2·7	3·9	7·2	7·8	14·6	16·9
Lawson cypress					1·1	1·0	2·7	1·6	1·6	3·0
Beech					1·9	4·1	4·9	6·6	8·7	11·3

*Approx. height.

†All trees at edges of experiment; none within groups.

Abies grandis has been the most successful introduction; of the other species only Lawson cypress has been a failure.

In the third experiment (Wykeham Exp. 76) Sitka spruce, *Tsuga*, and *Thuja* were introduced into Lodgepole pine, Japanese larch, and birch, all 12 to 15 feet tall. In the pine, groups of four trees were removed, and seven plants introduced; in the larch and birch existing gaps were used for the introductions. After six years, the spruce and *Thuja* were only two to three feet in height, and it was considered that there was no hope of their getting into the canopy. At ten years *Tsuga* under the pine was also partly suppressed, but under the larch and birch it was growing well. At 14 years, *Tsuga* had a height (tallest tree per group) of 21 feet under the larch (38 feet tall) and 22 feet under the birch (25 feet tall). Thus the *Tsuga* groups proved successful introductions under these two pioneer crops (see Plate 13).

Peat Moorlands

Sites

Only five experiments have been made on wet peat moorlands. Two were at Inchnacardoch Forest in Inverness-shire, and three at Kielder Forest, Northumberland. The three latter experiments were on shallow *Molinia* peat, but those at Inchnacardoch were on basin and slope peat with a vegetation dominated by *Trichophorum* (*Scirpus*). These peat sites were classified as moderately exposed.

Pioneer Crops

Scots pine, Lodgepole pine, and Norway and Sitka spruces have been used. The crops have been similar in age and height to those on the heathlands; all were growing fairly slowly but not abnormally for the sites, none of which was ploughed.

Introductions

Many different species have been used, especially in two experiments at Kielder planted in 1950; the commonest have been Douglas fir, *Abies grandis* and Western hemlock. All introductions received phosphate at planting. Two methods of introduction can be distinguished, corresponding approximately to the first two used on the heaths:

(1) Removal of *no* pioneer crop trees. Introductions made in groups of up to four plants.

(2) Removal of two lines of trees. Introductions made in single lines.

Description of Experiments

(1) **No removal of Pioneer Crop Trees.** In 1938 and 1940 at Inchnacardoch Forest, Sitka spruce and hemlock were introduced on turfs into Lodgepole pine about 4 feet tall, on deep basin peat with a *Trichophorum* vegetation (Exp. 52). The lodgepole pine grew too fast to allow the introduced spruce and hemlock to develop, and both species were suppressed.

(2) **Removal of Two Lines of Trees.** In 1950, two experiments were established at Kielder Forest in 5 feet tall Norway spruce (Exp. 58 and 59, see Plates 8 to 11). Two lines of trees were removed and one furrow was ploughed in the gap with a Cuthbertson single mouldboard draining plough. A large number of species, including some broadleaved trees, were planted on the ploughed ridge with 2 oz. ground mineral phosphate per plant. The two sites appeared similar at the time of planting the introductions, but they

developed differently. On one, grasses developed, while in the other, strong *Calluna* and *Vaccinium* grew in patches. This indication of site quality was reflected in the growth not only of the Norway spruce but of almost all the introductions. Table 40 shows the development of the crops.

Table 40

Mean Heights of Pioneer Crops, and Mean Heights and Losses of Introductions

Heights in feet
Percentage losses over 20% (in brackets)

End of Forest Year	1949		1955		1959	
Kielder Experiment	58	59	58	59	58	59
Pioneer crops						
Age, ...	11	11	17	17	21	21
Ht. Norway spruce	5	5	13	11‡	22*	21*
Introductions						
Age, ...			6	6	10	10
Ht. Pinus banksiana†			2·1	1·0	3·2	2·0
P. muricata ..				— (90)		— (90)
P. ponderosa ..			2·2		4·8 (27)	
P. radiata ..			— (100)		— (100)	
P. rigida† ..			2·7	2·1 (40)	4·8	— (100)
European larch			6·8	3·2	13·0	6·8
Japanese larch ..			6·4	4·8	13·4	10·7
Hybrid larch ..			6·1	3·6	14·0	8·4
Douglas fir ..			4·1	2·0 (27)	9·2 (22)	3·7 (33)
Abies concolor†			1·2	1·0 (67)	1·6 (27)	1·4 (73)
A. grandis ..			1·7	1·2	3·4	2·1
A. nordmanniana†			1·2 (60)	— (100)	1·4 (67)	— (100)
A. nobilis ..			1·4 (47)	1·3 (37)	4·1 (77)	3·0 (37)
A. veitchii ..			2·9		6·0	
Western hemlock			3·0	2·7	9·5	8·6
Cupressus macrocarpa			— (100)	— (100)	— (100)	— (100)
Cryptomeria japonica			3·5 (43)	2·3 (60)	6·4 (43)	6·3 (60)
Sessile oak ..			1·0 (24)	1·0 (88)	1·0 (24)	— (100)
Red oak ..			1·0 (60)	1·0 (85)	— (100)	— (100)
Beech			1·2 (47)	1·2 (83)	1·6 (66)	1·8 (83)
Sycamore† ..			— (100)	— (100)	— (100)	— (100)
Ash†				1·2 (60)		— (100)
Birch			6·4	6·5	10·3	15·5
Betula lenta† ..			— (100)	— (100)	— (100)	— (100)
B. lutea ..			2·1 (64)	4·1 (68)	2·5 (72)	5·7 (68)
Grey alder ..			8·1		11·7	
Robinia.. ..			— (100)	— (100)	— (100)	— (100)

Symbols. ‡Approx. height.
*Mean of tallest spruce adjacent to introduced lines.
†Planted 1951 and thus one year younger than shown.

Note. 1 plot of grey alder in Exp. 58 had a mean height of 17 ft. at 10 years.

The outstanding successes have been the three larches, hemlock, Grey alder and birch (see Plates 8 and 9). The good growth of some of the less common species, for example *Abies veitchii* and *Cryptomeria japonica*, is interesting. The broadleaved species suffered severely from cropping, probably by black-game. The branches of the pioneer crop spruce did not spread sufficiently to interfere with the introductions, even those which grew very slowly.

At Kielder Forest, hemlock and beech were introduced in 1940 into gaps in a thicket of 8 feet tall Sitka spruce (Exp. 16). There were heavy losses due to deer and frost and the introductions failed.

In 1950, groups of four plants of Douglas fir, *Picea omorika*, *Abies grandis*, hemlock, Sessile oak and Grey alder, were introduced into gaps in a pioneer crop of groups of Scots pine, Lodgepole pine and Sitka spruce, 9, 10 and 6 feet tall respectively, at Inchnacardoch Forest (Exp. 136), on shallow *Trichophorum/Calluna* peat. There was a high death rate and growth was poor in all species; this was mainly due to deer damage. Western hemlock alone grew fairly well, and showed some resistance to browsing.

Discussion

The experiments have been described in three main groups and it will be apparent that there have been successes and failures in all three. The reasons for these are not entirely clear, and almost certainly a complex of factors is involved. Two of these may be the species selected for the introduction, and the method of making it.

Until about 1949 Sitka spruce was the main species used, and it has succeeded in only two experiments (Wykeham Exp. 50 and 52). In these, the heavy clearing of the pioneer crop, begun at an early age and repeated frequently, has probably been the main factor of importance. In those experiments in which the spruce did not reach the canopy, the main reason for failure seems to have been the initial checking of the spruce in the dense *Calluna* in which it was planted. Frost also played a part in some cases. By the time the heather was killed by the pioneer crop and the spruce began to grow, the latter was so far behind the pioneer crop that it was soon suppressed. The heavy clearings used successfully at Wykeham are not practicable measures on a large scale.

There have been many successes however, with species other than Sitka spruce. Western hemlock has been outstanding, making good growth in all experiments which were not attacked by deer, and in which the pioneer crop was not completely dense overhead. *Abies grandis* has been the next best, again when free from deer damage. Douglas fir has often done well, but has been subject to severe attack by *Adelges* aphids, apparently because of heavy shading. In the older experiments, Lawson cypress has often survived and grown slowly, but only sufficiently well to allow it to remain as an understorey; beech has done only slightly better. Grey and Oregon alders have been successful in a number of experiments, but begin to die back after about fifteen years.

Of the upland heath experiments begun in 1950, in all of which a large number of species were planted, only that at Wykeham has escaped severe damage by deer. Here the best species have been European larch, Japanese larch, *Picea omorika* and *Abies veitchii*. At Devilla (Exp. 1), *Picea omorika* and birch have escaped damage and have done well.

In the experiment on shallow *Molinia* peat at Kielder, a large number of species have become established. The best are European, Japanese and Hybrid larch, Western hemlock, Grey alder and birch. Taking the experiments as a whole, the most important results are the success of Western hemlock and, to a limited extent, of *Abies grandis* and Douglas fir, and the very poor showing of Sitka spruce.

Some general conclusions may be drawn from the effect of the method of introduction although it is not possible, of course, to divorce this factor from that of species. Considering the many failures with Sitka spruce in the first group—where no pioneer crop trees were removed or where only one tree was removed, and one to three plants introduced—it seems probable that the balance between success and failure on the upland heaths is very fine; a slight variation in the conditions of light, soil and vegetation, makes the difference between success and failure. Since the successes with this method apparently depend on the early and drastic opening up of the pioneer crop, which is not practicable on a large scale, it may be concluded that the method is not a satisfactory one.

The second method—where one or two lines of trees were removed and one line of plants introduced (or where the line of plants introduced was made in an unplanted lane left for the purpose)—has produced good results in many cases. The removal of lines of trees allows the use of a plough for cultivation. With this method Western hemlock has grown very well, and many other species have become established (e.g. Wykeham Exp. 84 and Kielder Exp. 58). Sitka spruce has been a failure, however, on *Calluna* land. Removing two lines of trees in the pioneer crop has been satisfactory for the introduction of one line of new plants. Where only one line was removed, the pioneer crop closed firmly over the introductions within eight years, and very heavy thinning became necessary to try to save the latter (Broxa Exp. 86 and 88). The 10 feet wide lane planted with two lines at Teindland (Exp. 41) proved satisfactory but the use of only one centrally placed line of introductions would probably have given a better result.

Two experiments made under the third method—where an early thinning took place and one or more plants, or one line of plants, were introduced—have produced the most successful results. There are three important ways in which these experiments differed from the others. First, the pioneer crops were Japanese larch. Secondly, they were older and taller and had suppressed the vegetation (*Calluna*) completely. Thirdly, they were very heavily thinned before planting and the thinning was continued to the extent that in fifteen years only 100 to 200 trees per acre of the pioneer crop were left. *Abies grandis* and Douglas fir were successful, and beech and even Sitka spruce were moderately successful with this method. It is noteworthy that in the third experiment of this group (Wykeham Exp. 76) in which heavy thinning was not done, hemlock succeeded under Japanese larch and birch, but was suppressed under Lodgepole pine. It seems probable that the suppression of the ground vegetation is the most important single factor in the success of the method.

From the three methods of introduction discussed above, the following conclusions may be drawn:

(1) To make introductions without the removal of any pioneer crop trees is not practicable owing to the heavy clearing which has to be made later to prevent the suppression of the introduced trees.

(2) To use the method of planting in lanes cut in the pioneer crop is successful, provided the lanes are sufficiently wide; 15 feet appears to be the minimum width.

Table 41

Comparison between Various Species Grown in Pioneer Crops and in Approximately Similar Conditions in the Open

Upland Heaths — Feet

Species	Age, years	Experiment	Mean height	
			Introduced species	Afforestation species
Lodgepole pine	6	Teindland 41	2½	
	6	Teindland 81		3
Douglas fir	16	Wykeham 74	14	
	15	Wykeham 75	10	
	15	Wykeham 77	13	
	15	Wykeham 41		6
	10	Wykeham 84	5	
	10	Wykeham 85	4	
	10	Broxa 76		3
	8	Broxa 80		3
	6	Teindland 41	3	
	6	Teindland 82		2½
Sitka spruce	20	Teindland 41	8½	
	20	Teindland 23		5½
	9	Teindland 41	3½	
	10	Teindland 69		2
Picea omorika	15	Wykeham 41		6
	10	Wykeham 84	7	
	6	Teindland 82		6
Abies grandis	16	Wykeham 74	12	
	15	Wykeham 75	14½	
	15	Wykeham 77	17	
	14	Wykeham 9		3½
	10	Wykeham 84	7	
	10	Wykeham 85	5	
	10	Broxa 76		4½
	8	Broxa 80		2
Western hemlock	16	Wykeham 74	25**	
	15	Wykeham 76	21	
	15	Wykeham 63		12
	15	Wykeham 59		7
	15	Teindland 41	15½*	
	17	Teindland 23		9½
	10	Wykeham 85	12	
	10	Broxa 76		6
	8	Broxa 80		6
Thuja plicata	16	Wykeham 74	7½	
	15	Wykeham 59		1½
Grey alder	9	Teindland 41	9	
	10	Teindland 23		5½
	10	Teindland 48		8
	10	Teindland 62		3
	10	Wykeham 84	13	
	6	Broxa 86	5½	3
Oregon alder	10	Wykeham 84	10	
	15	Wykeham 41		8
	17	Teindland 41	20	
	10	Teindland 48		10

**Tallest per group. *Dominant height (see footnote to Table 36 for explanation).

(3) Waiting until the pioneer crop has suppressed the vegetation before making the introduction appears to give the most successful results. Heavy thinning must be used with this method to keep the introductions growing.

Thus, the use of the lane method in pioneer crops which are tall enough to have suppressed the ground vegetation might be the most practical method, either with or without ploughing in the lanes.

It was not part of the object of these experiments to make a comparison between the growth of species in pioneer crops and in the open, that is planted as afforestation species. However, an approximate comparison can be made, covering some of the principal species, and this is given in the tables below. The experiments under "Afforestation Species" are all on ploughing and all received phosphate. Table 41 deals with the upland heaths, and Table 42 with the peat moorlands. The latter table concerns Kielder Exp. 58 and 59 which have been described earlier, and an afforestation trial at the same Forest (Exp. 60) planted in 1950 and 1951.

Table 42

Peat Moorlands

feet

Species	Mean height at 6 years	
	Introduced species (Mean of Kielder 58 and 59)	Afforestation species (Mean of 1951 and 1952 plantings*)
Japanese larch	5·6	3·2
Hybrid larch	4·9	4·1
Douglas fir	5·1	1·9
Abies concolor	1·1**	1·0
A. grandis	1·5	2·4
A. nobilis	1·4	1·5
Western hemlock	2·9	2·8
Sessile oak	1·0	0·6
Red oak	1·0	0·9
Sycamore	Failed**	0·5
Grey alder	8·1	4·7

Notes. * 1951 planting was done on ploughing at 15 ft. intervals with 2 rows of turfs spread between the plough furrows. 1952 planting was on 5 ft. ploughing. Growth on the latter was much better than on the former.

**At 5 years.

The considerably better growth of the "Introductions" is most marked on the upland heaths.

Finally, the introductions experiments have been discussed only from the silvicultural angle; the economic aspect has not been considered. Successful methods of effecting introductions have been described, but economically it would seem quite unjustified to make introductions into pioneer crops before any saleable produce could be removed. It would be better to leave the pioneer crops, at least until they can produce small poles, before beginning the necessary openings for the new species. To do so would allow time for the vegetation to be suppressed, a point which seems to be of the greatest importance.

Conclusions

(1) A considerable number of species have been established successfully using a pioneer crop. On the upland heaths the most successful have been Western hemlock, *Abies grandis* and Douglas fir. On the *Molinia* sites, the best have been European, Japanese and Hybrid larches, Western hemlock, Grey alder and birch.

(2) The growing of Sitka spruce on the upland heaths by using a pioneer crop has proved as uncertain as growing it on the open moor.

(3) There is evidence that the early growth of many species is greatly improved by the use of a pioneer crop.

(4) Making introductions in a lane cut for the purpose is satisfactory. The complete suppression of the vegetation before the introductions are made is most important. The use of a fairly wide lane (5 to 7 rows of trees), in a crop sufficiently tall to have killed the ground vegetation, might be the best method of making the introductions.

(5) To make introductions before the pioneer crop can give saleable produce appears economically wasteful.

(6) One of the main hazards in these methods of establishment is the browsing of roe deer.

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PRUNING OF CONIFERS BY DISBUDDING

By D. W. HENMAN

A series of experiments on finger disbudding, or bud pruning, was begun in 1947-49, and the results after six years work were published in the *Report on Forest Research* for 1955 (Zehetmayr, 1956). The present report gives detailed results after nine years work, and further notes on the conditions of the experiments after eleven years.

The background to the project was described in the earlier report. The objects were as follows:

(1) To compare the cost of finger disbudding with other pruning methods in relation to the type and quality of timber produced.

(2) To compare the height and diameter growth of trees pruned by finger disbudding with that of trees subjected to more normal pruning methods and that of unpruned controls.

(3) To observe the relative incidence of damage from birds, insects, fungi, loss of leading buds, etc., that might occur in the different treatments.

Trees were selected from amongst the largest and most vigorous of the potential dominants in crops 4-6 years old and 2-4 feet tall, at a rate of 150-250 per acre. The following experimental treatments were then applied:

(A) Control. The selected potential dominants were left to develop normally. No thinning done to date.

(B) A duplicate control in which it was intended to carry out normal saw pruning when about 6 feet of stem could be pruned without removing live whorls. This stage has not yet been reached, and the trees have been left to develop normally as in (A). In presenting the results, data from Treatments (A) and (B) have been combined.

(C) Disbudded. On the selected potential dominants the lowest two complete whorls were left intact; above these all lateral buds were removed annually, together with any epicormic shoots arising since previous disbudding.

(D) Disbudded. The lowest four complete whorls were left intact; above these disbudding was applied as in (C).

(E) A pruning treatment outside the scope of this report.

The present report thus concerns three treatments, the control and two disbuddings.

Three or four years after disbudding was started it became apparent that the operation caused growth reduction in the treated trees, and it was decided to terminate the disbudding of a proportion of the trees in case prolonged treatment should lead to complete failure of the project. Accordingly, in each experiment disbudding was stopped, in two replications out of five, when each tree had formed 8 feet of clear stem, while in the remaining replications disbudding was to continue until 16 feet of clear stem had formed; crowns were then to be allowed to develop above the disbudded lengths. These two groups of replications are called "short-term" and "long-term" groups respectively.

Seven experiments were started: two in Corsican pine, two in Scots pine, one in Sitka spruce, one in Norway spruce and one in Douglas fir. The failure of the Douglas fir was described in the earlier report. The Norway spruce experiment was abandoned in 1957, after nine successive disbudding operations, owing to an increase of heather growth in the plots and the consequent "checking" of the plantation. Over that period height growth of the selected trees, both treated and untreated, averaged only 6 inches per year; and by the end only 30 per cent of the trees remained in good health, there being actually fewer control trees still dominant than disbudded trees. The present report therefore concerns only five experiments.

Survival of the Disbudded Trees

In forestry practices such as pruning, which entail the expensive treatment of a limited number of trees early in the life of the crop, it is of prime importance that the largest possible proportion of the treated trees be brought to maturity as dominants in the final crop. It is a matter of common observation, confirmed in sample plot studies, that any tree which falls below the rank of co-dominant is most unlikely to regain a place in the upper canopy of the final crop and thus make a major contribution to the final volume production. It is therefore important, even at this early stage of the experiments, to consider what proportion of the disbudded trees still have a chance of remaining in the final crop, and Table 43 gives the percentage of the initially selected trees (potential dominants) in each treatment which were either dominant or co-dominant nine years after selection. Trees which were suppressed, dying or diseased, as well as those which were dead, are considered, for practical purposes, not to have survived and in Table 43 the percentages of these are combined under the heading "Suppressed or Dead".

The result is disappointing. In the case of the pines, only half of the original number were in the upper canopy, with usually rather fewer Treatment (C) trees surviving than Treatment (D), the extra basal whorls having conferred a slight advantage. In the Sitka spruce, hardly any of the Treatment (C) trees were able to maintain their dominance, and only 14 per cent of Treatment (D) trees.

Table 43

Percentage of Control and Disbudded Trees in Various Canopy Classes after Nine Years

Species	Forest and Experiment Number	Number of trees per acre initially selected	Percentage of Dominants + Co-dominants			Percentage Suppressed or Dead		
			Treatments A + B Control	Treatment C Disbudded leaving 2 whorls at base	Treatment D Disbudded leaving 4 whorls at base	Treatments A + B	Treatments C	Treatments D
Scots pine	Mabie 1	250	86	47**	50**	0	43	30
	Millbuie 10	240	62	43**	53	13	48	33
Corsican pine	Lossie 1	200	82	40**	48**	18	58	50
	Wykeham 82	160	79	52**	45**	4	31	30
Sitka spruce	Kielder 52	150	71	4**	14**	0	83	57

In analysing the results for Dominants + Co-dominants the percentages were transformed to degrees; consequently standard errors are not shown, but those treatments in which the difference from control is significant at p = 1 per cent are indicated thus **.

At 14 years of age, between 45 and 160 dominant to sub-dominant disbudded trees remained to the acre, and further losses could be expected since many of these were in a weakened condition. This low rate of survival resulted in spite of a considerable amount of thinning and lopping of neighbouring matrix trees in the disbudded plots, in an attempt to reduce root and crown competition.

In all the experiments, except the Scots pine at Millbuie, disbudding in the short-term groups of plots ceased after about the seventh year. The succeeding two years of crown development, prior to the ninth year assessment, did not affect the percentage of dominants among the trees, except to a small degree at Wykeham (Corsican pine) where the short-term plots showed a slightly higher proportion of disbudded trees in the upper canopy classes.

A point of considerable interest is that in the untouched controls 10-40 per cent of the trees selected as potential dominants when five years old were less than co-dominant at fourteen years. Obviously one of the difficulties in this method of growing knot-free timber is that of starting with the right trees.

Causes of Loss of Experimental Trees

The rather high proportion of suppressed or dead control trees (Table 43) at Millbuie and Lossie was probably due to Pine sawfly attack and sea wind blasting respectively (few were actually killed); elsewhere, losses of control trees were few or nil. Losses of disbudded trees, on the other hand, were heavy and included a high proportion of actual deaths. At Millbuie and Lossie a proportion of the losses must be attributed to the insect and wind damage mentioned above, but elsewhere most losses were due directly to the disbudding treatments.

From time to time through the course of the experiments, loss of some of the current leading shoots occurred, attributed variously to the perching of birds, to shooting parties, frost or high winds; the number lost in this way was small and the damage could usually be repaired by allowing a shoot from a dormant bud below the break to take over the leadership, as frequently happened. Physical damage to, or loss of, disbudded stems below the leading shoot was rare. Losses or damage due to insects, apart from the sawfly damage already mentioned, did not occur. At Wykeham (Corsican pine), infection by the fungi *Hypodermella sulcigena* and *Brunchorstia destruens*, causing needle-cast, was general in the crop, and probably accounted for the few "lost" control trees. But there was no evidence that the disbudding treatments predisposed the crop to the infection nor that the disbudded trees were more severely attacked than control trees. Fungal disease did not occur in other experiments. Profuse growth of epicormic shoots was a feature of the disbudded trees, particularly Sitka spruce. While not a cause of damage, their removal was troublesome and expensive.

The great majority of the losses of disbudded trees was of a physiological rather than a physical nature, and came about in one of two ways; either the whorls of branches left at the base gradually perished, so that the whole tree died for want of nourishment, or the basal whorls grew so vigorously that they starved the disbudded stem in their bid to assume leadership. Neither removal nor lopping of neighbouring matrix trees (in the first case) nor lopping of the candelabra-like basal branches (in the second) was successful in preventing the eventual suppression of the disbudded stems. The slight advantage in survival shown by Treatment (D) trees, in which four basal whorls instead of two were left, probably results from fewer trees failing in the first way.

Losses of disbudded trees increased progressively during the period of the experiments, as the length of disbudded stem above the basal whorls increased. Cessation of disbudding in the "Short-term" groups of plots had not, after two years, effected much reduction in annual losses; but on present behaviour it seems certain that very few trees could survive to produce a 16-foot clear stem. Up to the end of 1959, only one tree had achieved this, a Scots pine at Mabie. This tree reached 16½ feet above the basal whorls after the 1957 growing season; it was allowed to form a whorl of branches in May 1958 but by March 1959 the stem had bowed right over, unable to support even the beginning of a crown (see Plate 4). By contrast, several of the surviving "Short-term" trees which have formed crowns above an 8 feet clear length appear healthy and able to support their crowns. These were trees which had maintained the dominance of their leaders during disbudding, together with healthy but not over-vigorous basal branches. Again, the necessity of being able to select the right type of tree for the operation of disbudding is demonstrated.

Height and Girth Growth

The reductions in height and girth of the disbudded trees relative to the controls, reported in 1956, increased over the following three years. Table 44 shows the mean heights and breast height girths of the surviving trees (those with live leading shoots) nine years after the commencement of disbudding.

Table 44

Mean Heights and Girths after Nine Years

Species and Forest	Height (feet)			Girth (inches)		
	Treats. A + B Control	Treat. C Disbudded	Treat. D Disbudded	Treats. A + B Control	Treat. C Disbudded	Treat. D Disbidded
Scots pine						
Mabie	16·5	15·1	15·7	10·8	6·0	6·5
Millbuie.. ..	9·5	10·1	10·0	5·3	4·1	4·3
Corsican pine						
Lossie	13·2	12·1	12·0	9·6	6·8	6·9
Wykeham ..	16·8	14·8	15·0	10·8	7·0	7·7
Sitka spruce						
Kielder	14·2	10·4	12·5	8·2	4·0	4·4

Except at Millbuie, where growth was generally very slow, height growth was reduced by disbudding—rather more where only two basal whorls were left. The relative reduction was greater in Sitka spruce than in the pines.

Girth was reduced considerably by disbudding, again to a greater extent where only two basal whorls were left, though differences between Treatments (C) and (D) were less at nine years than at six years.

Separation of the means of the "Short-term" and "Long-term" groups did not show any superiority in growth of the "Short-term treatments", except perhaps in girth at Wykeham (Corsican pine); the effect of the developing crowns had been operative for only about two years in most experiments at the time of the ninth year assessment.

Cost of Disbudding

The experiments were intended to provide comparisons of, among other things, the cost of annual disbudding with that of pruning a similar clear length in one or two operations (periodic pruning) in the same crops; but the poor survival of the disbudded trees has necessitated the closing of the experiments before periodic pruning could be applied in the plots provided. However, some very general comparisons can be made with costs of pruning obtained from other sources.

Table 45 shows the total cost in man/hours per 100 trees of disbudding annually for seven years (the period for which time records were kept) inclusive of walking time between the trees and of time required to remove epicormic shoots, and the approximate length of clear stem produced.

Table 45

Cost of producing the given clear length by annual disbudding over seven years

Species and forest	Disbudding treatment	Approximate clear length obtained (ft.)	Cost of seven operations (man/hours per 100 trees)
Scots pine			
Mabie ..	C	10	13·1
	D	9	11·1
Millbuie	C	5	5·6
	D	4	4·0
Corsican pine			
Lossie	C	8	4·8
	D	6½	3·0
Wykeham ..	C	10½	11·2
	D	9	10·3
Sitka spruce			
Kielder	C	6½	18·2
	D	8½	17·5

In the pines, lengths of 4-10 feet were produced in 3-13 man/hours per 100 stems. Sitka spruce took longer.

Published times for saw-pruning various pine species (Hawley and Clapp, 1935; Clinton, 1936; Anon, 1947; Mayer-Wegelin, 1952) vary from 3½-8 man/hours per 100 trees, for clear lengths of 6-10 feet.

These trials were carried out under a wide variety of conditions, and critical comparisons are not permissible, but they suggest that for lengths of stem up to 10 feet the basic cost of disbudding is fairly comparable with that of saw pruning. Further adjustment of the disbudding costs is required, however, to make the two methods more truly comparable. First, the extra overhead charges applicable to seven disbudding operations will be greater than those for a single saw pruning. Secondly, the survival rate of the disbudded trees is much lower than that expected from ordinary pruning; in the experiments, losses have more than doubled the cost, per tree, of disbudding. Thirdly, the disbudding required a considerable amount of lopping and thinning of matrix trees and basal whorls; this is not necessary in saw-pruning and was not included in the tabulated costs of disbudding. Removal of epicormic shoots, which was done concurrently with disbudding, was included in the disbudding costs, but shoots continued to arise after disbudding was stopped, involving further expense in their removal. Disbudding times rose sharply when the tree heights exceeded about 8 feet; the stem tips could then no longer be reached from the ground and ladders became necessary. In periodic pruning the work can be continued to a height of about 20 feet, using pole saws or chisels from the ground, without greatly increasing the cost per unit length pruned.

The Position after Eleven Years

A survey of the five remaining experiments was made at the end of 1959, eleven years after disbudding started. In Scots and Corsican pines further failures had occurred among the "long-term" trees, in which disbudding was still continuing in the hope of obtaining 16 feet of clear timber, and it is practically certain that no tree will complete this length and remain stable when the crown forms (see Plate 5). In the "Short-term" plots, trees which had four or more whorls above the 8 feet clear length and were still dominant or co-dominant (see Plate 6) looked capable of forming part of the final crop, but their numbers were few. In the case of Sitka spruce, almost all the disbudded trees were either dead or less than co-dominant, and the operation may be considered a complete failure for that species.

Conclusions

Finger disbudding as a means of producing knot-free timber has been a total failure in Douglas fir and Sitka spruce. The results obtained for Norway spruce were sufficient to show that the method cannot be applied in checked or very slow-growing crops. With Scots and Corsican pines the method is impracticable for clear lengths greater than about 8 feet. For this length some success has been achieved, but survival is so uncertain, the operation so much more expensive than normal pruning, and the diameter of the stem so reduced, that the method may be disregarded as a forest-scale operation.

The more successful experiments will be retained to provide material for future timber tests, though no further treatments will be applied, nor assessments made.

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THE PINE LOOPER MOTH BUPALUS PINIARIUS IN RENDLESHAM AND SHERWOOD FORESTS—1959

By D. BEVAN and R. M. BROWN

Introduction

In the account of work carried out in connection with an infestation of *Bupalus piniarius* L. at Tentsmuir in 1957 (Bevan 1960), some general remarks were made concerning the significance of pupal counts and upon the limits of their use in forecasting the likelihood of infestation. There it was observed that "... the later stage population actually realised from any pupal density is a very variable quantity, and that, therefore, pupal counts can only provide a warning".

In 1959, observation was kept upon two populations, at Rendlesham, and Sherwood IV, which, the routine pupal survey indicated, had reached a dangerous level. Both these populations failed to outbreak, and it is, therefore, of value to record the information gathered.

Rendlesham Forest and Sherwood Forest, Section IV

Both areas have sandy soils with soft sandstone and pebbles of the Bunter Pebble beds at Sherwood, Nottinghamshire, and glacial sands and gravels at Rendlesham, Suffolk. The annual rainfall at Rendlesham is about 24 inches, and the crop, in that part of the forest which contained the highest density of pupae, is Quality Class I (some Class II) Scots pine from 34 to 39 years old. At Sherwood the rainfall is about 26 inches, and the area is stocked with 31 and 32-year-old Corsican pine of Quality Classes II and III.

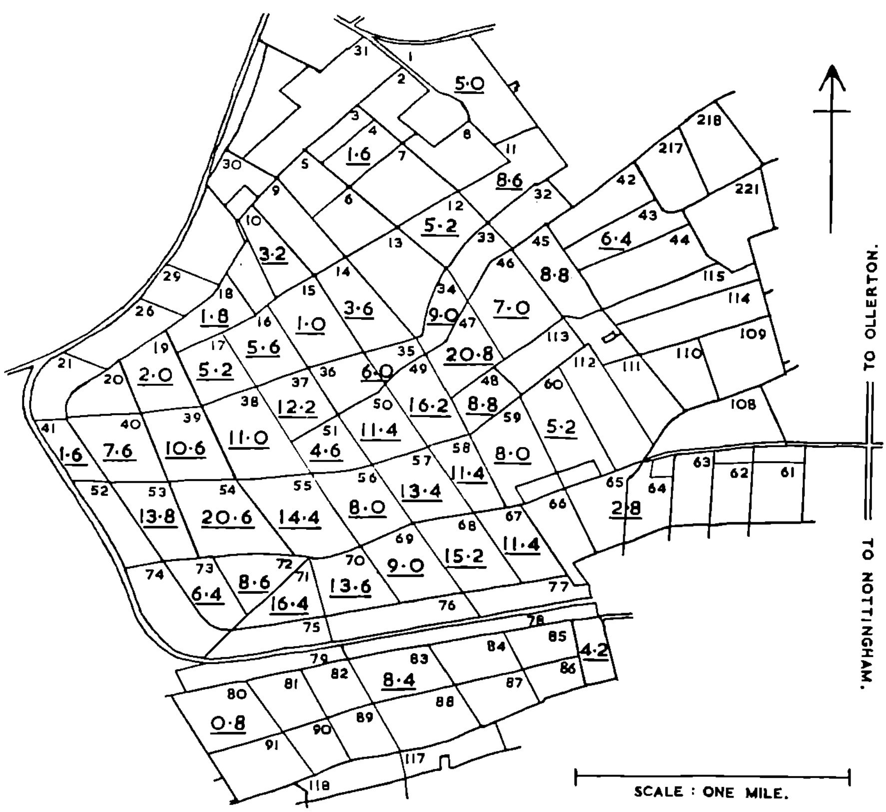

FIG. 12. Sherwood Forest, Section IV (Part only)—Underlined numbers show near pupal count per square yard, by numbered compartments, in Spring 1959.

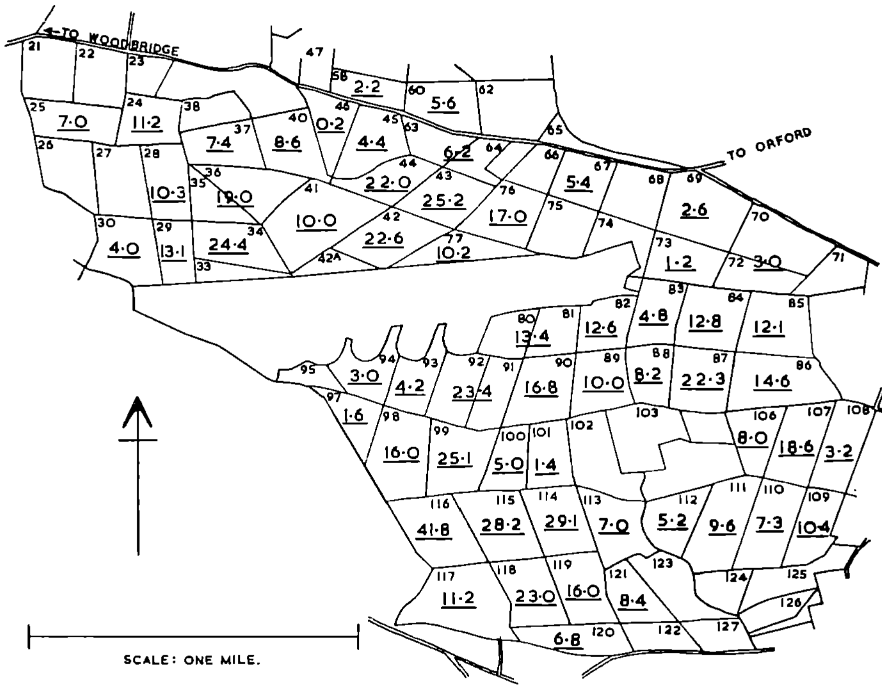

FIG. 13. Rendlesham Forest (Part only)—Underlined numbers show mean pupal count per square yard, by numbered compartments, in Spring 1959.

The history of *Bupalus* pupal populations at these two units, from 1954, when pupal surveying started, to the present day, is summarised in Table 46. Fluctuations in population, reaching maxima of up to 10 or so pupae per sq. yd. and descending in subsequent years to less than 1 pupa per sq. yd., appear to be typical of *Bupalus* population movements in this country. Such has been the case at Sherwood during the period under review. Rendlesham, on the other hand, has been unusual in that it has, until 1960, always contained at least some areas which have maintained a somewhat higher level of population than is normal. It was certain compartments within these areas which suffered the greatest increase in 1959.

Population Assessments, 1959

Pupal counts

The two maps (Figures 12 and 13) show the densities and distribution of pupal populations found in the normal survey and in the extension of it which followed the finding of high populations. A summary follows:

The female pupae collected during the surveys were heavier (Table 48) than any before recorded for these two forests and there should, therefore, be no doubt as to the reproductive capacity of the adults which arose from them. The fecundities to be expected at the mean pupal weights shown in the Table 48 for 1959 are 150 eggs per female for Rendlesham, and 130 eggs per female for Sherwood (Bevan and Paramonov, 1957).

Table 46

Yearly Population Levels by Pupal Count Classes

Forest	Cpt. Mean pupae per sq. yd.	No. of compartments in class						
		1954	1955	1956	1957	1958	1959	1960
RENDLESHAM (17 Compts.)	0– ·9	8	10	8	5	5	3	17
	1–1·9	1	4	2	3	5		
	2–2·9	4	1	3	6	3	1	
	3–3·9	3	2	1	2		2	
	4–4·9	1		1				
	5–5·9					2	1	
	6–6·9			1	1	2		
	7–7·9							
	8–8·9			1				
	9 or more						10	
SHERWOOD IV (21 Compts.)	0– ·9			8	21	17	1	2
	1–1·9	4	4	8		4	5	9
	2–2·9	5	5	3			1	6
	3–3·9	1	4	1			1	1
	4–4·9	3	5	1				1
	5–5·9	3	2				3	1
	6–6·9	2					1	1
	7–7·9	2						
	8–8·9	1					3	
	9 or more						6	

Table 47

Summary of 1958 Pupal Counts

Mean pupae per sq. yd.	Rendlesham No. of Cpts.	Sherwood IV No. of Cpts.
40–49	1	—
30–39	—	—
20–29	10	2
10–19	19	12
Less than 10	34	32

Table 48

Mean Pupal Weights

	Year	No. of samples	Mean Pupal weight		Year	No. of samples	Mean Pupal weight
RENDLESHAM	1956	85	137 m/gms	SHERWOOD IV	1956	69	105 m/gms
	1957	71	127 ,,		1957	5	87 ,,
	1958	85	137 ,,		1958	20	127 ,,
	1959	1,450	146 ,,		1959	1,068	132 ,,
	1960	8	127 ,,		1960	136	126 ,,

Adult and Egg Assessments

It is quite evident from the above data that both populations had the potential to cause damage and would therefore demand further investigation closer in time to the damaging larval stage. Egg assessments, in fact, would be required along the lines already described for Tentsmuir (Bevan 1960).

However, it was thought desirable, at least at Rendlesham where the risk of outbreak seemed to be the greater, to check on the success of the adult hatch, in view of the accumulating evidence that considerable mortality does often occur at this stage. This was done by the capture of adults emerging into 25 traps placed in a line across two compartments (115 and 116). Each trap consisted of an inverted opaque fibre glass bowl, 1 foot in diameter, having mounted on it a screw topped honey jar. Adults leaving the soil

Table 49

Egg Assessments and Pupal Means by Compartments

	Cpt. No.	Species & Planting Year	Mean Pupal Count 1959 per sq. yd.	(a) Mean eggs per tree	(b) Mean parasited eggs per tree	Parasitism	(a)-(b) Mean Effective Eggs per tree	Mean Pupal Count 1960 per sq. yd.
RENDLESHAM	86	SP, CP } P20	15	0	0	—	0	0·0
	91 & 92	SP P22	23	147	128	87	19	0·0
	121	SP P25	8	103	12	12	91	0·0
	40	SP P29	9	89	83	93	6	0·0
	107	SP P22	19	186	136	73	50	0·0
	114	SP P24, MP P22	29	136	114	84	22	0·2
	118	SP P22	23	593	358	60	235	0·0
	90	SP P21	17	994	362	36	632	0·0
	111	SP P22	10	461	304	66	157	0·0
	43	SP P23	25	583	527	90	56	0·6
	115	SP, MP } P22	28	732	714	97	18	0·0
	87	SP P20 & P25	22	253	209	83	44	0·0
	42	CP P23	23	621	354	57	267	0·0
	116	SP P22	42	635	15	2	620	0·0
	84	CP P20	13	217	100	46	117	0·0
	99	SP P24	25	455	29	6·4	426	0·0
SHERWOOD IV	54	CP P27	23	1,752	578	33	1,174	1·4
	47	CP P30	21	1,257	377	30	880	2·8
	49	CP P27	18	4,051	848	21	3,203	3·4
	71	CP P28	16	1,453	735	50	618	1·2
	53	CP P27	14	1,750	713	41	1,037	6·0
	68	CP P28	17	2,423	1,683	69	740	0·4
	57	CP P28	13	2,158	1,306	60	852	2·4
	37	CP P27	13	1,943	551	28	1,392	1·0
	55	CP P27	16	2,271	1,586	70	695	1·2
	50	CP P27	11	2,108	798	38	1,310	1·8
	58	CP P28	12	2,256	1,097	49	1,159	1·2
	35 & 36	CP P27	6	2,506	1,091	44	1,415	3·2

Note: C.P. = Corsican pine; M.P. = Maritime pine; S.P. = Scots pine.

enclosed by the bowl then flew up into the jar, and were collected from the traps daily.

Since the traps were performing the dual function of providing basic data on parasites, as well as on the more routine matter of adult check, an additional operation was included in the above method. Davies has pointed out (Bevan, Davies and Brown, 1957) the possibility of the repeated parasitisation of a single generation of *Bupalus* by successive ones of *Cratichneumon nigritarius Grav.*, and has since obtained evidence that such is, in fact, the case. In order to collect data on this, each trap was moved a standard distance every two days. A secondary advantage of the moving trap over a permanently placed one was that it would limit interference with the pupa's environment due to the presence of the trap.

Results of adult captures at Rendlesham gave a total of 110 adults emerging into the traps between 18.6.59 and 22.7.59, an average of 50·6 adults per square yard, of which 21·6 were females. The adult hatch had obviously been successful.

The assessment of eggs was carried out, using pupal densities as a guide, in the same way as that described for Tentsmuir (Bevan, 1960), the only major change being that trees were felled for collection of branch samples,

Table 50

Collection of Head Capsules, Dead Larvae and Prepupae in Funnel Traps: Rendlesham

Item	Instar	Date											Total
		21·7	6·8	19·8	2·9	15·9	29·9	8·10	20·10	3·11	18·11	8·12	
HEAD CAPSULE	1		16	20		1		1	2				40
	2		6	11	5	4							27
	3		1	5	12	7	4						29
	4				6	2	10	2	3				23
	5								1				1
	Total		24	36	23	q4	14	3	6				120
DEAD LARVAE	3							1					1
	4					3			1				4
	5							1	2	1*			4
	Total					3		2	3	1			9
PREPUPAE	5						1			1			2

*Parasitised

not climbed, it having first been established by test felling that the fall did not cause any major loss of eggs. The assessment thus became speedier and less dangerous.

Results of the egg assessments appear in Table 49, together with pupal densities.

Larval Assessments

A measurement of larval numbers was made at Rendlesham by collection of head capsules falling into funnel traps (Paramanov 1958). Twenty-five such funnels, each one-fifth sq. yd. top diameter, were placed out in a line parallel to that of the adult traps. To the neck of the funnels were attached muslin bags which were removed each fortnight for the contents to be examined in the laboratory. The head capsules were counted, measured and an estimate made of the proportion of the varying instars present. At the same time note was taken of falling larvae and prepupae (Table 50).

A similar set of traps was erected at Sherwood as soon as it was realised that larval populations were dense enough to justify further investigation. In this case the funnels were collapsible and were constructed of polythene film suspended from wire frames, each one having a top diameter of ⅓ sq. yd. Twelve of them were placed at random in each of compartments 49 and 57, and daily examinations made of the contents of their muslin bags between the dates 14.10.59 and 21.11.59. The results of the collection appear in Table 51.

Table 51

Collection of Larvae, Prepupae and Parasites in Funnel Traps: Sherwood

Item	Instar	Alive	Dead
Larva	4th		10
	5th	2	10
Prepupa	—	2	7
Pupa	—	5	1
C. oxyacanthae . .	—	22	—
Total		31	28

Final Pupal Counts, Spring 1960

A summary of results from this survey appears in Table 46. The last column of Table 49 gives the individual counts for those compartments which were also egg sampled.

Discussion

The main points of interest arising from this work are:

(a) At Rendlesham, although adult assessments indicated successful emergence, very few eggs were actually laid.

(b) At both forests many of the eggs were parasitised and heavy losses occurred in the larval stage.

(c) Pupal counts made in the spring of 1960 show the lowest pupal density yet recorded for Rendlesham, and a reduced population with no immediate threat at Sherwood.

The adults must somehow have been prevented from laying anything more than a fraction of their full complement of eggs. Whether this was due to predation or some other factor remains unresolved. The effect was less at Sherwood.

Egg parasitism was dramatically high at Rendlesham and considerable at Sherwood. However, even had this parasitism not taken place, in only one compartment (Sherwood Cpt. 49) would the mean egg density have been high enough to justify artificial control. Some slight visible damage would almost certainly have occurred, but only in this single compartment did the figure for mean effective eggs per tree exceed the 3,000 mark which had been set as "critical" for the crop.

Reference to the pupal counts carried out in the spring of 1960 shows clearly that only a small part of the population remaining after egg parasitism succeeded in pupating. There were considerable losses in the larval stage, but at Rendlesham only a small fraction of these can be accounted for. Table 50 shows the gradual wastage of larvae, including the numbers of dead falling from the trees. These dead larvae appeared blackened and distorted, but the cause of death is not known. Parasitism by either of the two more commonly found larval parasites cannot have been an important factor. The very low figure for pupae rule out *Heteropelma calcator* Wesm., since, although this species attacks the larva, it emerges from the pupa later in the following spring. Similarly, not only was *Campoplex oxyacanthae* Boie. very scarce in the autumn of 1959, but no cocoons were found in the pupal plots during the survey in the spring of 1960. The fact that only two prepupae, one of which was parasited, were found in the traps suggests that some form of predation had taken place in the crowns of the trees. On the other hand, at Sherwood, *C. oxyacanthae* was an important factor and was responsible for almost as much of the later stage larval loss as that due to other agencies (Table 51).

Thus it may be concluded that a number of natural controls were operating effectively at various stages, and together reduced these two populations to less than epidemic numbers. No one of them can be said to be more important than another, though, from the practical point of view the unknown factor which, by causing a reduction in oviposition, lowered the population so much that artificial control was not needed, deserves special attention.

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PROPAGATION OF ELMS AND POPLARS FROM SUMMERWOOD CUTTINGS

By J. D. MATTHEWS and J. JOBLING

Introduction

Most of the widely used cultivars of Black and Balsam poplars are propagated from dormant cuttings taken in spring and rooted by a simple procedure in the open nursery. The White poplars are not so readily propagated from dormant cuttings, and because of this some useful cultivars cannot be fully used in forest practice. The aspens are very difficult to root from dormant stem cuttings but can, with care, be raised from seed, this being the method in common use. Similarly the elms may be raised from seed but are not easy subjects from dormant cuttings. If the improved cultivars of aspen, White poplar and elm likely to become available are to be widely used, some method of rooting cuttings must be evolved which is cheap, easily controlled and gives results which can be regularly repeated. The development of the "mist" method of watering provides good control over humidity and watering, and has made the propagation of many hitherto difficult subjects much more practical. This paper describes the application of the mist method to the rooting of summerwood cuttings derived from cultivars of poplar and elm which are difficult to root from dormant cuttings.

Experiments with Poplar

The National Institute of Agricultural Engineering system of intermittent mist controlled by an "electronic leaf" (Bean et al. 1956) was installed at Alice Holt in July 1957, in a span-roofed propagation frame equipped with electrical soil warming, sufficient to maintain soil temperatures of 70 degrees Fahrenheit. Cuttings of a number of species were immediately inserted in this propagation frame, including four clones of poplar. The results were promising, cuttings of *Populus x canescens* S.B. rooting in 21 days and *P. tremula* M in 30 days. The results of this first small trial suggested that tip cuttings were more suitable than cuttings taken from the middle and basal parts of the current year's shoot.

The 1958 Experiments. In 1958 propagation experiments were set up for both poplar and elm. The poplar experiment compared eight sources of cuttings, four times of insertion, two rooting media and three methods of hardening off. The experimental design comprised two randomized blocks with split plots.

The cuttings consisted of the tips of lateral shoots taken without a heel of older wood, and from four to five inches long. The eight sources were four clones of White poplar, two aspens, an aspen x White poplar hybrid, and a clone of Black poplar which is difficult to root from dormant cuttings. The cuttings were collected in the neighbourhood of the Alice Holt Research Station, transported in polythene bags and inserted on the same day, the dates of insertion being 30th May, 20th June, 11th July and 1st August, 1958. The two rooting media consisted of an equal mixture, by volume, of fine Bedford silver sand and Sorbex granulated peat; and a mixture of ¼ fine sand, ¼ coarse sand and ½ Sorbex peat.

Assessments were made of the number of cuttings rooted three and six weeks after each time of insertion. Table 52 summarises the results three weeks after insertion.

Table 52

Number of Cuttings Rooted Three weeks after Insertion

Clone	Times of Insertion				All times
	30.5.58	20.6.58	11.7.58	1.8.58	
P. tremula M	15·0 (1)%	18·5%	18·5%	42·3%	23·6%
P. tremuloides H	61·8	39·0	58·3	18·5	44·4
P. x canescens C	65·3	60·0	50·3	66·3	60·4
P. x canescens W	58·3	45·0	56·5	53·8	53·4
P. x canescens S	71·5	75·0	75·0	71·5	73·3
P. x canescens BS	65·3	75·0	59·3	50·3	62·4
P. grandidentata tomentosa S..	42·3	34·3	25·5	37·3	34·8
P. deltoides angulata R ..	62·8	45·0	59·0	45·3	53·0
All clones	55·3	49·0	50·3	48·1	SE 3·08
					SE 1·72

(1) These percentage figures have been transformed by an angular method.

The statistical analysis revealed a highly significant difference in the rooting ability of the eight clones, the four clones of *Populus x canescens* emerging as the easiest, and *P. tremula* M as the most difficult. There was a significant interaction between times of insertion and clones, and this is most clearly seen in *P. tremula* M and *P. tremuloides* H. In the former it was difficult to find suitable material for cuttings early in the growing season; in the latter, late May and mid-July were the best times for insertion.

When the results from all the clones were taken together, the four times of insertion did not differ significantly in respect of number of cuttings rooted; but at the end of the first growing season it became evident that much larger plants could be obtained from cuttings inserted early in the growing season, i.e. late May and early June.

Plate 16 shows the growth of these cuttings.

The rooted cuttings were subjected to three methods of after-care. One-third were potted up, placed in a cold frame, and later lined out on the open nursery; one-third were bedded-out in a cold frame and later lined out; and one-third were lined out direct on the open nursery. In general, survival was highest in those cuttings which had been potted up or bedded out for three weeks before being lined out. (The rooting medium used in the pots and cold frame consisted of $\frac{1}{3}$ sand, $\frac{1}{3}$ peat, $\frac{1}{3}$ sterilised loam.) The difference between these treatments was greatest in plants from the fourth time of insertion, i.e. 1st August.

The 1959 Experiments. Most of the cuttings which rooted in 1958 had done so in three weeks after insertion. When this fact was considered in relation to the advantage of a hardening-off period before lining-out, it became obvious that the cuttings might conveniently be inserted in fibre or similar pots, using a potting compost as a rooting medium.

In July 1959 sixty cuttings of *P.* × *canescens* W were inserted in small peat pots 2½ inches in diameter and 3 to 3½ inches deep. The rooting medium in half the pots consisted of the half-and-half mixture of fine sand and Sorbex peat used in 1958; that in the other half was a potting compost of ⅓ sand, ⅓ peat and ⅓ sterilised loam. When the cuttings were placed in the propagation frame the two batches of cuttings were again split, half the pots being plunged in a mixture of peat and sand and half being stood on the surface.The results in numbers of rooted cuttings were strongly in favour of the potting compost as a rooting medium and of standing the pots on the surface of the peat and sand. This technique is now (i.e. 1960) being followed up in more detail.

A second aspect of technique studied in 1959 concerned the use of growth substances as an aid to rooting. The application of indole-butyric acid at 1,000 parts per million in talc to the base of the cuttings before insertion appreciably increased the speed of rooting and the number of cuttings rooted of many clones.

A final point which received attention in both 1958 and 1959 was that of survival of rooted cuttings. Once cuttings are rooted, subsequent survival depends to a large extent on the original size and physiological condition of the cuttings at insertion. Sturdy, vigorous tip cuttings which were at least 5 inches long when taken and inserted survived well enough; smaller material did not. Of the 1,139 cuttings rooted in 1959, 726 or 63 per cent survived the winter of 1959/60.

The Rooting Behaviour of a Number of Poplar Clones

Once a suitable procedure had been evolved for rooting summerwood cuttings under mist, batches of cuttings from ninety clones were inserted in the "mist" frame. The rooting ability from dormant cuttings of most of these clones was already known. Table 54 gives details of the results obtained from summerwood cuttings and it suffices here to summarise the principal results.

The White poplars of Section *Leuce* generally give moderate results from dormant cuttings. Summerwood cuttings of eight clones of *P. x canescens* proved easy to root under "mist" and they can be inserted from June through to the end of July. *P. alba* 'Bolleana' B and *P. x canescens* 'Megaleuce' were difficult clones. Several inter-Section hybrids were tried. Of these the clone *P. grandidentata x tomentosa* S was the most difficult. The white x black, and white x balsam, hybrids, had something of the high rooting ability of their black and balsam parents.

The aspens of Section *Leuce* are difficult to strike from dormant cuttings, though Peace (1952) could report that young shoots could be rooted under glass in the early summer. Summerwood cuttings of thirteen clones of *P. tremula* were tried under "mist" with results ranging from 5 to 100 per cent of rooted cuttings. One factor affecting success was the thinness and smallness of the cuttings from some clones. A similar range in percentage of cuttings rooted was obtained with the clones of *P. tremuloides* and *P. grandidentata*, but these were easier to root than *P. tremula*. The majority of the seventeen clones of the hybrid *P. tremula x tremuloides* rooted moderately well, but no cuttings of hybrid clones E2B or E3A were rooted. Time of insertion is most important for the aspens; suitable material for cuttings is often not produced until early July.

Balsam poplars of Section *Tacamahaca* are generally easily propagated from dormant cuttings, and the twelve clones tried rooted quickly and easily from summerwood cuttings. Most of the Black poplars of Section *Aigeiros* are also easy to root from both dormant and summerwood cuttings but there are exceptions, one being *P. deltoides* var. *angulata.* Table 52 shows that in this case late May and early July are suitable times for inserting summerwood cuttings under mist.

Finally there are the poplars of Section *Leucoides.* These are difficult to root as dormant cuttings but easier as summerwood cuttings taken in July. *P. wilsonii* H was the most difficult of the four *Leucoides* clones tried under mist.

The present state of knowledge may be summarised thus:

(a) There is an apparent relationship between the rooting ability of poplar clones from dormant and summerwood cuttings. Those difficult to root from dormant cuttings are also relatively difficult to root from summerwood cuttings.

(b) The "mist" system provides a useful method of propagating cuttings of Sections *Leuce* and *Leucoides* and also the few *Aigeiros* poplars which are difficult to root from dormant cuttings.

(c) Best results on both rooting and subsequent survival are obtained from sturdy and vigorous cuttings at least five inches long. Material of this type and size is often not obtainable from the aspens until early July, but can be found on most other poplars throughout June and July. The application of indole-butyric acid in talc is an advantage.

(d) Once the behaviour of the individual clones is known, the mist frame can be adapted for mass production of rooted cuttings. The cuttings can be inserted direct into peat or similar pots, and the process of hardening-off or "weaning" begun by tapering-off the water supply some 3 to 4 weeks after insertion.

(e) There still remain several intractable subjects. If progress is to be made with these, a more fundamental physiological approach is required to determine the essential barrier or barriers to the rooting of cuttings.

The Experiments with Elm

As already stated, propagation experiments were set up in 1958 for both poplars and elms. The elm experiment included twelve sources of cuttings, four times of insertion, one level of application of a growth substance and two rooting media. The cuttings consisted of the tips of lateral shoots taken without a heel of older wood and from four to five inches long. They were derived from a collection of grafted plants at the Alice Holt Research Station and were all collected, transported in polythene, and inserted on the same day; the dates of insertion being 17th and 30th June and 14th and 28th July. The two rooting media were those employed for the poplars and assessments of the number of cuttings rooted were made four, six, eight and ten weeks after insertion.

Table 53 summarises two of the principal results from this experiment.

Table 53

Total Number of Cuttings Rooted for all Twelve Clones

Expressed as a Percentage of Cuttings Inserted

Times of Insertion								Total (1)	
17th June		30th June		14th July		28th July			
Control	I.B.A.	Control	I.B.A.	Control	I.B.A.	Control	I.B.A.	Control	I.B.A.
57	72	54	59	42	46	46	46	50	57

(1) The total number of cuttings inserted was 526, half of which were treated with Indole-butyric acid (I.B.A.).

It will be seen that, in general, the latter half of June is a suitable time to insert summerwood cuttings, and this period is better than July. This generalised statement does not, however, hold good for all the clones tried in 1958; three of the twelve clones rooted better from cuttings taken in July.

With the exception of cuttings inserted on 17th June, the application of Indole-butyric acid, at a concentration of 1,000 parts per million in a talc carrier, to the base of the cuttings did not increase total rooting, but it did increase the speed of rooting when all the results were taken together. One-third of untreated cuttings had rooted four weeks after insertion compared with one-half for the treated cuttings. At six weeks after insertion the difference was less marked and at eight weeks it had disappeared. The data collected also suggested that it was not worth while leaving cuttings in the frame for more than eight weeks, as 95 per cent of the cuttings which eventually rooted had done so by that time.

No statistical comparisons were possible between the two rooting media, but the root systems of the cuttings were appreciably better in the mixture of fine sand and peat.

Immediately after removal from the mist propagation frame (which it will be remembered was also equipped with electrical soil warming wires to maintain the temperature of the rooting medium to 70 degrees Fahrenheit) the cuttings were bedded out in half-and-half sand and peat, and watered frequently for one week. They were then put into 4½-inch pots. This technique was improved in 1959 when the cuttings were immediately potted up, plunged in soil in a cold frame and watered frequently over a period of three weeks.

Survival of the rooted cuttings was good. More than eighty per cent of the cuttings rooted in 1958, and almost ninety per cent of the cuttings rooted in 1959, survived the succeeding winters.

The Rooting Behaviour of a Number of Elm Clones

In June and July 1959, batches of cuttings from twenty-five sources were inserted in the mist frame. Table 55 gives details of the combined results for both 1958 and 1959 so that the rooting ability of these clones may be assessed.

The cuttings inserted in 1959 were derived both from graftings at Alice Holt and direct from parent trees in Britain. Cuttings of all the clones were rooted but the Dutch clones 19, 202, 284 and 285 were more difficult than the remainder. The present state of knowledge may be summarised thus:

(a) There is no apparent relationship between the rooting of the clones and their parentage.

(b) The mist method of propagation provides a useful method of rooting summerwood cuttings. Although propagation by grafting is more certain, the production of clonal material on its own roots has obvious advantages for experimental purposes and, when more is known about the subsequent growth of rooted cuttings, perhaps for practical use also.

(c) The best results in both rooting and subsequent survival are obtained from sturdy and vigorous cuttings at least five inches long. Material of this type and size can be obtained from most clones during the latter half of June and throughout July. The application of 1,000 p.p.m. Indole-butyric acid in talc is an advantage.

(d) Care must be taken in hardening-off summerwood cuttings rooted under "mist". Insertion of the cuttings in peat or similar pots has obvious advantages in simplifying after-care.

Summary

Summerwood cuttings of 90 poplar and 25 elm clones were inserted under "mist" in 1958 and 1959 in a series of experiments, and an extensive trial of the method. Tip cuttings at least five inches long, taken in June or July depending on the clone, can be rooted. Indole butyric-acid applied in talc increases the speed of rooting. The after-care of cuttings is simplified if they are inserted and rooted in peat or similar pots, and work continues to further develop this procedure. The "mist" method is a most useful technique, supplementing dormant cuttings in poplars and grafting in elms.

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Table 54

The Rooting of Poplar Clones from Dormant and Summerwood Cuttings

Clone	Number of batches inserted	Total number of cuttings	Rooting Ability Dormant	Rooting Ability Summerwood	Notes
(1)	(2)	(3)	(4)	(5)	(6)
(1) SECTION LEUCE: WHITE POPLARS					
Populus:					
alba 'Bolleana ' B	2	27	2	3	
alba 'Richardii'	2	20	?	1	
tomentosa H	2	35	3	1	
x *canescens* B	2	32	2	1	
x *canescens* BS	6	105	2	1	
x *canescens* C	5	90	2	1	
x *canescens* CE	2	46	2	1	
x *canescens* GA	2	45	2	1	
x *canescens* LG20	2	37	2	1	
x *canescens* S	6	103	2	1	
x *canescens* W	8	268+	2	1	
x *canescens* 'Megaleuce'	2	130	2	3	
grandidentata x *tomentosa* S	6	212+	2	3	Variable; best result July 44%
canescens x *nigra* 448-1	2	14	2	1	White x black hybrids
canescens x *nigra* 448-2	2	5	2	2	
Alba x *grandidentata* 190	2	10	1–2	1	White x aspen hybrid
alba x *trichocarpa* 1	2	26	1–2	1	White x balsam hybrid
(2) SECTION LEUCE: ASPENS					
Populus:					
tremula B	2	20	3	3	
tremula BM.2	2	51	3	3	
tremula BM.3	2	50	3	3	
tremula BM.4	2	37	3	3	
tremula BM.5	2	57	3	2–3	Best result July 55%
tremula BM.7	2	57	3	3	
tremula C	3	181+	3	3	Best result July 54%
tremula LH.2	2	20	3	2–3	
tremula LH.3 (A)	2	20	3	3	
tremula L.H.3 (B)	1	5	3	3	
tremula LH.4	2	25	3	3	
tremula M	7	138+	3	2–3	Best result July 1959—100%
tremula MB	3	30+	3	3	
tremula davidiana F(A)	3	55+	3	3	
tremula davidiana F (B)	1	8	3	Failure	
tremula davidiana M	1	10	3	Failure	
tremula 'Gigas'	2	50	3	2–3	Best result July 1959 60%
tremuloides H	6	132+	3	2	Variable; best result July 100%
tremuloides T	3	61+	3	Failure	
grandidentata H	3	132+	3	3	
grandidentata S	2	50	3	3	
adenopoda H	3	20+	2	2	Best result July 100%
sieboldii H	2	50	3	3	
adenopoda x *tremuloides* 23	2	25	3	2–3	
tremula x *tremuloides* A	2	70	3	2	
tremula x *tremuloides* E1A	2	35	3	3	
tremula x *tremuloides* E1B	2	16	3	3	
tremula x *tremuloides* E2A	1	4	3	2	
tremula x *tremuloides* E2B	1	12	3	Failure	

Clone	Number of batches inserted	Total number of cuttings	Rooting Ability Dormant	Rooting Ability Summerwood	Notes
(1)	(2)	(3)	(4)	(5)	(6)
(2) SECTION LEUCE: ASPENS—*continued*					
Populus—continued:					
tremula x *tremuloides* E3A	1	9	3	Failure	
tremula x *tremuloides* E3B	1	28	3	3	
tremula x *tremuloides* E4A	2	24	3	3	
tremula x *tremuloides* E4B	2	15	3	3	
tremula x *tremuloides* H 451-2	2	8	3	2	
tremula x *tremuloides* H 452-6	2	25	3	2	
tremula x *tremuloides* H 379-3	2	21	3	2	
tremula x *tremuloides* J	2	45	3	2	
tremula x *tremuloides* J1	2	50	3	2	
tremula x *tremuloides* J2	2	40	3	2	
tremula x *tremuloides* J3	2	35	3	3	
tremula x *tremuloides* 254	3	12	3	2	
'Hybrida' 1					
(3) SECTION AIGEIROS, BLACK POPLARS					
Populus:					
nigra 63	2	14	1	1	
nigra 103	2	15	1	1	
nigra S1	3	19+	1	1	
nigra S2	3	19+	1	1	
nigra charkowiensis S	3	47+	1	1	
deltoides S189	1	25	1	1	
deltoides var. 'angulata' R	4	80	3	2	
deltoides var. 'angulata' D	2	36	3	1	
'Kornik' II	1	3	1	2	Thought to be hybrids
'Kornik' 21	1	4	1	2	
'Kornik' 25	1	4	1	1	
wislisenii D.2	1	5	1	1	
(4) SECTION TACAMAHACA BALSAM POPLARS					
Populus:					
Suaveolens S2	3	18+	1	1	
Suaveolens S3	3	14+	1	1	
Suaveolens S5	1	10	1	1	
Suaveolens S6	3	18+	1	1	
Suaveolens E1344	3	29+	1	1	
koreana S1	3	29+	1	1	
koreana S2	1	15	1	1	
"*Kornik*" 4	1	5	1	1	Closely related to *P. 'suaveolens'*
"*Kornik*" 5	1	10	1	1	
"*Kornik*" 6	1	2	1	1	
"*Kornik*" 7	1	5	1	1	
(5) SECTION LEUCOIDES					
Populus:					
lasiocarpa H	3	28+	3	1–2	Best result June 100%
wilsonii H	3	40+	3	3	
wilsonii P	3	15+	3	3	Best result July 1959 75%
ciliata	2	20	1	1	
heterophylla K2	3	56+	3	2	

Notes: Column 1. The nomenclature follows the rules of the International Code of Nomenclature for Cultivated Plants. The suffix letters and numbers refer to the origin of the clones and are used for record purposes only.

Column 2. Batches of cuttings were inserted in July 1957; May, June, July, August 1958; June and July 1959.

Column 4. Rooting Ability from Dormant Cuttings 1 = readily rooted.
2 = rooted with some difficulty.
3 = practically impossible to root.

Column 5. Rooting Ability from Summerwood Cuttings 1 = readily rooted; with results in excess of 66%.
2 = rooted with some difficulty; with results ranging between 34 and 66%.
3 = difficult to root or failure; with results ranging between 0 and 33%

Table 55

The Rooting of Elm Clones from Summerwood Cuttings

Clone (1)	Parentage (2)	Number of batches inserted (3)	Total number of cuttings (4)	Rooting ability (5)
Variegated	*U. procera*	1	33	3
297	*U. carpinifolia* 'Christine Buisman' (free pollinated seedling origin)	4	76	1
Bath E	*U. carpinifolia*	1	36	1
284	*U. carpinifolia* 61 (selfed)	5	110	2
285	*U. carpinifolia* 62 (selfed)	5	120	2
283	*U. carpinifolia* 62 x *carpinifolia* 1	3	95	1
M	*U. stricta*	1	47	1
W	*U. stricta*	1	14	1
G2	*U. carpinifolia* x *glabra*	1	41	1
RT	*U. carpinifolia* x *glabra*	5	133	1
5A	*U. carpinifolia* x *glabra*	4	130	1
19	*U. carpinifolia* x *glabra*	5	123	2
O2	*U. carpinifolia* x *glabra*	1	50	1
Bath	*U. hollandica vegeta*	1	49	2
177	*U. hollandica vegeta* x *carpinifolia* 1	4	66	1
274	*U. hollandica vegeta* x *carpinifolia* 1	4	69	1
148	*U. hollandica vegeta* x *carpinifolia* 28	4	72	1
B1	*U. hollandica hollandica*	1	64	2
B2	*U. hollandica hollandica*	1	39	2
B3	*U. hollandica hollandica*	1	49	2
B4	*U. hollandica hollandica*	1	26	2
260	*U. pumila* pinnato ramosa x *hollandica vegeta*	4	53	1
202	*U. wallichiana* x *glabra fastigiata*	4	97	2
248	*U. wallichiana* x *carpinifolia*	1	24	1

Notes: Column 1. These letters and numbers refer to the origin of the clones and are used for record purposes only.

Column 3. Batches of cuttings were inserted in June and July 1958 and 1959.

Column 5. Rooting ability from summerwood cuttings.

1 = readily rooted with results in excess of 66%.

2 = rooted with some difficulty; with results ranging between 34 and 66%).

3 = difficult to root or failure; with results ranging between 0 and 33%.

ESTIMATING YIELD OF HARDWOOD COPPICE FOR PULPWOOD GROWING

By C. D. BEGLEY and A. E. COATES

The establishment of a pulp mill at Sudbrook near Chepstow (Monmouthshire), using the neutral sulphite semi-chemical process for pulping hardwoods, has led to an increased interest in renewable sources of hardwood. In 1957 a small committee, composed of representatives from the growers, the timber trade and allied interests, and the pulp mill itself, undertook a study of the various problems associated with the growing of hardwood for pulpwood and in particular the possible yields. For high forests, information, some published and some unpublished, was already available (Waters & Christie, 1958; Christie 1959). For the coppice, separate information was available for Sweet chestnut and hazel only. A study on these species had been undertaken some years earlier (Begley 1955; Richards et al. 1956).

The Committee were particularly interested in coppice as a form of management, for it offered a simple method of regeneration apparently far less expensive than the establishment of new plantations; furthermore it was an obvious method to adopt for the rehabilitation of derelict or scrub hardwoods; finally it was a well-tried method for growing timber of the size at present regarded as suitable for the pulpwood market, viz. 3½ to 12 inch top diameter. Pulpwood in fact corresponds to fuel wood specifications in some respects, and for centuries coppice regeneration had been the usual method of growing fuel wood.

To obtain reliable yield tables for coppice hardwoods would have been a time-consuming operation, involving the establishment of sample plots in numerous stands and measurements extending over a period of many years. It was therefore decided to gain some idea of the yielding capacity of various hardwood species by selecting a number of stands and assessing their vigour and stocking. The yield figures for such stands would be used as an indication of the species potential on the clear understanding that the use of the results would be qualified by the subjective method of choosing the sites and that the results did *not* represent average yields under unspecified sites conditions.

It was decided that, as far as possible, well-developed stands, of good stocking and properly managed (this was interpreted to mean free from obvious signs of mismanagement) should be chosen, because, in so far as these conditions were fulfilled, so the results would represent the ability of each species to exploit a site appropriate to it. In the event, some sites fell short of this requirement and this will be dealt with at greater length in the discussion on the experimental field work.

Objects of the Experiment

The objects of the experiment were defined in the experiment plan as the determination of the gross yield, in dry weight, of the following species:—oak, birch, alder, sycamore, ash, white willow, poplar and lime. The limits of size of material specified were:—less than 3½ inches diameter over bark for pulpwood and less than two inches diameter over bark for boardwood material. No poles less than four feet in length to these diameter limits were taken into account. The reasons for these definitions were that manufacturers' production estimates are based on dry weight of wood and that these are the limits used, as a rule, by them.

In order to assess the dry weight yield it was necessary to assess the normal specific gravity (green volume/dry weight) and incidentally the moisture content of the freshly felled timber. These assessments were made by the Forest Products Research Laboratory of the Department of Scientific and Industrial Research and are given in Table 57. The dry weight yields are quoted in the summary of results given in Table 58 as maxima and minima because, as was expected from an earlier study (Begley and Jeffers, 1958) there was considerable variation from pole to pole and within poles. Elsewhere the results are given as green weights, for simplicity. The weight of bark was included in the results—it is about the same density as wood and therefore its inclusion should not seriously affect the value of the results.

Selection of Site and Plots

Oak is the dominant coppicing species in the West country, and is usually grown as coppice with standards. It is normally in mixture with birch on dry sites and with ash and alder on wet sites. With the exception of oak, and to a much lesser extent Sweet chestnut, the presence of coppice growth of any of the hardwood species on any particular site is fortuitous, being due merely to their ability to develop from felled or devastated broadleaved high forest. Coppice develops either from the stumps of the felled standards or, more frequently, from the stumps of pole-size growth which lie between the standards. Birch does not coppice well, but often comes in freely on felled sites. Of all the sites in which plots were measured, only the oak at Penyard in south Herefordshire, had been grown purposely as coppice. Here the crop had formerly been managed as coppice-with-standards (the standards having now been removed) and oak was the dominant species. The alder at Shobden, in north Herefordshire, was growing on a site subject to periodical flooding and probably represented the vegetation climax.

When selecting the site for the one-tenth-acre plots, a thorough inspection was made, so as to have an area where the species concerned was growing relatively pure, and was satisfactory from a point of view of stocking, stem form and rate of growth. This objective was generally achieved in all the plots, but in some the distribution of stools and stems was uneven and it is uncertain to what extent this may have affected increment. Details of the stocking of each plot, including the number of stools per acre and the number of poles per acre above and below the diameter limits for pulpwood, are given in Table 56.

So far as could be ascertained, with the exception of the ash at Wellesbourne Wood, Warwickshire, and the oak at Penyard, Herefordshire, no thinning had been done in any of the plots, so that the weights recorded represent total production. In the ash plot at Wellesbourne Wood, a light thinning had been applied the winter previously. The thinnings had been left by the stumps and were weighed in with the standing materials. The standards over the coppice oak at Penyard were felled when the coppice crop was aged 5-10 years and a small amount of cutting was done in the coppice at the same time. Since the number of poles removed was quite small, this would not have had much effect on yield.

Weighing of Material

The weights of all material were recorded over bark, the weighing being done as soon as possible after felling to avoid loss of weight through drying out. In all plots, except the poplar and willow plots at Rudhall, near Ross-on-Wye, Herefordshire, all the poles were trimmed to 3½ inches top diameter over bark, and weighed. In addition, ten sample coppice stems were selected at random and their weights to both 3½ inches and 2 inches top diameter over bark were recorded. The weight in each plot, to 2 inches top diameter, over bark, was estimated from these sample stems, and the known weight to 3½ inches top diameter over bark.

Because of the large size of the coppice stems involved it was not practicable to weigh all the material in the poplar and willow plots at Rudhall (plots 12 and 13). Here, the girth of each coppice stem was recorded and the total basal area in each plot calculated. A pole with a girth corresponding to the mean girth of the plot was felled and weighed. The total weight of the plot to 3½ inches and 2 inches top diameter o.b. was calculated from the weight of the sample plot to these limits as follows:

$$\text{Total weight of plot} = \frac{\text{Weight of sample pole (lbs.)} \times \text{Total Basal Area of plot (sq. ft. q.g.)}}{\text{Basal Area Sample pole (sq. ft. q.g.)}}$$

The results of these calculations are given in terms of dry weight and green weight and are given in Table 58.

Stem Analysis

Although the experimental data are only of limited value since they concern yields of species at specific ages, stem analysis of selected coppice poles was carried out in order that an estimate could be made of the past growth and increment of each species on these sites.

In the poplar and willow plots at Rudhall the stem analysis was done on the one pole, in each plot, which was felled for weighing. This pole would therefore represent the mean for the plot. In the other plots, the stem analyses were made on 3 vigorous coppice poles in each plot and these, therefore, trace the development of the growth of the dominant coppice poles in each plot and may lead to an overestimate of increment.

With birch, the annual growth rings were often indistinct, false rings were common, and towards the outside of each disc the rings were so close together that it was impossible to distinguish between annual rings and false rings. It was therefore necessary to evolve a system by which the annual rings could be clearly seen and measured accurately. The method eventually developed involved planing and sanding the discs to get a perfectly smooth surface because irregularities on the surface became accentuated with any type of stain applied. A solution of ferric chloride was then painted on, allowed to dry and then sanded lightly to remove the dark patches caused by the stain which obliterated some of the detail. Finally a clear varnish was applied to bring out the detail produced by the stain.

Discussion of the Results

The stem analysis data enabled the past growth in each plot to be estimated. That is shown in Table 59, in which the height development, the periodic annual increment and mean annual increment in green tons per acre to 3½ inches top diameter over bark, are given at intervals of three to five years, up to the age at which the various plots were measured. This information gives an approximation of the periodic annual increment, with age of each plot. Its value is limited because analysis was done on only three poles in the plot (except for the poplar and willow plots) and these poles were subjectively chosen for their vigour. Furthermore, measurements were taken during the period June-August when the trees were in process of putting on their annual growth. During early June, when the new ring was very narrow and could hardly be distinguished, it was usually included in the measurement of the last ring width. In August the new annual ring was measured separately. In July the new annual ring was not measured.

The results do not represent a real comparison of the rate of growth between the species, since the species were growing on a wide range of sites, some favourable and some not. For example, the sycamore at Hinckley (Plot 1) was growing on a sandy loam of good structure and high base status, whereas the ash at Wellesbourne (Plots 2 and 3) was on an impervious water-logged clay. In addition to differences in soil conditions, and in other factors such as elevation and degrees of exposure, although all the plots were properly stocked, in that there was complete canopy cover, there were differences in stocking in the different plots (see Table 56) which might in some cases have caused some loss of increment during the early stages.

However, with these qualifications in mind, the results are of some value. Tables 58 and 59 illustrate, for example, the high yields of lime, poplar and willow coppice, and the low yield of ash, on the sites investigated. Table 58 enables the yields to be compared only at the ages at which the various species were felled. In Table 59, on the other hand, comparison can also be made between the yields and increment of the different species at the same age. This table shows the marked increase in yield at various ages for the different species due to the recruitment of poles from the category of "unmeasurables" (i.e. below the girth limit for pulpwood) as the crop matures. The fast growing poplar, willow and lime plots yield appreciable quantities of pulpwood from the early age of 10 years, while it is not until the 16th year for birch and oak and the 20th year for ash that material becomes available. In addition, although pulpwood yield commences late, the periodic annual increment in the ash plots has already started to decline after 30 years. The periodic annual increment of the oak coppice shows a marked reduction after 35 years and the poplar a slight reduction between 20 and 25 years. In the other plots the point of maximum periodic annual increment had not been reached when they were felled.

Finally it is suggested that the results obtained from these analyses may be of greater interest if read in conjunction with the published data already available for high forest crops and referred to in the introduction. Differences would be expected between crops grown under the widely different silvicultural systems as "coppice" and "high forest". Nevertheless, it is instructive to compare the yields obtained, at comparable ages, under the two systems. For example, it is worth noting that volume production for the poplar plot from this study is considerably greater than is given in the yield tables. The total volume production for the Rudhall plot of 5,260 hoppus feet at 93 feet mean height compares with a total volume production of 3,500 hoppus feet at a mean height of 93 feet read from the mean height graph on page 4 of the published poplar yield tables. The higher volume production is clearly related to the heavier stocking of 338 stems per acre compared with an initial stocking of only 100 trees per acre assumed in the yield table.

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Table 56

Number of Stools and Stems (by Size Classes) per Acre

Plot No.	Site	Species	Age yrs.	Top height ft.	No. of stools per acre	No. of poles per acre (diam at b.h.) (1"—2")	(2½" and over)
1	Hinckley, Warwick	Sycamore	16	40	240	510	1,000
2	Wellesbourne ,,	Ash	32	49	240	80	850
3	,, ,,	Ash	32	44	240	200	920
4	Coughton ,,	Lime	12	30	150	390	980
5	,, ,,	Lime	12	31	150	530	1,380
6	Rowlstone, Hereford	Birch	37	53	—	Nil	1,050
7	,, ,,	Birch	37	53	—	50	850
8	Penyard ,,	Oak	37	41	170	140	630
9	,, ,,	Oak	40	45	160	80	570
10	Shobdcn ,,	Alder	20	32	280	570	1,530
11	,, ,,	Alder	20	37	190	580	1,540
12	Rudhall ,,	Poplar	25	93	111	Nil	338
13	Rudhall ,,	White Willow	25	75	—	130	540

Table 57

Range of Moisture Content and Green Volume/Dry Weight Density (over bark)

Plot No.	Species	Age (Years)	M.C.%	Green Volume/Dry Weight Density	
				gms/c.c.	lbs/hoppus ft.
1	Sycamore	16	101·4—64·7	0·409—0·464	32·5—36·9
2	Ash	32	54·4—43·1	0·478—0·591	38·0—47·0
3	Ash	32	59·1—49·0	0·510—0·575	40·5—45·7
4	Lime	12	161·5—81·3	0·207—0·417	16·5—33·2
5	Lime	12	163·1—90·6	0·224—0·386	17·8—31·5
6	Birch	37	90·3—58·7	0·472—0·567	37·5—45·1
7	Birch	37	90·9—62·0	0·491—0·562	39·0—44·7
8	Oak	37	92·6—64·6	0·544—0·664	43·2—52·8
9	Oak	40	84·8—70·9	0·563—0·639	44·8—50·8
10	Alder	20	126·1—99·2	0·408—0·445	32·4—35·4
11	Alder	20	114·0—88·2	0·397—0·480	31·6—38·2
12	Poplar	25	186·2—66·7	0·336—0·432	26·7—34·3
13	Willow	25	93·5—84·0	0·307—0·423	24·4—33·6

Notes: Moisture Content % $= \frac{Ww - WD}{WD} \times 100$

Ww — Wet Weight.

WD — Dry Weight.

Table 58

Yields of Dry Wood (including Bark) per acre to 2 inch and 3½ inch Top Diameters

Plot No.	Species	Age (years)	Weight to 3½″ top diam. Tons per acre	Mean Annual Increment Tons per acre	Weight to 2″ top diam. Tons per acre	Mean Annual Increment Tons per acre
1	Sycamore	16	9·31–11·39 (18·76)	0·58–0·71 (1·173)	13·25–16·20 (26·68)	0·83–1·01 (1·667)
2	Ash	32	19·53–21·07 (30·16)	0·61–0·66 (·942)	24·47–26·40 (37·78)	0–76–0·83 (1·181)
3	Ash	32	25·63–27·37 (40·78)	0·82–0·88 (1·305)	31·63–33·78 (50·33)	0·88–1·06 (1·573)
4	Lime	12	5·25–7·58 (13·74)	0·44–0·63 (1·145)	7·46–10·76 (19·50)	0·62–0·90 (1·625)
5	Lime	12	6·41–8·85 (16·87)	0·53–0·74 (1·406)	9–71·13·41 (25·56)	0·81–1·11 (2·130)
6	Birch	31	31·31–37·55 (59·59)	0·82–1·02 (1·611)	39–96·47·92 (76·05)	1–08–1·30 (02·6)
7	Birch	31	32·34–38·11 (61·74)	0·87–1·03 (1·669)	36·48–42·99 (69·64)	0·99–1·16 (1·88)
8	Oak	37	37·36–46·05 (75·80)	1·06–1·24 (2·049)	44·94–52·58 (86·55)	1·21–1·42 (2·34)
9	Oak	40	33·65–36·38 (62·18)	0·84–0·91 (1·554)	34·30–37·92 (63·39)	0·86–0·95 (1·585)
10	Alder	20	11·73–13·32 (26·53)	0·59–0·67 (1·326)	15·52–17·61 (35·08)	0·78–0·88 (1·750)
11	Alder	20	18·0–20·47 (38·53)	0·90–1·02 (1·927)	22·72–29·25 (55·04)	1·29–1·46 (2·752)
12	Poplar	25	53·99–92·70 (154·53)	2·16–3·71 (6·182)	56·25–96·58 (161·0)	2·25–3·86 (6·440)
13	Willow	25	58·25–61·26 (112·72)	2·33–2·45 (4·509)	61·07–64·23 (118·18)	2·44–2·57 (4·727)

Note: The figures in brackets are the fresh felled weights.

Table 59

Estimate of Height Growth and Increment (in tons per acre). Material to 3½ inch Top Diameter:

Plot No.	Species		Age in Years 6	10	13	16	20	25	30	35	40
1	Sycamore	Ht. (ft.)		29	34	39					
		Tot. Production			7·24	18·76					
		P.A.I.				3·84					
		P.A.I.%				29·5%					
		M.A.I.			·56						
2	Ash	Ht. (ft.)		22	27	30	34	41	46	49 (32 yrs)	
		Tot. Production					4·66	14·26	25·86	30·16	
		P.A.I.						1·92	2·32	2·15	
		P.A.I.%						11·6%	7·7%		
		M.A.I.					·23	·57	·86	·94	
3	Ash	Ht. (ft.)		16	20	24	30	36	42	44 (32 years)	
		Tot. Production				·36	8·64	21·14	35·84	40·78	
		P.A.I.					2·07	2·50	2·94	2·47	
		P.A.I.%						16·8%	10·3%	6·5%	
		M.A.I.				·02	·43	·85	1·19	1·27	

Plot No.	Species		Age in years								
			6	10	13	16	20	25	30	35	40
4	Lime	Ht. (ft.)	16	25	30 (12 yrs)						
		Tot. Production		7·38	13·74						
		P.A.I.			3·18						
		P.A.I.%			30·1%						
		M.A.I.		·74	1·15						
5	Lime	Ht. (ft.)	18	27	31 (12 yrs)						
		Tot. Production		9·65	16·87						
		P.A.I.			3·61						
		P.A.I.%			27·2%						
		M.A.I.		·96	1·41						
6	Birch	Ht. (ft.)			28	34	39	45	51 (31 yrs)		
		Tot. Production				2·90	16·46	36·01	55·56	59·59	
		P.A.I.					3·39	3·91	3·91	4·03	
		P.A.I.%						14·9%	8·6%	7·0%	
		M.A.I.				·18	·82	1·44	1·85	1·92	
7	Birch	Ht. (ft.)			28	33	39	45	51 (31 yrs)		
		Tot. Production				7·08	19·72	38·92	58·12	61·74	
		P.A.I.					3·16	3·84	3·84	3·62	
		P.A.I.%						13·1%	7·9%	6·0%	
		M.A.I.				·44	·99	1·56	1·94	1·99	
8	Oak	Ht. (ft.)			19	22	26	30	34	39	41 (37 yrs)
		Tot. Production				2·20	13·68	30·78	51·28	69·78	75·80
		P.A.I.					2·87	3·42	4·10	3·70	3·01
		P.A.I.%						15·4%	10·0%	6·1%	4·1%
		M.A.I.				·14	·68	1·23	1·71	1·99	2·05
9	Oak	Ht. (ft.)			16	21	26	31	38	41	45
		Tot. Production			·80	3·79	11·23	23·33	37·48	51·38	62·18
		P.A.I.				·997	1·86	2·42	2·83	2·78	2·16
		P.A.I.%					24·7%	13·9%	9·3%	6·3%	3·8%
		M.A.I.			0·6	·24	·56	·93	1·25	1·47	1·55
10	Alder	Ht. (ft.)			23	26	32				
		Tot. Production			3·33	12·59	26·53				
		P.A.I.				3·12	3·46				
		P.A.I.%				38·9%	17·7%				
		M.A.I.			·26	·79	1·33				
11	Alder	Ht. (ft.)		20	25	30	37				
		Tot. Production			·58	15·97	38·53				
		P.A.I.				5·13	5·64				
		P.A.I.%					20·7%				
		M.A.I.			0·4	1·00	1·93				
12	Poplar	Ht. (ft.)		37	45	59	75	88			
		Tot. Production		15·50	39·65	65·15	105·03	154·53			
		P.A.I.			8·05	8·50	9·97	9·90			
		P.A.I.%			29·2%	16·2%	11·7%	7·6%			
		M.A.I.		1·55	3·05	4·07	5·25	6·18			
13	White Willow	Ht. (ft.)		35	42	50	61	71			
		Tot. Production		4·74	20·70	39·93	68·97	112·72			
		P.A.I.			5·32	6·41	7·26	8·75			
		P.A.I.%				21·1%	13·3%	9·6%			
		M.A.I.		·47	1·59	2·50	3·45	4·51			

Notes: M.A.I. = Mean Annual Increment.

P.A.I. = Periodic Annual Increment.

The P.A.I. and P.A.I.% relate in each case to the preceding period; e.g. for Sycamore, the figures 3·84 (tons) and 29·5% relate to the increment between the 13th and 16th years.

APPENDIX I

List of Main Experimental Projects and the Localities where Work is Concentrated

While the investigations and experiments of the Research Branch are scattered throughout forests all over the country, there are certain areas where work on some projects is more or less concentrated. These are briefly given below:

NURSERY EXPERIMENTS

Benmore Forest Nursery, near Dunoon (Argyll)
Bramshill Nursery (Hampshire)
Bush Nursery, near Edinburgh
Fleet Forest Nursery, Gatehouse of Fleet (Kirkcudbrightshire)
Inchnacardoch Forest Nursery, near Fort Augustus (Inverness-shire)
Kennington Nursery, near Oxford
Newton Nursery, near Elgin (Morayshire)
Sugar Hill Nursery, Wareham Forest (Dorset)
Tulliallan Agricultural type and Woodland Nurseries (Fife) near Alloa

AFFORESTATION EXPERIMENTS ON PEAT

Achnashellach Forest (Wester Ross)
Beddgelert Forest (Caernarvonshire)
Clocaenog Forest (Denbighshire)
Inchnacardoch Forest (Inverness-shire)
Kielder Forest (Northumberland)
Strathy Forest (Sutherland)
Watten (Caithness)—in conjunction with Department of Agriculture and Fisheries for Scotland
Wauchope Forest (Roxburghshire)

AFFORESTATION EXPERIMENTS ON HEATHLAND

Croft Pascoe, Lands End Forest (Cornwall)
Harwood Dale in Allerston Forest (Yorkshire)
Teindland Forest (Morayshire)
Wareham Forest (Dorset)
Wykeham and Broxa in Allerston Forest (Yorkshire)

NUTRITION OF ESTABLISHED CROPS

Bramshill Forest (Hampshire)
Haldon Forest (Devon)
Tarenig Forest (Cardiganshire)
Wareham Forest (Dorset)
Wilsey Down Forest (Cornwall)

CONVERSION OF COPPICE

Alice Holt Forest (Marelands, Hampshire)
Forest of Dean (Penyard, Herefordshire)
Cranborne Chase Forest (Wilts.)

PROVENANCE EXPERIMENTS

Scots pine:	Findon Forest (Easter Ross) Thetford Chase (Norfolk)
Lodgepole pine:	Achnashellach Forest (Wester Ross) Clocaenog Forest (Denbigh) Millbuie Forest (Easter Ross) Wykeham in Allerston Forest (Yorkshire)
European larch:	Coed y Brenin (Merioneth) Savernake (Wilts.) Mortimer (Hereford)
European and Japanese larches:	Clashindarroch Forest (Aberdeenshire) Drummond Hill Forest (Perthshire) Lael Forest (Wester Ross)
Douglas fir:	Glentress Forest (Peebles-shire) Laiken Forest (Nairnshire) Mortimer (Salop) Shouldham, Lynn Forest (Norfolk) St. Clement, Lands End Forest (Cornwall)
Norway and Sitka spruces:	Newcastleton Forest (Roxburghshire) The Bin Forest (Aberdeenshire)
Sitka spruce:	Radnor Forest (Radnor)
Beech:	Queen Elizabeth Forest (Hampshire) Savernake (Wilts.)

PRUNING EXPERIMENTS

Drummond Hill Forest (Perthshire)
Monaughty Forest (Moray)

PLANTING EXPERIMENTS ON CHALK DOWNLANDS

Friston Forest (Sussex)
Queen Elizabeth Forest (Buriton, Hants., and Sussex)

ESTABLISHMENT OF OAK

Forest of Dean (Gloucester, Hereford and Monmouth)
Dymock (Gloucester and Hereford)

POPLAR TRIALS AND SILVICULTURAL EXPERIMENTS

Blandford (Dorset)
Cannock Chase (Stafford)
Creran (Argyll)
Doncaster, South Yorkshire Forest
Dyfnant (Montgomeryshire)
Forest of Dean (Gloucestershire)
Harling, Thetford Chase (Norfolk)
Hockham, Thetford Chase (Norfolk)
Quantock Forest (Somerset)
Stenton (East Lothian)
Wynyard (Durham)
Yardley Chase (Beds. and Northants.)

SPECIES PLOTS

Beddgelert Forest (Caernarvonshire)
Bedgebury Forest (Kent)
Benmore Forest (Argyll)
Crarae, near Minard Forest (Argyll)
Thetford Chase (Norfolk)
Wareham Forest (Dorset)

GENETICS

Propagation Centres

Alice Holt (Hampshire)
Grizedale (Lancashire)
Kennington, near Oxford
Westonbirt (Gloucestershire)
Bush (Midlothian)

Tree Banks

Newton (Morayshire)
Alice Holt (Hampshire)
Rendlesham (Suffolk)
Bush (Midlothian)
Bradon (Wiltshire)

Seed Orchards

Newton (Morayshire)
Ledmore (Perthshire)
Drumtochty (Kincardineshire)
Archerfield and Whittingehame (East Lothian)
Alice Holt (Hampshire)
Bradon (Wiltshire)
Forest of Dean (Gloucestershire)
Rendlesham (Suffolk)

PATHOLOGICAL RESEARCH AREAS

Muirburnhead (Dumfries-shire):	Group dying of Conifers
Knapdale (Argyll):	Top dying of Norway Spruce
The Bin (Aberdeenshire)	Fomes annosus
Lael (Wester Ross):	,, ,,
Thetford (Norfolk):	,, ,,
Kerry (Montgomeryshire):	,, ,,
Mundford, Thetford (Norfolk):	Bacterial canker of poplar
Queen Elizabeth Forest (Hampshire):	Wound Protectants

ARBORETA

Bedgebury Pinetum (Kent)
Westonbirt Arboretum (Gloucestershire)
Whittingehame (East Lothian)

RE-AFFORESTATION EXPERIMENTS

Forest of Ae (Dumfries-shire)
Newcastleton (Roxburgh)

APPENDIX II

Staff of Research Branch as at 31st March, 1960

FOREST RESEARCH STATION. Alice Holt Lodge, Wrecclesham, Farnham, Surrey. Tel.: Bentley 2255.

T. R. Peace, M.A.	Conservator, Chief Research Officer
R. Rendle	Higher Executive Officer

SILVICULTURIST (SOUTH) (Alice Holt)

R. F. Wood, B.A., B.Sc.	Divisional Officer
G. D. Holmes, B.Sc.	Divisional Officer
M. Nimmo	District Officer
J. R. Aldhous, B.A.	,, ,,
J. Jobling, B.Sc.	,, ,,
J. M. B. Brown, B.Sc., Dip. For.	,, ,,
A. I. Fraser, B.Sc.	,, ,,
W. H. Hinson, B.Sc., Ph.D.	Senior Scientific Officer
G. Buszewicz, Mgr. Ing.	Experimental Officer

SILVICULTURIST (NORTH) Government Buildings, Bankhead Avenue, Sighthill, Edinburgh, 11. Tel : Craiglockhart 4010.

M. V. Edwards, M.A.	Divisional Officer
G. G. Stewart, M.C., T.D., B.Sc.	District Officer
R. Lines, B.Sc.	,, ,,
D. W. Henman, B.Sc.	,, ,,
J. Atterson, B.Sc.	,, ,,

MANAGEMENT (Alice Holt)

F. C. Hummel, M.A., D.Phil.	Divisional Officer
A. M. Mackenzie (Edinburgh)	District Officer
G. M. L. Locke, B.Sc.	,, ,,
A. J. Grayson, M.A.	,, ,,
D. R. Johnston, B.A.	,, ,,

STATISTICS

J. N. R. Jeffers, F.I.S.	Senior Scientific Officer
R. S. Howell (Edinburgh)	Scientific Officer

FOREST PATHOLOGY

J. S. Murray, B.Sc.	District Officer
R. G. Pawsey, B.Sc., M.Sc., Ph.D.	Senior Scientific Officer
S. Batko, D.Ing.	Experimental Officer

FOREST ENTOMOLOGY

M. Crooke, B.Sc., Ph.D.	District Officer
D. Bevan, B.Sc.	,, ,,
Miss J. Davies, B.Sc.	Experimental Officer

FOREST GENETICS

J. D. Matthews, B.Sc.	District Officer
R. Faulkner, B.Sc. (Edinburgh)	District Officer
A. F. Mitchell, B.A., B.Ag.	,, ,,

DOCUMENTATION AND PHOTOGRAPHY

G. D. Kitchingman, M.A., Dip. For.	District Officer
I. A. Anderson, F.I.B.P.	Principal Photographer
Miss T. K. Wood, A.R.P.S.	Photographer

GREY SQUIRREL RESEARCH

K. D. Taylor	Scientific Officer

MACHINERY

R. G. Shaw, B.A., A.M.I.Mech.E.	Machinery Research Officer

UTILIZATION DEVELOPMENT

E. G. Richards, M.C., B.Sc.	Conservator
C. D. Begley, B.Sc.	District Officer
H. G. Dowden, B.Sc.	,, ,,

APPENDIX III

List of Publications by Research Branch Staff

Aaron, J. R.	*Use of home-grown timber in house construction.* Forest Record, For. Comm. Lond. No. 42.
Aldhous, J. R.	Le transport des plants forestiers. *For. France* 88 (1959) 14-18.
Aldhous, J. R.	Nursery plants in polythene. *Quart. J. For.* 54 (1960) 28-32.
Aldhous, J. R.	Control of cutworm in forest nurseries. *Forestry* 32 (1959) 155-165.
Begley, C. D.	Dwelling house made from thinning timber. *J. For. Comm.* Lond. No. 27 (1958) 91–3.
Booth, C. and Murray, J. S.	*Calonectria hederae* Arnaud and its *Cylindrocladium* conidial state. *Trans. Brit. mycol.* Soc., 43 (1960) 69–72.
Crooke, M.	Insecticidal control of the pine looper in Great Britain. I-Aerial spraying. *Forestry* 32 (1959) 166–196.
Crofts, E. A.	Crarae Forest Garden. *J. For. Comm.*, London No. 26 (1957) 79–82.
Edwards, M. V.	Abnormally heavy thinnings in young larch. *Forestry* 32 (1959) 23–30.
Edwards, M. V.	The most important problem in silvicultural research. *Scot. For.* 14 (1960) 58–60.
Edwards, M. V.	Peat afforestation. (1960) 7. 16–18.
Edwards, M. V.	The formation of Scots pine plantations with particular reference to seed provenance. In "Society of Foresters of Great Britain—Excursion to the North of Scotland". *Emp. For. Rev.* 38 (1959) 406-7.
Edwards, M. V. and Wood, R. F.	A review of Research Branch trial plantations. *J. For. Comm.* London No. 26 (1957) 113–8.
Holmes, G. D. and Buszewicz, G.	The assessment of seed sowing value. *Quart. J. For.* 53 (1959) 220–7.
Howell, R. S. and Kemp, D.	Comparison of methods of sampling for the measurement of moisture content in green timber. *Rep. For. Res. For. Comm.*, Lond. (1958) 156–60.
Hummel, F. C., Lock, G. M. L., Jeffers, J. N. R. and Christie, J. M.	*Code of sample plot procedure.* Bull. For. Comm. Lond. No. 31. 1959 (H.M.S.O. 15/-)
Jeffers, J. N. R.	Multiple regression analysis by electronic computer. *Emp. For. Rev.* 38 (1959) 278–86.
Jeffers, J. N. R.	*Experimental design and analysis in Forest Research.* Almqvist and Wiksell, Stockholm (1960) pps. 172.

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Johnston, D. R. A new Working Plans Code in Great Britain. *Emp. For. Rev.* 39 (1960) 54–60.

Kitchingman, G. D. Bibliography on Windblow. *J. For. Comm.* Lond. No. 27 (1958) 132–3.

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Lines, R. Common silver fir in Britain. *Scot. For.* 14 (1960) 20-30.

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Matthews, J. D. The permanent seed identification Code. *J. For. Comm.* Lond. No. 27 (1958) 12–18.

Ogilvie, J. A. The benefit of lath covers for protection against frost. *J. For. Comm.* Lond. No. 26 (1957) 112–3.

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Shaw, R. G. Machinery aids in the woods. *Timb. Tr. J.* 232 (4355) 27th Feb. 1960. Supplement pp. XXVII-XXXII.

Styles, J. H. *Panchlora* species (Orthophera:Blattidae). *Ent. Gazette*, October, 1959, p. 174. 1 plate.

Styles, J. H. *Cephalcia alpina* Klug. (Hym. Pamphiliidae). Notes on the collection of the adults and the web-spinning larvae of this sawfly species. *Ent. Mon. Mag.* July 1959. 152–3. 2 plates.

Styles, J. H. Observations on the spinning of cocoons by larvae of the sawfly *Neodiprion sertifer* Geoff. (Hym. Diprionidae). *Ent. Mon. Mag.* August 1959, pp. 178.

Styles, J. H. *Syndemis* (=*Tortrix*) *musculana* Hübn., (lep. Tortricidae) in conifer plantations and forest nurseries in the British Isles. *Ent. Gazette* (accepted 27.2.60). 2 plates.

Worsley, R. G. F. The processing of pollen. *Silvae Genetica* 8 (1959) 143–8.

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