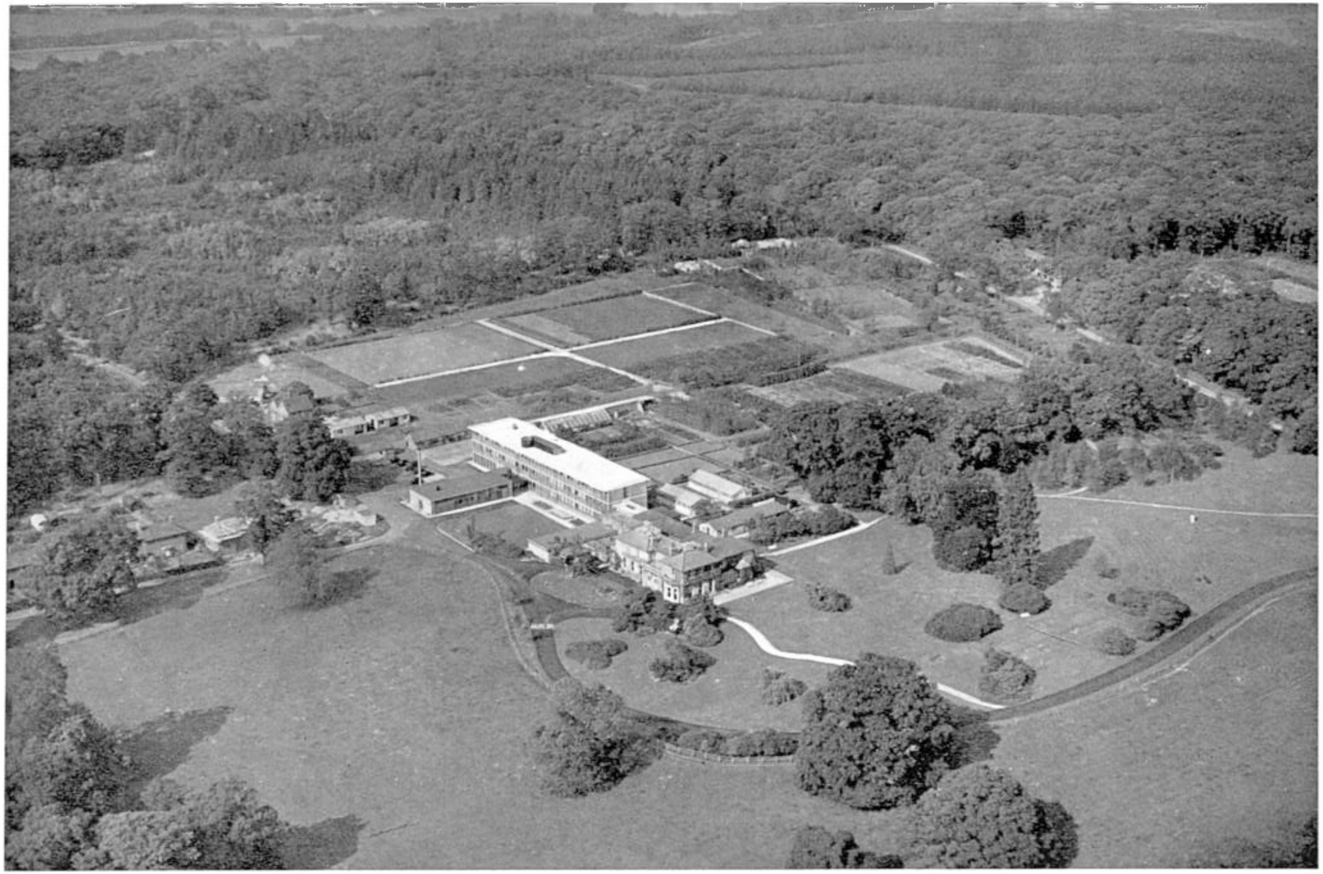

Aerial view of Alice Holt Research Station, showing the old building in the centre, the new wing to the left, and the experimental grounds. Alice Holt Forest lies beyond.

FORESTRY COMMISSION

REPORT ON FOREST RESEARCH

for the year ended March, 1961

LONDON
HER MAJESTY'S STATIONERY OFFICE
1962

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Forest Research Station, Forestry Commission, Alice Holt Lodge, Wrecclesham, Farnham, Surrey.

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ACKNOWLEDGMENTS

Plates 6 and 7 were provided by the Fire Research Station. Plate 12 is from a photograph by Mr. J. D. U. Ward. All the other photographs are drawn from the Forestry Commission's own collection, and all the text figures are based on data provided by the respective authors.

INTRODUCTION

By JAMES MACDONALD

Deputy Director General

During the year under review, there have been several changes in the Research staff. Mr. G. D. Kitchingman retired in October 1960 after 13 years' service as Librarian at Alice Holt and was replaced by Mr. R. M. G. Semple. Dr. M. Crooke resigned in October 1960 on appointment as Lecturer in Forest Zoology in the University of Aberdeen, and in February 1961 Mr. J. S. Murray, Forest Pathologist, left for the same University in which he has become Senior Lecturer on Forest Botany. Dr. Crooke was replaced by Mr. D. Bevan, while the Pathology section has been placed temporarily in the charge of Dr. R. G. Pawsey. Mr. G. G. Stewart, one of the silvicultural research officers in Scotland, was transferred to field duties on promotion and his post in research was filled by Mr. S. A. Neustein, transferred from the South Conservancy in Scotland. Mr. K. D. Taylor, who was engaged on research on squirrels, resigned in November 1960. Mr. R. T. Bradley and Mr. R. E. F. Heslop joined the staff in October, the former to work in Mensuration and the latter on Working Plans. Mr. D. H. Stewart was appointed to the Statistics section as Experimental Officer.

Visitors to Alice Holt numbered 300, rather fewer than in recent years. In addition to visitors from this country, they came from Australia, Belgium, Burma, Canada, Denmark, Ireland, Finland, France, Ghana, Germany, Italy, India, Israel, Japan, Kenya, the Netherlands, New Zealand, Portugal, Rhodesia, Sweden, Switzerland, Tasmania, United States of America, and Yugoslavia. Among them were Mr. V. L. Grenning, Director of Forestry in Queensland, Mr. A. L. Poole, Assistant Director of Forestry in New Zealand, Mr. C. A. R. Bhadran, Chief Conservator of Forests for Madras, India, and Mr. V. H. Phelps from the Forest Research Division, Canada.

A party of students from l'Ecole Nationale des Eaux et Forêts at Nancy, during their first visit to this country, were engaged on a study tour which included various of our experimental areas as well as a visit to Alice Holt. Other organised visits to Alice Holt included the Senior Forestry Officers of the Overseas Colonial Service, and a party of Yugoslav Forest Officers. Forestry students from the Imperial Forestry Institute, Oxford, from the Universities of Aberdeen and Edinburgh, and the University College of North Wales at Bangor, paid their annual visits to the Research Station.

Several visitors spent longer periods at the Research Station. Among these was Mr. M. R. Badan from Switzerland who started a year's work with the Management Section in August 1960; in the same section, Mr. M. A. Solak from Turkey, visiting England for a year, under a Baghdad Pact Fellowship, has spent several periods with the Research Branch, alternating with work at Oxford. Two students from the Ministry of Aviation, studying for the Diploma of Technology, spent six months with the statistics section gaining experience in the application of statistical methods to a wide variety of problems.

In Scotland, experiments at Glen Righ, Inverness-shire, were visited by a party of German woodland owners and foresters while the Forest Garden at Crarae, Argyll, was visited by members of the National Trust for Scotland. A special press tour to show some of the Commission's research work in Scotland was also organised. Forestry students from Aberdeen, Bangor and Edinburgh, as well as students from Swansea, were able to see experimental work in a number of forests, while a party of Forest Officers from the Commonwealth also made visits from the Imperial Forestry Institute at Oxford. Experiments at Allerston and in the nurseries at Bush and Grizedale were visited by parties of schoolchildren.

Mr. J. D. Matthews represented the International Union of Forest Research Organisations at a meeting of the International Commission for the Nomenclature of Cultivated Plants at Cambridge. Mr. M. V. Edwards and Mr. G. G. Stewart visited various parts of Lancashire to study the tree planting which had been carried out by the County Council on old spoil heaps.

Visits Overseas

In September 1960, Mr. G. D. Holmes visited the main seed suppliers in British Columbia and Washington to enquire into the organisation of future seed supplies, and the methods of control and certification of seed origin. He also attended the World Forestry Congress at Seattle. Mr. D. Bevan visited Vienna for the 11th International Entomological Conference, and he took the opportunity to study *Semasia diniana* and *Taeniothrips laricivorus* in Switzerland. Mr. J. D. Matthews was invited to act as an instructor at a Field Institute of Forest Biology arranged by the Forestry Department of the North Carolina State College and sponsored by the National Science Foundation. He gave eleven lectures on Forest Genetics. He spent one month in the United States. Mr. Matthews also served for four months as a Technical Assistance Expert of the Food and Agriculture Organisation. His assignment was to advise on the formation of a Forest Genetics Section at the Indian Forest Research Institute at Dehra Dun. Mr. D. R. Johnston, the Working Plans officer, was awarded a Nuffield Fellowship to study problems of management planning in a number of countries including South Africa, Southern Rhodesia, Tanganyika, Kenya and Sweden. He started his tour just before the end of the year under review and is due to be away for about six months. Mr. M. V. Edwards and Dr. W. H. Hinson visited the Peat Research Station at Glenamoy in County Mayo, Ireland. Colonel R. G. Shaw visited Geneva to attend a meeting of the Joint F.A.O./E.C.E. Committee's study group on machinery development, while Mr. E. G. Richards paid three visits to the same town, one to attend the E.C.E. Timber Committee and the others for the purpose of discussing the Utilisation of Small-sized Wood at meetings of the F.A.O./E.C.E. Committee.

Mr. T. R. Peace presided over the forestry sub-Section at the Meeting of the British Association at Cardiff in 1960, while Dr. F. C. Hummel gave a lecture by invitation at the Eidgenössene Technische Hochschule in Zurich on Forest Working Plans in Great Britain. A second exhibition of forest machinery, organised by Colonel Shaw, was held at Harrogate in May 1960; it is planned to hold a third in 1962 in the vicinity of Edinburgh.

The programme of research into the properties of home-grown timber, which is proceeding in co-operation with the Department of Scientific and Industrial Research at the Forest Products Research Laboratory at Princes Risborough, is making good progress. The Commission is greatly indebted to D.S.I.R. and to the Director of the Laboratory for the help they have given. Work also continues at the Fire Research Station at Boreham Wood where important research into the spread of forest fires has been started. Thanks are due to the Fire Research and Training Trust who have provided funds, and to the Director of the Laboratory under whom the work is proceeding.

The Utilisation Development Committee held two meetings in London during the year and the Mechanical Development Committee held one meeting in London and one at Pitlochry. The joint informal committee with Nature Conservancy held one meeting during the year.

During the year the usual close contacts have been made with the Macaulay Institute for Soil Research at Aberdeen, Rothamsted Experimental Station and the Imperial Forestry Institute at Oxford. The Commission is indebted to those Institutes and to their Directors for all the help they have given.

SUMMARY OF THE YEAR'S WORK

By T. R. PEACE

Chief Research Officer

The Report takes much the same form as previous years, except that rather more papers are included in Part III. This is partly the result of a very conscious effort to complete the write-up of all projects which have reached a properly publishable stage.

In Part I, Mensuration again appears as a separate report, following the appointment of Mr. R. T. Bradley as Mensuration Officer. The Work Study section, which is not part of the Research Branch, has also submitted a report for Part I, since its work constantly impinges on research and is likely to be of interest to forest research workers in other countries.

Work on Entomology, Pathology, and Grey Squirrels (a joint project with the Infestation Control Division of the Ministry of Agriculture) has been hampered by staff changes, but all three should be in full swing again before the end of 1961.

In Silviculture there has been a definite swing during the year towards research on drainage, root development and windblow. In fact we are tending to pay increased attention to the below-ground parts of the tree and their effect on growth and stability.

The introduction of electronic computing into the Research Branch continues to exert a profound influence on the design of experiments and the amount and type of information that can be gleaned from them. Successful efforts to put mensurational data direct on computer tape, described under Mensuration in Part I and in the paper by Mr. D. R. Johnston in Part III, are particularly noteworthy.

The paper on Utilisation in Part I inevitably fails to give a full picture of the very active co-operation that now exists between the Research Branch and the Forest Products Research Laboratory of the Department of Scientific and Industrial Research. Similarly, the papers in Part II give a very incomplete picture of the close collaboration that exists with the institutions where work is being carried out. In each case a member of the Forestry Commission research staff acts as liaison with the research worker in the other institution. Apart from all this there has been active collaboration with other institutions too numerous to mention. Forest research must inevitably seek information in many related fields, and it is a pleasure to acknowledge how willingly this information has been given.

The Season

The effects of the dry summer of 1959, though far less marked than was expected, were still visible in the spring of 1960. They were then somewhat masked by further damage due to an exceptionally dry spring. The wet late-summer, autumn and winter caused a complete reversal of conditions. There is no doubt that these climatic vacillations are unfavourable to tree growth, especially on difficult sites. Even the warm winter cannot be regarded as wholly favourable. Although species such as *Sequoia sempervirens*, which usually gets browned in the winter, escaped unharmed, there is more than a suspicion that failure to achieve full dormancy has led to damage to spruces and pines during the brief cold, windy periods that did occur.

PART I

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

Forest Tree Seed

The main development in the Central Seed Store, which is now under the control of the Chief Research Officer, has been the installation of a seed mixer. Experiments have indicated that this gives very satisfactory mixing over very short periods of time, without damaging the seed. It may also prove possible to use it for dewinging seed.

Routine seed testing continues to take a great deal of the time in the seed laboratory, in particular tests for moisture content have increased and have now become a routine procedure for stored seed.

Preliminary results have now been obtained from a large-scale experiment on the storage of Noble fir. Beech seed storage results are the subject of a special paper in Part III (page 117).

Work has continued on the germination requirements of the major species, and on the practical difficulties involved in the accurate determination of moisture content.

Nursery Investigations

Experiments on date of sowing and on irrigation were repeated. In view of the wet summer, irrigation had little effect. Seed of *Abies*, a difficult genus, was again subjected to pre-sowing treatments in an effort to increase the low germination percentage. Experiments with Sistan for the partial sterilisation of seedbeds did not give very promising results.

Long-term fertility experiments were continued at a number of nurseries. The effect of late nitrogen application on the time of bud formation in the autumn again showed delays of up to 14 days on manured plots.

Further experiments were done on the cold storage of seedlings. Storage at 36°F was successful up to eight months, but, when lined-out, these plants continued growth too late and were damaged by frost.

Tests of new herbicides were continued. Particular attention was paid to the susceptibility of dormant transplants to Dalapon. Experiments on frequency of weeding again showed that frequent weeding lessened the overall time taken.

The use of polythene as a seedbed covering gave protection against birds, but with certain species damage to seedlings was liable to occur in hot weather.

Computer programmes were prepared for the calculation of nursery yields, etc.

Silvicultural Investigations in the Forest; South and Central England and Wales

Under work on the afforestation of special sites, it is reported that the first five years' results of experiments at Croft Pascoe on the Lizard in Cornwall, planted between 1954 and 1957, have been sufficiently promising to encourage further planting on a trial scale.

Work on the regeneration of existing plantations has so far been mainly concerned with the artificial regeneration of ground at present occupied by Scots pine or Japanese larch. Work on natural regeneration is proceeding on a small scale.

Manuring experiments continue to bulk large in the silvicultural work, but the emphasis is passing from manuring at the time of planting to work on checked plantations and pole-stage crops. In many cases checked trees have responded very satisfactorily to manuring, but in some cases, for instance, Douglas fir, in the Weald of Kent, inadequate nutrition does not appear to be the controlling factor. The growth of pole-stage crops has not yet responded to manuring in the experiments laid down in 1958 and 1959, but the nutrient uptake has been increased, and some treatments have had a very noticeable effect on litter breakdown.

Two developments have taken place in the study of wind stability. The reporting of actual occurrences of wind damage is being placed on a more definite basis, and the 'tree pulling' technique has been tried out on a sufficient scale to indicate its value as a method of comparing stability between different trees and different sites.

The results of the drainage experiment on heavy clay, has encouraged extension of this work on to other soil types. In particular mole-drainage is being tried on Culm soils in Devon.

Work on total weed control has now been extended to include planting areas. The possibility of the selective control of grasses among existing crops has been further investigated. The use of low-volume sprays becomes very important if spraying is to be used on a large scale. For this reason work on low-volume sprays is being extended. Experimental work on the poisoning of woody weeds was concentrated on the control of unwanted species in planted areas.

Experiments on the exclusion of deer from newly planted areas, and on deer repellents, have been continued.

Work on fire retardants has indicated that monammonium phosphate is the best of the substances investigated.

Further work has been done on the chemical treatment of standing crooked hardwoods to facilitate debarking after felling.

Silvicultural Investigations in the Forest: Scotland and North England

In connection with the artificial regeneration of conifer woodlands, a problem which will be facing the Commission in years to come, several experiments have been established to find whether ploughing is possible and economic. It has been found that, in windblown gaps at any rate, large plants are more successful than smaller ones. The best size of felling area is being investigated in a new experiment at the Forest of Ae.

Further experiments have been established to study the shrinkage and disintegration of peat after single-furrow ploughing. The first of a new series of experiments to evaluate the benefits of ploughing on sites where ploughing is not a necessity for establishment has been laid down. Loosening of young trees on ploughed ground by wind is causing some concern. Preliminary work has indicated that, on sites where this type of damage has occurred, trees planted in the furrow are worse affected than those on the ridge, and that pine is much more susceptible than larch. A drainage experiment has been established on a difficult clay soil at Lennox Forest.

Another mixture experiment, using Scots pine and birch, has been laid down in Yorkshire. An effort to find existing mixtures, which could be used for detailed study, has proved very disappointing.

A number of new manuring experiments have been started. Several of these are sited in peat areas.

Weed control experiments have particularly concentrated on methods suitable for establishing and maintaining firebreaks around isolated trial plantations in north Scotland.

Experiments to exclude roe deer from newly planted areas by the use of brushwood have been abandoned, but trials with various forms of netting and with electric fencing continue.

Provenance Studies

Reassessment of one of the older Scots pine provenance experiments showed that two German provenances were still the most vigorous. Two new *Pinus nigra* provenance experiments were planted, one in a polluted area to test resistance to industrial fumes and the other on an area heavily infected with the root fungus *Fomes annosus*, to which some forms of *P. nigra* are said on the Continent to be resistant. Three additional experiments with Lodgepole pine, *Pinus contorta*, were planted. This species shows great differences between provenances and it is clearly important to elucidate these further. Two experiments have been planted with the Canadian Jack pine, *P. banksiana*, a species which has considerable potential in breeding work, and so one where the selection of the best provenance to provide parent trees is of some importance.

A collection of 12 provenances of Sitka spruce has now been planted on a wide range of sites from Cornwall to the north of Scotland, including one at 2,300 feet elevation. A full account of the behaviour of these provenances in the nursery is given in Part III of this Report.

Douglas fir experiments in all three countries have been assessed at the end of their sixth growing season for date of flushing and attack by *Adelges*, as well as for height growth. Results displayed some points of interest, but were often rather contradictory.

The collection of Western hemlock provenances have shown, in the nursery, differences in rate and in cessation of growth associated with latitude of origin. Some of these plants have already been used in experiments on six sites. More will be planted out later.

Very little is known about possible provenance differences in Western red cedar. Stocks now in the nurseries will enable experiments to be set up on suitable sites.

A good start has been made on a provenance study of European silver fir, since seed of 35 provenances has been received. Germination of the seed, however, varied from 56 per cent to nil, with an average of 10–12 per cent. Raising of sufficient stocks may not therefore be so easy.

Poplars and Elms

The planting of varietal trial plots is now virtually limited to the replacement of existing plots which have failed or are no longer of practical value. Only five clones were added to the varietal collection during the year, but 13 clones were added to the Populetum.

Experiments on method of planting and on after-planting treatment with mulches are giving interesting results. In the older spacing experiments, the start of canopy closure after six and seven years, in the closest spacing (8 feet x 8 feet), has not yet affected the growth rate. Another experiment has been planted to study the effect of admixture of alder with poplar. The distribution of cuttings showed a marked reduction on the previous year.

Mist propagation was again successful with summerwood cuttings of 'difficult' poplars, as well as with elms.

Further progress has been made in the selection of 'plus' elm trees. Visits to elm woodland have disclosed that they mostly consist of Wych or sometimes English elm. It seems doubtful if information can be obtained from existing woodlands on the growth of the less common species and hybrids under woodland conditions.

Forest Ecology

The general survey of the performance of Corsican pine has been concluded and the data are now being prepared for writing-up. In the meantime, Mr. Read, working at the Botany Department of Hull University, has started a study of Corsican pine dieback in Allerston Forest, in which the pathologist, as well as the ecologist, are co-operating.

The disease behaviour of Corsican pine in Britain is reviewed, in particular in comparison to its behaviour in Belgium and Holland.

Satisfactory flowering of Corsican pine, following the hot, dry summer of 1959, has justified a rapid survey of expected cone yields in different parts of Britain.

Opportunity for an investigation of the behaviour of different species on opencast mining soil has been provided by the expected reworking of such an area in South Wales. Trees of several species planted in 1954 have been excavated. Interpretation of the results is difficult, owing to the number of variables, such as aspect, slope, drainage and soil composition, but it is clear that growth on the slopes is generally better than on the flats, which often have compacted soils. Among the species planted, alder in particular has been successful. This may be due to a greater tolerance to the slightly alkaline soils or to its ability to fix nitrogen; since conifers display symptoms typical of nitrogen deficiency on this site.

Forest Soils

Facilities for the analyses of needle samples from manuring experiments have improved during the year and arrears are being overtaken. It is hoped that this will allow a start to be made on long-term studies of the nutrient relations of forest crops and sites.

The effect of alder on the water relationship of a heavy clay soil is being studied at Lennox Forest. The site at Crowthorne, in Bramshill Forest, Berkshire, established by Dr. Rutter of Imperial College for the study of the water relationships of forested and grass-covered soil, has been maintained in his absence abroad. A pair of lysimeters have been set up at Alice Holt.

Techniques for the estimation of calcium, for the measurement of soil moisture, and for the simultaneous automatic recording of a number of readings, have been elaborated.

Forest Genetics

The survey and classification of seed sources by members of the Genetics Section is now close to completion. An interim Register of Seed Sources for Britain was issued in September so that advantage could be taken of the seed crops produced by several species in autumn 1960. This register contains 403 classified entries totalling 7,261 acres. The selection of trees for breeding purposes is also well advanced and 2,959 Plus and Special trees are now registered. Almost half of these trees are now represented, in collections called 'tree banks', by clones of grafts or rooted cuttings, thus preserving valuable genes against loss, permitting observations of relative flowering times, and also making possible controlled crosses between parents which are often very widely separated in the forest.

13,373 grafts were attempted in spring 1960 and the success overall was 68 per cent. These grafts were used in seed orchards and tree banks. Rooted cuttings of the hybrid Leyland cypress and Western red cedar were again distributed for field trials.

Controlled crossing and progeny testing continued, the most important project being inter-provenance crosses in Lodgepole pine with the object of producing improved cultivars of this species, which has an increasing and important place on upland sites in Britain.

The formation and management of seed orchards comprise a large part of the work of the Genetics Section. Two seed orchards, one larch and the other beech, produced small crops of seed in the autumn of 1960. The larch seed was distributed for general use and the beech nuts are being sown in a progeny trial. Observations made on the relative flowering times of European and Japanese larch clones in two seed orchards revealed that in the production of seed of Hybrid larch the Japanese larch clones largely act as pollinators.

New pollination bags made from non-woven 'Terylene' plastic fabric have been introduced. The Terylene bags are stronger and the conditions of temperature and humidity inside are better than in paper or polythene bags.

A small experiment in which scions from one tree of Corsican pine were grafted on to transplants of several two-needled pines produced an interesting but not conclusive result. This clone of Coriscan pine evidently grows and cones best on rootstocks of a Scots pine provenance from eastern England; growth and coning are poorer on a Scottish provenance of Scots pine and on other pine species.

Forest Pathology

The most important event during the year was the organisation, in Scotland, in June 1960, of an international study tour composed of workers on the butt-rotting and root-killing fungus *Fomes annosus*. Work on *Fomes* has continued to play a major part in the work of the section. Following advice from the Research Branch, protective treatments of stumps has now become general practice in Commission forests.

Rotational use of nurseries, to avoid build up of infection by *Keithia* (*Didymascella*) *thujina* on *Thuja*, is now in operation in England and Wales, as well as in Scotland.

Grey mould, *Botrytis cinerea*, was not as much in evidence in 1960 as the wet season had led us to expect. It has proved impossible to forecast *Botrytis* ttacks by the study of temperature and humidity records.

The disease of Norway spruce, known as Top-dying, is certainly often associated with increased exposure of the crowns, but it now appears the climatic conditions in particular years are also important in causing this disease.

Observations continued on the test beds for *Melampsora pinitorqua* on Two-needled pines and Aspen poplars, and for *Cronartium ribicola* on Five-needled pines and *Ribes* species.

Collection and propagation of selected elm clones continued. Resistance to Elm disease, *Ceratocystis ulmi*, is only one of the factors being considered.

Experiments on wound protectants have yielded preliminary results. Full information will only be available when the trees have been felled and the protected wounds dissected.

Forest Entomology

During 1960 both field and laboratory studies were continued on the three insects – Pine looper moth, *Bupalus piniarius*, larch sawfly, *Anoplonyx destructor*, and the ambrosia beetle *Trypodendron lineatum*. In the case of *B. pinarius*, the main object has been to investigate the causes of fluctuations in population density. This work has been carried out for several years in permanent experiment plots set up in two forests, one being Thetford Chase, the other Cannock Chase. The annual pupal survey for 1959–60, however, showed that in one forest only – namely Cannock – the population had reached a threatening level. An additional short-term investigation yielded information which suggested that the pupal parasite *Cratichneumon nigritarius* played an important part in reducing the host population below infestation level. (*See* paper by Miss J. Davies in Part III, page 176).

Similar field work on *Anoplonyx destructor* continues at Mortimer Forest. Certain sampling techniques applied at egg and larval stages appear promising. It is also now possible to distinguish with certainty between the various larch sawfly cocoons, and so relate the parasites bred from this material to the specific host. Finally, special mention should be made of an egg parasite, *Metasecodes* sp., which as yet is undescribed and its biology unknown. At Drumtochty a long-term experiment has been laid down to measure increment loss following defoliation by the sawfly.

Further trials of insecticides for log protection against *Trypodendron lineatum* were carried out at Glenduror. Two chemicals – Hexaplus and Protoplus (BHC base) gave almost complete control. The investigations into relationship between felling date and susceptibility of attack, and comparison between stump and log infestation, gave us little information this year, since the beetle population was at too low a level.

Squirrel Research

Work on squirrels has continued in collaboration with the Infestation Control Laboratory of the Ministry of Agriculture. Cage tests and field trials of the anticoagulant poison Warfarin, carried out in 1960 using ground nuts as a bait, were successful. The field trials are being repeated in 1961.

Field trials of humane spring traps in comparison with cage traps have been continued. A small cage trap, which it is hoped can be produced more cheaply, is undergoing preliminary trials.

Plans have been made for an expansion of the research programme in 1961. This will include studies on the degree of protection afforded by various control methods at various times of year, and an investigation of feeding habits, with particular reference to the reasons for bark-stripping.

Forest Management and Working Plans

The Work of the Mensuration staff and that of the Economist, all of whom form part of the Management Section, form separate reports. The section continues to provide assistance to the field staff in the preparation of working plans. An officer has been appointed to carry out soil and site surveys in connection with this work. A number of research problems have arisen in the course of working plan activities, and these are dealt with jointly by the Working Plans Officer, the Economist and the Mensuration Officer.

Mensuration

The decennial review of permanent sample plots, which form the basic source of data, was completed and a broad policy formulated for the next ten years.

Multiple yield tables for four thinning treatments have been prepared for Sitka spruce, based on slight revision and considerable extension of the existing Sitka spruce general yield table published in 1953; work has been commenced on similar tables for Norway spruce. The possibility of using electronic computers for the construction of yield tables is being investigated and work has continued on the preparation of stand tables for conifers.

New research work has been mainly directed towards the problem of increment determination for working plan purposes; a new approach is being investigated and a prototype instrument has been developed during the past six months to measure stem diameter and increment cores and to record these measurements directly on to computer tape.

Forest Economics and Census

Work in the three fields of statistical compilation (including the maintenance of Census records), methodology of timber trend studies, and economics of private forestry, has proceeded.

In planning the management of Commission forests, wide use has been made of the profitability criterion referred to in last year's Report. This test of profitability involves the calculation of net discounted revenue at constant costs and prices, using an interest rate of 3½ per cent. The criterion has been applied to stands on the basis of expected revenues and expenditures on a representative acre, as well as to the consideration of alternative courses of management for whole forests or groups of forests.

'Model-acre' calculations have been made for: choice of rotation, with certain assumptions as to price and thinning grade; techniques of pruning, including pruning for telegraph poles; and the determination of optimum times of replacement of relatively unprofitable chestnut coppice.

The application of net discounted revenue computations to whole forests represents a new departure. Two functions are performed by these calculations. Economically desirable courses may be demonstrated, and if other considerations dictate that the most profitable pattern of management cannot be adopted, then the economic benefit foregone may be compared with the other managerial advantages conferred. Thus the opportunity cost of hardwood growing can be judged alongside the amenity benefits produced. Optimum patterns of thinning and felling, making provision for differential transport costs and other factors, may also be worked out for any areas of forest which are required to supply given quantities of produce. Thus the criterion is both flexible and powerful in use. Further developments in its application will, it is hoped, involve the introduction of linear programming techniques.

Work Study

This is the first occasion that the work carried out by the Commission's Work Study Section, which is not part of the Research Branch, has appeared in this report. Some details are therefore given of the structure of the section and of the nature and method of its work.

So far work has been concentrated on production, i.e. felling, extraction, and conversion as far as it takes place in the forest. In this connection, work has been carried out on tools and their use, and on machinery and equipment. The work on production methods carried out in previous years has now been consolidated by the development of basic piecework rates calculated from standard times for different operations.

Recommendations have also been made on forest organisation and management. These arise inevitably from observing how jobs are performed.

Costings have been carried out on selected production compartments, and on different sizes of pole and different specifications of pitwood and other produce. These have given realistic bases for a minimum size of pole to be marked in thinnings, and for the choice of the type of produce to be prepared.

Under the heading of Produce Control, comparisons have been made between estimates of standing timber and actual out-turn. Conversion losses have been calculated for various types of produce.

Utilisation Development

Nearly all the work included under this head has been done in co-operation with the Forest Products Research Laboratory of the Department of Scientific and Industrial Research.

Statistical examination of the data collected on home-grown pitprops showed that, provided they are properly made and well seasoned, they are perfectly satisfactory.

The comprehensive study of the properties of home-grown timber was continued. Laboratory work on the mechanical properties of Sitka spruce has been completed. Work on the examination of the pulping properties has been transferred to the Forest Products Research Laboratory. Work on the Lodgepole pine, *Pinus contorta*, and on Japanese larch has been started.

The field sampling of the major coniferous species for the collection of data on moisture content and specific gravity has been completed. The data show very wide variations.

An experiment has been laid down to investigate the amount of drying which occurs in close-piled stacks of peeled material during the winter.

Assessments of the fence-post trials have disclosed rapid deterioration of untreated Scots pine, Sitka spruce, birch and ash.

A wooden bungalow made from home-grown thinnings has been erected at Alice Holt.

Machinery Research

Increasing use continues to be made of four-wheel-drive tractors. Hydraulic transmission has not year appeared on any quantity-produced tractor but progress has been made on this attractive development for forestry tractors.

A new method of hauling heavy logs with part of the weight shared on all four wheels of the tractor is being developed. Simultaneous ploughing and fertilizing is under trial. Experiments have been carried out with twin-drum winches for extraction, and new hydraulically-driven winches are giving very promising results. New machines for cleaning open drains have had some success, but none of them provides a complete answer.

Design and Analysis of Experiments

The staff of the Statistics Section has been increased to enable it to cope with the increasing load of work of providing advice on the design and analysis of experiments and surveys, of the analysis and interpretation of collected data, and of research into the application of statistical methods and modern computing techniques to problems of forest research and management. The analytical work has been carried out on two types of electronic digital computer, a Ferranti Pegasus computer and a Ferranti Sirius computer. A number of special programmes have been written for these computers, to supplement the general-purpose programmes which were already in existence for these machines.

A very much greater proportion of the work of the Section has been devoted to problems of forest management and administration than in the past, and a series of talks on information theory, statistical methods, and electronic computers has been given to a wide range of the staff of the Forestry Commission out with the Research Branch. Advisory work on the design and analysis of experiments and surveys has also been undertaken for Overseas Forest Departments and for other organisations and research stations interested in forest problems. 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 Library and the Photographic Section

A start has been made on the extension and reorganisation of the library. In particular this will provide greatly improved reading and study facilities, which will be especially valuable to visiting students. It is hoped to speed up the progress of documentation by greater use of the title cards issued by the Commonwealth Forestry Bureau. The general work of the library, issue of books and periodicals, provision of translations, etc., continues to increase.

The Photographic Section continues to build up the collections of colour transparencies and black and white prints. The demand for the former for lecturing purposes remains high, and the latter are in constant demand for exhibitions, publications, etc. In order to co-ordinate 'illustration', the illustrator has now been placed in the Photographic Section.

PART II

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

Research on Scottish Forest Soils

Dr. W. O. Binns reports on work in progress under the Forest Soil Section of the Macaulay Institute for Soil Research, Aberdeen. At Culbin Forest, the beneficial effect of added mineral nitrogen on the height growth of young Corsican pine lasted three years, and experiments comparing soluble with slow-acting nitrogen fertiliser are to be started.

At the Lon Mor, further responses to potassium fertiliser have been observed, and checked Sitka spruce has shown good nitrogen uptake and improvement of colour after top—dressing with nitrochalk. Japanese larch needs additional potassium, but no nitrogen.

A survey of nine deep peat areas has shown that most blanket and raised bogs will need potassium as well as phosphorous fertilisers. Nitrogen and ash contents may be useful criteria in deciding if Sitka spruce will grow satisfactorily.

The study of nitrogen mineralisation in deep and shallow plough ridges on deep peat has been taken over by Dr. J. Keay, and a new experiment has been started at Glentrool. First results show that added ammonium ions disappeared more rapidly under deep ridges than under shallow ridges, although moisture contents were not different.

Nutrition Experiments in Forest Nurseries

Work at Rothamsted Experimental Station has been continued by Miss Benzian. The long-term rotation experiments have been continued. The problem of 'worn out' nurseries has been further considered. In this connection it may be significant that compost-treated plots in the long-term experiment at Kennington showed reduction in plant size in 1959 and in yield in 1960.

Experiments have been carried out on soil diluents with the idea of improving soil structure.

The write-up of the main series of past experiments continues.

Protein-fixing Constituents of Plants

Mr. C. W. Love, working at the Dyson Perrins Laboratory, Oxford, under Professor B. R. Brown, has continued his attempts (described in the last Report) to isolate the condensed tannin present in heather, *Calluna vulgaris.* Further attempts to isolate the tannin from an aqueous acetone extract by salting out, followed by solvent extraction or precipitation with ether have led to successful methods of isolation. Quercetin has also been isolated from the extract.

Biology of Forest Soils

Mr. G. W. Heath, at Rothamsted Experimental Station, has studied the rate of disappearance and decay of leaf litter in oak and beech woodland, by following the rate of change in weight, total carbon and hydrolysable carbohydrates. The amount and type of litter falling on the woodland floor is measured by means of leaf traps. Measurements of respiration of soil animals and the soil itself are being investigated as a means of providing an index to activity.

Soil Faunal Research

Mr. D. R. Gifford, working in the Department of Forestry at Edinburgh University, has completed the ecological comparison of the mite fauna of *Molinia* grass moorland at Ae Forest with the fauna of Sitka spruce litter in a 30-year-old plantation on a similar site at the Forest of Ae. The 'immaturity' of the fauna in most of the Sitka spruce was apparent. A detailed account of this work is in preparation.

Long-established deciduous woodland and natural Scots pine woodland were also examined, together with a 180-year-old Scots pine plantation, to examine the characteristics of 'mature' woodland faunas, and between all these there was considerable similarity in the mite populations of the litter. All were richer than the Sitka spruce fauna.

The programme is being re-sited in the Black Wood, Rannoch Forest, where a 'mature' profile and fauna have developed.

Soil Mycology

Work on soil mycology has been continued in the Forest Botany Section at the University College of North Wales, Bangor. The assay of spore germination on 12 forest soils, begun in March 1957, was terminated in July 1960, and some of the data were tested for significance.

Significant differences included: a consistently higher germination level on the litter than on the other soil layers, more germination on beech-oak litter than on pine litter on the same site; less germination on all layers under a beech-oak mixture on the higher, steeper and more exposed site than under the same species at the lower site. The natural germination of fungal spores on beech and oak litter after rain has been demonstrated by Miss M. G. Hay.

Certain sugars, identified by chromatography in fresh soil extracts, have failed to show the counter-inhibitory effects of glucose. The mycostatic activity of soil extracts is removed by seven minutes' oxygen bubbling, by mild heating, by passing through charcoal and alumina columns. It cannot be removed by passing through a filter of small pore-size (5 $m\mu$). The inhibitory effects of some calcareous soils have again been confirmed, and the susceptibility of the basidiospores of *Fomes annosus* to soil mycostasis has been shown for the first time by Mr. M. S. Johnson.

Dr. D. A. Griffiths has now left Bangor for a lectureship in the University of Malaya, and the work has been taken over by Dr. Nancy C. C. Carter.

Hydrological Relations of Forest Stands

Dr. Leyton and Dr. Reynolds of the Commonwealth Forestry Institute, Oxford, have continued to study and develop techniques for the investigation of the hydrological cycle in a spruce plantation. The precipitation over the stand has been measured by gauges at, and above, tree canopy level, there being little difference in the estimates obtained for the two positions. Trough gauges used in the estimation of 'throughfall' have been made self-recording, and improvements have also been effected to lysimeters used to estimate evaporation from the forest floor. A heat-flow method to measure sap flow has been developed in the laboratory, and preparations are in hand to calibrate the process for the estimation of the transpiration of whole trees.

Shelter Research

Mr. R. Baltaxe, working at the Department of Forestry, Edinburgh University, has continued his investigation of shelter effects. The work of the past two years shows that for relating the action of windbreaks to direct shelter effect, the primary feature of air flow to be investigated is its turbulence, or fluctuation. There is also evidence that shelter effect is likely to change significantly with the level of turbulence and convection in the free wind. This implies that to meet specific shelter requirements it will be necessary to provide more detailed specifications for the performance of windbreaks, in terms of their effect on air flow, than is generally done or possible at present.

The wind tunnel experiments referred to in the previous Report indicated the fundamental aerodynamic factors governing the performance of windbreaks. They gave a clear picture of the flow patterns generated by windbreaks, showing that these are a function of their form drag, as determined by their shape and/or permeability. This indicates the aerodynamic status of windbreaks and how their effect on air flow may be controlled. The importance of fluctuating flow, in the typically turbulent wakes, for the determination of shelter effect was demonstrated. It is suggested that a windbreak may properly be regarded as a device for damping the turbulence of the natural wind, from which follows the importance of investigating this feature.

Instruments for this purpose are being designed and constructed. A vane which gives a continuous record of wind direction over 180 degrees of rotation was made and is described.

The difficulties which were encountered in carrying out field work on an extensive basis made it imperative to devise a more intensive method, using a single variable, and mobile, semi-artificial shelterbelt.

Fire Spread in Forest and Heathland Materials

Dr. P. H. Thomas and Mr. R. W. Pickard have started work on this subject at the Fire Research Station, Boreham Wood, Hertfordshire.

The project is being financed by funds from the Fire Research and Training Trust. So far they have confined themselves mainly to a study of the spread of fire in long wooden cribs and of the burning of localised fires. The rates of spread of the front and rear faces of the burning zone were measured over a range of wind speeds. Although increasing the wind speed increased the rate of spread, this effect became progressively less marked as wind speed rose.

A limited number of experiments on grass and heather gave rates of spread about ten times greater than those obtained from wooden cribs.

Measurements of flame length from localised fires have shown that for a given rate of burning the flame length decreases as the wind speed rises. It is hoped that it will be possible to estimate the heat transfer ahead of the burning zone. This heat transfer to a large extent controls the rate of spread.

Studies of Variation among Oak Populations in Scotland

Mr. J. E. Cousens, working at the Department of Forestry in Edinburgh, has been studying variations in Scottish oaks.

The first collections (made in 1959) showed that there is enormous variation, particularly in the leaf form of both species, on individual specimens. It also seemed that there would be significant differences in the same material collected at different times during the growing season. Two preliminary studies were therefore instituted into the variability of diagnostic characters:

(1) on different parts of the tree,
and (2) at different times of the year.

These were pursued far enough to work out a reliable collecting procedure which would eliminate much extraneous variation.

Both objectives described above require countrywide collecting and it was possible while collecting material for the species study to carry out what might be described as a pilot survey of the types of populations likely to be encountered. To date some 640 specimens have been collected in Scotland. Nearly 400 of these have been mounted and recorded for a number of biometric and other characters which should be adequate to separate the two species and may eventually serve also to identify populations of indigenous ecotypes and exotic provenances.

These collections show a preponderance of *Quercus petraea* types and are rather poorly representative of the North East, where collections were made early in the year (May-June). Collections in 1961 will aim to redress the balance between *Q. petraea* and *Q. robur* types, and provide reasonably complete geographical coverage in Scotland. Some samples larger than those taken to date are required, in order to determine the optimum sample size.

Some tentative observations and conclusions based on analyses made to date are:

(i) *Q. petraea* is a much happier botanical entity than *Q. robur*. The natural limits of variation in the important diagnostic characters of *Q. petraea* in Scotland could already be described.

(ii) Semi-natural oakwood composed predominantly of *Q. petraea* types is far more common than woodland dominated by *Q. robur* types.

(iii) In *Q. robur*-dominated woodland, 'good' *Q. robur* has so far always been found with apparent *Q. robur* forms which have abaxial stellate pubescence.

(iv) The variation between individuals in every sample is so great that if ecotypes and provenances are to be recognised it will only be possible with the use of biometric indices from standardised samples.

Tracheid Length in Corsican Pine

At the Commonwealth Forestry Institute, Oxford, Mr. J. Ladell is examining the possibilities of predicting tracheid length in the mature stem of trees from that in the first-year shoot. During the year he studied the pattern of tracheid length within the leading shoots of Corsican pine and found that changes in length and diameter of cells, and the ratio of cell wall to lumen, are associated with the external variation in needle density and differing rates of elongation of the shoot. Wide needle spacing towards the base of leading shoots is associated with long tracheids. Needle density may prove to be a useful external index of tracheid length.

The Juvenility Problem in Woody Plants

Professor P. F. Wareing and Mr. L. W. Robinson, at the University College of Wales, Aberystwyth, have continued their studies on the physiology of juvenility and flowering. Their material includes birch, larch, ivy and blackcurrant because those provide suitable subjects for experimentation. Present indications are that the onset of flowering in seedlings depends on the attainment of a certain minimum size, and attempts are now being made to determine the operative factor in this 'size-effect'.

Studies of Fomes Annosus

Dr. J. Rishbeth, working at the Botany School, University of Cambridge, has found inoculation of pine stumps with the fungus *Peniophora gigantea*, to protect against their infection by the fungus *Fomes annosus*, very satisfactory in small-scale trials. He has devised a new method for measuring deposition of spores of certain wood-rotting fungi.

The Effects of Stump Treatments on Fungal Colonisation of Conifer Stumps

Mr. D. Punter, working with Dr. J. Rishbeth, at the Botany School, Cambridge, has investigated the effects of a range of chemicals on the colonisation of pine stumps by *Fomes annosus* and harmless primary stump invaders such as *Peniophora gigantea* and 'blue stain' fungi. Laboratory trials have been followed by field experiments. The great majority of substances caused some reduction in colonisation by *Fomes annosus*. Some, notably two borates, appeared to be selectively toxic to *F. annosus.*

PART III

Part III consists mainly of accounts of individual research projects carried out by the staff of the Research Branch. In most cases they describe work carried out over a period of several years. Since they are not therefore strictly accounts of the 'Year's work', they are here only listed and commented on, not summarised.

Mr. G. D. Holmes and Mr. G. M. Buszewicz describe experiments on the storage of beech seed.

Mr. M. Nimmo and Mr. J. Weatherell describe experiments, extending back many years, on the nursing effects of broom and other leguminous plants when grown in mixture with young tree crops.

Mr. J. R. Aldhous reports on the nursery stages of a large-scale provenance experiment with Sitka spruce. Some clear differences between seed origins have already become apparent. Aldhous also gives an account of simazine as a weed-killer for forest nurseries.

Mr. R. F. Wood contributes a short general description of the arboretum at Westonbirt in Gloucestershire, which is now in the charge of the Forestry Commission.

Mr. G. G. Stewart and Mr. S. A. Neustein give an account of a number of unsuccessful experiments to exclude deer from newly planted areas. Deer damage is an increasing problem, and it is disappointing that these relatively simple methods did not succeed.

Mr. D. Bevan and Mr. A. Paramonov report very briefly on the fecundity of the Pine looper moth (*Bupalus piniarius*). Miss J. Davies describes at greater length population studies of the same insect with particular reference to parasitism.

Mr. D. W. Henman presents data on the effect of high pruning on the subsequent cost of peeling the pruned logs.

Mr. G. D. Holmes reports on the chemical treatment of standing hardwoods to facilitate subsequent peeling. This work is of importance in connection with the peeling of crooked stems, which cannot readily be peeled by purely mechanical methods.

Finally, Mr. D. R. Johnston writes on the application of electronic computing to forest inventory, one of the many instances where automatic data processing is opening up new possibilities in forest management.

PART I

Reports of Work carried out by Forestry Commission Research Staff

FOREST TREE SEED

By G. D. HOLMES and G. M. BUSZEWICZ

Service Work

Seed Supply and Storage

The Central Refrigerated Seed Store, completed at Alice Holt in 1959, is now under Research Branch management, the Chief Research Officer being responsible for organisation of seed supplies, maintenance of seed stocks, and technical supervision of seed collection, processing, and storage procedures. In practice, these duties are shared by the Silvicultural and Genetics sections, which collaborate closely on seed supply matters. All tree seed imports purchased by the Forestry Commission pass through this store, as do many home-collections made by the Commission in England and Wales.

The Alice Holt Store, together with a new refrigerated store at Tulliallan for the Commission's Scottish home-collections, have a combined capacity of about 55,000 lb. seed, or nearly four times the average annual requirement of the Commission and the forest seed trade. To ensure sustained supplies each year, the present storage policy aims at maintaining stocks equivalent to at least two years' supply after current season's requirements have been met.

During the course of the seed season just ended (1960–61) the Seed Store staff made some 215 despatches of seed to Forestry Commission nurseries involving about 550 individual lots of seed. The total weight of seed was 9,800 lbs. Despatches included all the main species and a large number of minor species. In addition, 140 despatches totalling 3,500 lbs. and involving 465 individual seed lots were made to the nursery trade, private owners and others. The species most in demand were Norway spruce, Sitka spruce, Douglas fir and Japanese larch.

In addition to the main programme of seed despatches, some 5,000 measured and packeted lots of seed were prepared for use in Research Branch nursery experiments during 1960.

New developments at the store include installation of a specially designed seed dryer, described in the last Report, and a large-capacity mechanical seed mixer. The latter is now in regular use to make seed lots more homogeneous, and for combination of seed lots where appropriate.

The total stock of seed at present held in the Central Seed Store is 22,306 lb. and this is valued at approximately £85,000.

Seed Testing

The Licensed Seed Testing Station at Alice Holt operates in close liaison with the two main seed stores in sampling and testing stored and newly imported and home-collected seed. During 1960, 709 seed samples were received for testing, and the following analyses completed:

Purity Analyses.	404
Seed Weight Tests	470
Germination Tests .	1,414
Tetrazolium Tests .	22
Moisture Content Tests . . .	427

These numbers include 337 germination tests and 143 seed moisture tests carried out as part of the experimental work described below. The seed moisture testing programme has risen from less than 200 tests per annum in 1957 to over 400 per annum, as it is now a routine procedure to test and adjust seed moisture levels before sealing for storage.

Research Work

Seed Mixing

As noted earlier, a seed-mixer has been installed in the seed store, following a programme of tests with several types of equipment. The type finally selected was a 'Carier' 10 cwt capacity mixer, consisting of a vertical hopper fitted with a fixed shrouded auger, and provision for filling at floor level (Plate 2).

Several tests were completed to assess the efficiency of mixing and the time required in relation to seed quantities, also to determine whether there was any risk of damage to seed during the process. For this purpose, three species were selected, namely Japanese larch, Douglas fir and Noble fir, to cover a range of seed size and seed-coat toughness. The tests were completed separately for each species by loading the hopper and adding 1 per cent by weight of dyed seed which could be picked out readily in the final mix.

In each case the mixer was run for a period of 15 minutes, and stopped every two to three minutes, when seed samples were taken for examination. Analysis of the results showed that in all species, mixture was complete and homogeneous by nine minutes' mixing time. The time required to achieve a satisfactory mix seemed more dependent on seed quantity rather than on the species concerned, viz.:

Species	*Mixing Time Required for Homogeneity (minutes)*	*Weight of Seed Mixed (lb.)*
Japanese larch	9	653
Noble fir	6	483
Douglas fir	4	147

Subsequent examination and germination tests of these seeds showed no signs of damage even after the longest period of 15 minutes' mixing, as shown in Table 1.

Certainly no immediate damage occurred, but stored samples of these seeds will be tested at intervals to check possible residual effects which may appear after storage.

Initially, the machine has been found safe and effective, and further tests are now in hand to assess its possible use for seed dewinging. Indications are encouraging and the process would be much less damaging than conventional brush type dewingers.

Table 1

Seed Germination Capacity After Mixing in a Vertical Auger Type Mixer

Mixing Time (minutes)	Germination per cent by Species		
	Japanese larch	Noble fir	Douglas fir
0	45	41	90
2	47	44	89
4	46	42	87
6	44	42	87
9	52	44	86
12	55	45	82
15	50	44	87

Seed Storage

(a) *Noble fir:* Arising out of past difficulties in satisfactory long-storage of *Abies* species, a comprehensive seed storage experiment was started in 1959 using Noble fir as the test species. The tests are aimed at assessment of the effects and interaction of storage temperatures, atmosphere (air, CO_2 and vacuum) and seed moisture content, on seed longevity.

Seed moisture was adjusted to a range of levels from 4–16 per cent and samples sealed in tinplate containers in air, vacuum or CO_2 gas. (These treatments were made possible through the kind co-operation of the Metal Box Co. Ltd.) Sample containers are now stored at temperature levels ranging from —20°C to +20°C, the whole trial being planned to run for a maximum of 10 years. The results of the first tests carried out in 1960 after *one year's* storage show that:

(i) Seed stored at moisture levels of 6–8 per cent in sealed containers showed no deterioration irrespective of storage temperature.

(ii) Seed at moisture levels of 16 per cent showed some deterioration at the temperature extremes of +20°C and —20°C.

(iii) No differences were observed between vacuum, CO_2 and air storage conditions.

It was noted that pre-chilling reduced germination capacity compared with no treatment, especially for the driest seed.

(b) *Beech:* The results of recent storage tests extending over a three-year period are presented in Part III of this Report, page 117. Fresh tests of selected storage methods were laid down in 1960 to follow-up the main conclusions of the earlier work.

Germination

Research on germination requirements of the major species was continued, with special emphasis on a programme for improvement and standardisation of test methods in collaboration with the International Seed Testing Association. Tests have been organised in six countries to examine the germination requirements of a range of seed origins of *Abies alba* to permit definition of a precise and uniform test method. Similarly, the Station is co-operating in a series of tests on several origins of *Pinus pinaster*.

As chairman of the Forest Seeds Committee of I.S.T.A., the senior author (G. D. Holmes) was responsible for initiating international exchange of correspondence and test data required for future revision of the International Seed Testing Rules.

Apart from the I.S.T.A. programme, a study was started on the ripening, germination and storage requirements of elm seed. Seed collected in 1960 was of good quality and stored well for eight months at 3°C.

Seed Moisture Content

There are practical difficulties in accurate moisture content determination for many conifer seeds owing to their relatively high content of volatile oils. At present, tests are done mainly with an air-drying oven at 105°C, but results are not fully satisfactory. To help standardise the oven method, joint tests have been started with the Dutch Seed Testing Station at Wageningen, comparing results with toluene distillation, the P_2O_5 method and others. On conclusion of these tests, it is hoped that standard methods will be defined.

NURSERY INVESTIGATIONS

By J. R. ALDHOUS and J. ATTERSON

Factors Influencing Yield of Seedlings

Date of Sowing and Irrigation

This experiment is repeated annually at Bramshill, Kennington and Wareham Nurseries to facilitate the comparison of experiments sown at different times in any given nursery. Seed was sown on six dates separated by a fortnight and starting in early March. Highest yields in all three experiments were obtained from sowing in March and early April. Later sowings yielded fewer and smaller seedlings, especially at Wareham and Bramshill. These results confirm those of previous years. At Kennington, certain plots in the 'date of sowing' experiment were irrigated by overhead spray line. The water applied was proportional to the daily estimated evapo-transpiration loss. The summer was wet and little water was required from June onwards, but in May, when there was very little rain apart from two heavy thunderstorms, water was applied by irrigation on seven occasions. There was little response to irrigation from any species in the experiment – a result which would be expected in view of the weather during the growing season.

Seed Pre-treatment: Abies species

In an experiment repeated for the third year, yields from seed of *Abies grandis* and *A. procera* (*nobilis*) stratified in sand for three weeks, or pre-chilled in moist filter paper for three, six, or nine weeks, were compared with yields of seed sown dry on dates from early February to late April. The treatments yielding the highest number of seedlings and tallest seedlings were those where seed had been pre-chilled for nine weeks, or where it had been sown in early February. These results agreed with those of previous years. The seed used in this and in the two previous years' experiments was the same, seed of both species having been collected in 1957 and 1958; this year, in addition, *Abies procera* seed collected in 1959 was included. The yields of *A. grandis* seedlings from the 1958 seed were very much higher than from the 1957 seed, but there were only small differences in the yields of the three ages of seed of *Abies procera*. The low yield of the 1957 *A. grandis* is undoubtedly associated with the fact that the percentage germination of this lot of seed dropped substantially during the three years it had been stored, whereas the percentage germination of the other lots of seed was more or less constant.

Partial Sterilisation of Seedbeds

'Sistan', a proprietary chemical, was used as a partial soil-sterilant of seedbeds of Sitka spruce and Japanese larch. The results were not promising on the spruce seedbeds when compared with formalin sterilisation, neither numbers nor heights being as high as those on formalin-sterilised beds. These results confirm those of 1959. Weeds were considerably reduced on 'Sistan'-sterilised beds, again as in 1959, but were not eliminated. On Japanese larch seedbeds, however, this chemical produced superior growth, but did not increase the number of seedlings when compared with unsterilised and formalin-sterilised beds. This indicates a marked selectivity between species.

At Inchnacardoch and Benmore Nurseries, 1959 experiments with 'Sistan' were re-sown to determine any residual effects of this chemical. Apart from slight increases in height and numbers at Benmore, no residual effects were found.

Maintenance of Fertility

Long-term Fertility Experiments

The experiment at Bramshill was continued for its eleventh year. Growth on all plots was slightly less than average, probable due to the cool, wet season. Bracken/hops compost (at approx. 20 tons per acre) continued to give slightly taller seedlings than the inorganic fertiliser regime (PK+Mg applied in the winter with two top dressings of N), though there were, on the latter plots, about 20 per cent more seedlings than on the compost plots. The yield and growth of seedlings on plots having compost + inorganic fertiliser was very similar to that on plots having compost alone.

The slightly greater height growth of seedlings on compost plots has been observed for the last four seasons. The greater yield of seedlings on fertiliser plots has occurred in almost every season of this experiment, though the difference in 1960 is greater than usual.

The demonstration at Wareham, which since 1945 has followed Dr. Rayner's prescription for the maintenance of fertility, continues to give satisfactory results, though here, as at Bramshill, growth was slightly below average.

Other long-term demonstrations were continued at Fleet, Inchnacardoch, Newton and Teindland Nurseries. At Teindland Nursery, the compost treatment produced larger Sitka spruce and Lodgepole pine seedlings than sterilisation or no treatment, but reduced the numbers of the former species by 15 per cent. Sterilised plots and composted plots were more severely affected by the fungus *Botrytis* than control plots.

Nitrogen Manuring

An experiment at Inchnacardoch Nursery on Japanese larch and Douglas fir 1+0 seedlings has again indicated that late or heavy applications of nitrogen delay bud formation. Height growth was not significantly affected by the amount of nitrogen applied, but the earlier dates of application (late July) increased height growth more than the later dates (early August). Bud-formation was delayed by 14 days in the case of Japanese larch, and by eight days in the case of Douglas fir, by any application of nitrogen; neither the amount applied nor the date of application of nitrogen affected this delay.

Cold Storage of Surplus Seedlings

Small-scale experiments were continued for the third year on the survival of seedlings following storage at temperatures around freezing point. The object of these experiments is to enable surplus seedlings to be carried through a growing season without making any substantial growth, thus enabling them to be used for planting a year later than would otherwise be the case. The plants were stored at temperatures of 36°F or 23°F, being fully enclosed in polythene bags while in storage.

In experiments commenced in 1959 and 1960, seedlings were lifted in late February or early March while dormant, and were stored for up to 14 months. The two years' results show that Sitka spruce, Japanese larch, Western hemlock, Scots and Lodgepole pine seedlings were able to tolerate storage at 36°F for up to eight months without harm, but that plants deteriorated when stored for the same period at 23°F. Storage for 10 months or more at either temperature was not satisfactory, survival rates being poor. Douglas fir seedlings stored well in 1960, but not in 1959.

All plants commenced growth soon after lining-out following storage, even if lined-out in the autumn, and those plants with leaves and shoots which were still growing at the time of the first autumn frosts were severely damaged. Scots and Lodgepole pines, Sitka spruce, Western hemlock and Douglas fir, stored for five to six months and lined-out in late July–mid August, were able to flush, make a short shoot and harden off (but not necessarily form a well-developed terminal bud) before the first frosts. Japanese larch appeared to be unable to harden off a terminal bud before the autumn frosts, even if lined out at the end of June.

Height growth made by plants in the year of lining-out was the less, the later the date of lining-out (as might be expected). Plants lined-out in July–August, 1959, were, at the end of 1960, similar in size to plants a year younger which were lined-out normally at the beginning of 1960. Plants lined-out in 1960 are still under observation.

Weed Control

Pre-sowing Application of Herbicides to Seedbeds

A new herbicide, 2,6-dichlorobenzonitrile, was applied before sowing at $\frac{1}{2}$–2 lb. per acre to seedbeds at Kennington. The weed control obtained with 1 lb. or more per acre was good, though there was some crop damage. The results of this experiment are fully described elsewhere (Aldhous, 1961(a)).

Experiments were also conducted with this substance on seedbeds of Sitka spruce at Tulliallan and Fleet nurseries. At both sites the weed population was considerably reduced by applications of ½ lb. or 1 lb. per acre applied four weeks before sowing, though at Tulliallan there was reinvasion by pearlwort (*Cerastium erectum*) late in the season; and at neither site was there any significant reduction in the numbers or heights of seedlings.

Control of Weeds in Transplant Lines

Simazine was sprayed on transplant lines of a wide variety of species at the main research nurseries, and in field trials in 14 Conservancy nurseries. Generally, applications of simazine at 2 lb. (active ingredient) per acre, were found to give good weed control and not to damage the crop. A full account of these experiments is given in Part III of this research report.

Susceptibility of Transplants to Dalapon

Experiments to obtain information on the susceptibility to Dalapon of conifers when dormant were carried out at several nurseries; the information obtained will, it is hoped, be of application in newly-planted areas in the forest (*see* page 31.) Dalapon (the sodium salt of 2,2-dichloroproprionic acid) was applied at 2½, 5, 10 lb. active ingredient as an inter-row or overall spray to several species of conifer transplants. Sprays were applied to dormant plants in early spring 1960, late autumn 1960, or early spring 1961.

Transplants of Douglas fir, Western hemlock and Western red cedar sprayed in early spring 1960 with the highest rate of application (10 lb. per ac.), suffered slight to moderate damage, young shoots being distorted and the needles stuck together (by slight wax or gum exudations); Lawson cypress foliage lost its glaucous appearance but otherwise was not affected. Other species, Norway and Sitka spruce, pines, larch, etc., were not damaged. Plants sprayed more recently are still under observation.

Frequency of Weeding

The experiments started in 1959, in which plots were weeded at intervals of 1½, 3, 6 or 12 weeks (Aldhous, 1961(b)), were continued on the same plots, treatments being rearranged so that information would be obtained on the effect of all possible combinations of interval of weeding in the two years. Weeding intervals in 1960 were 2, 4, 6 or 8 weeks. Plots weeded every fortnight in 1961 took far less time in aggregate to weed during the growing season than plots weeded every eight weeks, this result being in accord with previous observations. The residual effect of interval of weeding in the previous year was small compared with the effect of the current year's interval.

Protection Against Birds

In experiments on the effect of coverings on seed yield, polythene sheet laid over normally-sown and covered seedbeds, and removed soon after germination, had been found to do little harm to seedlings (Faulkner and Aldhous, 1960). It was thought that such a cover might be a cheaper alternative to netting, which is the standard method pf preventing bird damage to seedbeds.

Experiments were carried out at Wareham and Bramshill with Scots pine, Corsican pine, Sitka spruce and Japanese larch seedbeds in sections where birds have been troublesome in the past; some plots were covered with clear polythene sheet immediately after sowing, some covered with netting and others left uncovered. The polythene was laid directly on the surface of the seedbed and was removed either when germination was first observed, or three, six, and nine weeks after this. The netting used was ¾-inch mesh galvanised wire netting raised three inches over the seedbed and turned down at the sides to prevent birds running in under it. Control plots were left without protection.

There was little bird damage at Bramshill, but birds very significantly reduced the number of seedlings of Corsican and Scots pine at Wareham on unprotected plots. Seedbeds kept under polythene from the time of sowing until the time of germination (or three weeks later) were not attacked by birds. The number of Sitka spruce and Japanese larch seedlings at the end of the season was significantly reduced on beds kept under polythene until six or nine weeks after germination, especially on the plots covered for the longest period; the number of seedlings of the two pines was not reduced on these beds, however, and at both nurseries, but especially Wareham, the seedlings were appreciably taller.

During a hot period of weather in mid-June, pellets of wax of known melting point were half-embedded in the soil surface on control and polythene-covered beds in this experiment (beds covered for nine weeks were still covered at this time). Pellets melting at 113°F were completely melted on all beds; pellets melting at 125°F were completely melted under the polythene but only partly melted at ground level on the control (open) bed; pellets melting at 138°F were unaffected on open ground, but were partly melted at ground level under the polythene. These figures can be taken to indicate temperatures in full sunshine at the soil surface, and show that the temperatures under the polythene may be at least 12°F greater than in the open. The higher temperatures under polythene in this particularly hot spell were apparently damaging to Japanese larch and Sitka spruce seedlings, but did not affect the two pine species.

Similar experiments were carried out at Inchnacardoch nursery on seedbeds of Douglas fir and Western hemlock, though here the chief interest lay in hastening germination. Results differed from those in the southern nurseries in that polythene covers were markedly detrimental to the growth and yield of seedlings, however, they were successful in preventing bird damage to Douglas fir, which suffered severely without protection. Black polythene covers had some success in discouraging weed germination.

Use of Computers for Summaries of Nursery Yields, Percentage Survival, etc.

Programmes have been prepared to enable yields of seedlings per lb. of seed, percentage survival of plants in transplant lines, etc., to be calculated on a Pegasus electronic computer. The data so obtained will be used as the basis for planning future Forestry Commission nursery programmes. Computer programmes to facilitate stock-taking and plant allocations are also being prepared.

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SILVICULTURAL INVESTIGATIONS IN THE FOREST: SOUTH AND CENTRAL ENGLAND AND WALES

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Afforestation Problems

Afforestation of Special Sites

Relatively little new work was carried out in 1960, which reflects the recent switch in effort from afforestation to the increasingly important questions of regeneration and stand treatment.

At Croft Pascoe, Land's End Forest, on an exposed shallow, *Erica vagans*/ Dwarf gorse heath, overlying serpentine rock, some 24 experiments were planted between 1954 and 1957, to provide establishment data on which to base more extensive planting. Over 20 species were planted on an experimental scale, and growth rates show that coastal exposure and site infertility will probably confine the initial choice of species to Lodgepole pine, *Pinus contorta* (coastal Oregon and Washington), Monterey pine, *P. radiata*, and Maritime pine, *P. pinaster*. For all species, ploughing and phosphate dressings are essential for satisfactory early growth.

Acting on these results, the Conservator of Forests for South West England has ploughed and planted a further 100 acres of heath close to the experimental area, using *Pinus radiata* and Lodgepole pine. *P. radiata* has proved difficult to establish, but good results have been obtained by early autumn planting of seedlings or direct sowing in the spring. Also, in a new experiment in 1960, excellent results were obtained by planting-out seedlings raised in soil-blocks contained by individual polythene tubes.

There has been a marked fall-off in growth of many species in the original plantings due to vegetation competition and phosphate deficiency, despite initial dressings at planting. To ensure canopy closure of as many of the test species as possible, a large part of the experimental area was top-dressed with triple-superphosphate at 3 cwt/acre (67 lb. P.) in spring 1960. Also, many of the less successful species were in danger of suppression by vigorous gorse development following ploughing and manuring. In these areas 2,4,5-T ester at 2 lb. (acid) per acre, was applied in late summer 1960, with excellent results. Gorse seems to have been effectively controlled with little injury to any tree species.

At Wareham Forest, Dorset, in 1960, an extensive trial of species was planted on the 'hill and dale' formations of disused gravel workings. There is an increasing area of such workings in the district, and these plots were designed to give early information on choice of species and planting methods. Growth in the first year has been exceptionally good, particularly with *Pinus radiata*, Corsican pine and the Leyland cypress X *Cupressocyparis leylandii*. The indications are that there will be no special difficulties other than extraction of produce on such sites.

At Taliesin Forest, Cardigan, a site representative of a large area of steep, freely-drained mineral soil in Wales, Sitka spruce, Noble fir and Lodgepole pine continue to be outstanding among the many species tested. In 1960, the species represented were increased by the planting of plots of *Tsuga mertensiana* under similar conditions at Tarenig Forest.

Afforestation of Exposed and Elevated Sites

Five sites have been planted during the year in Wales at high elevation with Sitka spruce, Lodgepole pine and Noble fir. Some further sites will become available in the next year or so, which will probably bring the total to eight. These cover a range of altitudes from 1,500 ft. to 2,400 ft. and will in due course give a useful indication of the performance of these species in crop conditions at high elevations.

Regeneration Problems

Artificial Regeneration

The work on this project has conveniently divided itself into two main parts. The long-term investigation of silvicultural systems for regeneration and species to be used in the second rotation, and the more short-term investigations on such subjects as brash disposal and weed control.

All the studies have so far been restricted to the large forest areas of Japanese larch and Scots pine plantations. In both species the main object is to test the performance of a range of possible alternative species, which will be established under some form of shelterwood, retaining forest conditions as far as possible. These experiments, which will be laid down over the next few years, will give useful experience and data which should be available for application to the large areas of plantings made after the 1939–45 war, which may fall due for regeneration in some 20 years' time.

The most important 'short-term' development is that of a machine for disposing of the lop-and-top left after a clear felling, or final heavy thinning. The machine, an adaptation of an agricultural forage-harvester, is towed over the brash, which it chops, leaving a fine mulch of needles and twigs on the ground and a number of larger branches stripped bare. An experiment has been established to compare three methods of brash disposal, namely chopping, burning, and leaving for natural decomposition. The possible advantages of chopping the brash include:

(1) Improved moisture retention in the surface layers of the soil during periods of spring drought.
(2) Reduction of weed re-invasion.
(3) Return of nutrients over the whole site rather than in local spots as with burning.
(4) The ability to dispose of brash at any time of year rather than at certain times, as with burning.
(5) The cost of the operation, which appears to be a half to one-third of the cost of burning.

The risks of chopping as opposed to burning are the invasion of the *Fomes annosus* fungus in stumps bruised by the machine, and the breeding of insects in the chopped material. These points are also being investigated. Larger scale trials are being arranged during the coming year to investigate costs in greater detail, and to assess the reliability of the machine in continuous use.

Natural Regeneration

The scope for natural regeneration in the Commission's forests as yet is small, as there are only a few woods old enough to regenerate freely, and in many cases a change of species or provenance is called for. However, there are areas where natural regeneration must be seriously considered, and in due course, once the species and strains have been modified, larger areas could be regenerated naturally. It has therefore been decided to go ahead on a small scale, accumulating experimental evidence that will be useful when natural regeneration becomes more important.

At present, efforts are being directed on to study of the periodicity, quantity and quality of seed produced by the major species in relation to geographical distribution. As this is very closely related to the work of the Genetics Section, close co-operation is being maintained and much of the work will actually be done in registered seed stands. So far, provisional sites have been chosen, and seed trapping will be carried out over a period of years.

Forest Stand Improvement

Manuring Trees at Planting

Recent experiments have been concerned mainly with rates and methods of application of phosphates on the poorer mineral soils. Phosphate is normally applied in practice on such sites at rates of 1½–2 oz. ground mineral phosphate or ¾–1 oz. triple-superphosphate per tree (i.e. about 25 lb. P. per acre) as a placed dressing to each plant. Results on the poorest heaths, e.g. Croft Pascoe at Land's End Forest, Exeter Forest and Wareham Forest show these rates to be inadequate for sustained vigorous growth, and an increase of the rate seems justified on such sites. Placement beneath the plough ridge, and broadcast methods of application, are being tested at several forests as a preliminary to trials of mechanised fertiliser application.

Potash additions to mineral soils at the time of planting have rarely been beneficial, a point which was borne out by the results of P x K factorial experiments laid down on five contrasting mineral soils in 1956. However, on peat areas, potash can be important, as was noted in a 1960 trial-dressing on discoloured Sitka spruce and Lodgepole pine at Dyfnant Forest. Here, despite initial P dressings, extensive yellowing of the plants occurred within two years of planting, and a N.P.K.Mg. factorial test was laid down for purposes of diagnosis. Within a few months of application of potassium chloride at ½ oz. per plant, colour was restored to normal and growth resumed vigorously.

It was also noted that potash-treated Lodgepole pine were free of *Lophodermium* fungal infection while untreated trees showed a moderate to high incidence of infection. It is not suggested that there is any fundamental relationship between K deficiency and *Lophodermium* infection, but it seems likely that the reduced vigour of deficient plants may be a pre-disposing factor to infection.

Improvement of Checked Plantations

A considerable number of experiments were established on checked plantations of a variety of species from 1956-60, and observations have continued on these trials. The symptoms of 'check' have varied greatly between species and sites and no consistent, clear relationship has emerged between symptoms and confirmed nutrient deficiencies. Because of the importance of identifying deficiency symptoms for purposes of diagnosis, a series of plots were established in 1960 with the aim of deliberately inducing deficiencies of each major element, to assist definition of symptoms for the main species of conifers. These plots were planted at Wareham on a blown-sand area of very low nutrient status to provide a contrasting series with 'unbalanced' manuring in respect of N, P, K, Ca, and Mg. All plots are being kept free of vegetation and nutrient dressings repeated at intervals.

Manuring experiments on checked S.P. and C.P. on the heather (*Calluna vulgaris*) dominated Bagshot sands and Plateau gravels at Exeter, Ringwood and Wareham Forests are now yielding useful results, showing that growth can be accelerated by addition of N. and P. top-dressings in areas where inadequate drainage is not the dominant factor. Several N. Forms have been tested with the aim of securing more persistent effects than normal soluble forms. So far, the responses obtained with urea (46 per cent N.) or diammonium phosphate (18 per cent N., 50 per cent P_2O_5), have been the most striking, giving responses persisting over three seasons. On existing evidence, it seems that checked pine crops in *Calluna* can be restored to normal growth by this means, but further N. top-dressings at about 90 lb. N. per acre *may* be necessary at intervals of three to four years, to ensure canopy closure.

The alternative of phosphate addition *plus* heather eradication by chemical means is a possible, and probably a more lasting, remedy, which is now being examined.

A programme of aerial application of di-ammonium phosphate to some 120 acres of poor pine at Ringwood in spring 1961 has so far been baulked by bad weather, and aircraft faults. Depending on observed persistence, the results of these trials will probable be extended to more general top-dressing of problem areas within the next two to three years.

In South West England, experiments have been concentrated on poor spruce crops on Culm soils, and experiments from 1954 have shown complete recovery from check following P. dressings at forests such as Wilsey Down and Halwill. As reported last year, over 100 acres of checked spruce at Wilsey Down was top-dressed from the air with triple-superphosphate at 3 cwt (67 lb. P.) per acre. This operation was carried out at a total cost of £6–£7 per acre, and results have been most satisfactory judging by growth responses during 1960. All remaining poor areas at this forest will probably be treated the same way in the next forest-year. On the same soils, slow-growing Lodgepole pine, top-dressed in 1959, has shown only a limited growth response.

Shoot 'wilting', and dieback in the early summer, is a characteristic symptom on checked spruce on Culm soils, and this condition is completely relieved by phosphate addition. However, the curious symptoms suggest that the condition could be basically a minor-element disorder aggravated by phosphate deficiency. Foliar spraying of test trees with Zn, Cu, Mb, Bo, Fe, and Mn, failed to confirm this idea. Also, in 1960, analyses of foliage and soil samples from 'checked' and normal areas by Dr. Le Riche of Rothamsted, failed to bring out any clear relationship with minor-element levels.

Observations on experiments laid down in 1959, confirmed that broadcast phosphate dressings were more effective than equivalent rates applied to lines or discrete positions throughout the crops. Also, there has been no advantage in the use of more slowly-soluble P. forms compared with water-soluble superphosphate. The 'yellow-tip' phenomenon on spruce, caused by an induced K. deficiency following P. top-dressing, has recurred following new applications, but the condition is not persistent, and appears to have little effect on the large growth response to P.

In Wales recent experimental top-dressings of checked or slow-growing Sitka spruce, Scots pine, Corsican pine and Lodgepole pine on *Calluna* heath at Clocaenog and Clwyd Forests have failed to show any marked growth improvement following N., P. and K. additions. However, in mid-Wales, at Tarenig Forest on steep mineral soils with dwarf-gorse and *Calluna*, P. alone at 2–4 cwt/acre has resulted in a notable improvement in the growth of checked Sitka and Norway spruce.

Unsatisfactory growth of Douglas fir on the dry acid silts and fine sands of the Weald of Kent and Sussex was investigated in 1959 by carrying out a survey of growth in relation to site characteristics. Very shallow rooting was a quite general feature of the poor crops, and seasonal failure of moisture supply seems a key factor. The mechanism is obscure, but the effect is extensive death of roots and failure of the species to produce fresh roots deeper than about 4–6 inches. The general infertility of the soils, the small volume rooted, and summer-drought conditions in the surface layers, probably combine to cause growth failure. Attempts were made in 1959 to increase the extent of rooting and growth by enrichment of the surface-soil with N.P.K.Ca.Mg. fertiliser dressings at several locations, but, by the end of 1960, no responses had been recorded.

The work noted covers examples of checked and unsatisfactory crops over a wide range of site conditions. They are treated almost as separate enquiries, but they are linked through a considerable programme of nutrient uptake analyses, which are now being made on samples from these crops. These analyses are providing valuable data on the nutrient status of the crops, and the uptake of added nutrients. As this work progresses, it is hoped that patterns will emerge which will facilitate diagnosis of deficiencies and point to remedial treatments.

Manuring of Pole-Stage Crops

No new experiments were laid down on this project during the year, and work was confined to assessments and analyses on the existing series of 15 factorial N x P x K x Ca x Mg experiments formed in 1958 and 1959. These experiments were established in Sitka spruce, Scots pine, and Douglas fir crops at the first thinning stage of development, over a range of site conditions, to provide evidence on major nutrient uptake and the responsiveness of such crops to fertiliser dressings.

Both the chemical and statistical analyses required in these experiments are very time-consuming, and up-to-date summaries of assessments are at present available for only a few. In general, there have been no striking effects of fertiliser treatments on growth rates in pole-stage crops, but there have been effects on nutrient uptake by the crops, and on the process of litter decomposition in treated plots. The eventual significance of these effects cannot be estimated.

Effects on litter decomposition as judged by visual inspection, have been marked, notably following N. or heavy lime (Ca) dressings. Improved litter breakdown could be important through mobilisation of nutrients accumulated in raw humus, and the extent of nutrient release following such breakdown will shortly be under investigation. Profuse growth of fungi, notably Agarics, has occurred on many N. and Ca. plots, and it has been noted with interest that one species in particular, *Clitocybe fragrans*, was characteristic on these plots in experiments as far apart as North and South Wales, and South-West and South-East England.

Further field experimentation will depend on the outcome of analysis of existing data, but will almost certainly include more detailed studies of forms of N. additions and their uptake and effects on crop growth.

Crop Composition – Studies of Long-Term Mixtures

The series of long-term mixture experiments started in 1954, was increased in 1961 to include a replicated set of pure and mixed plots of Scots pine and birch on an acid heathland site in the New Forest. As for all the experiments in the series, the objects are to provide reliable evidence on the long-term effects of admixture of species on growth and increment, and on the characteristics and productivity of the site for subsequent crops. Recent efforts to progress more quickly on this project, by means of studies in existing mixed stands, have proved unrewarding on account of uncontrollable site variations, changes in past management practices, and the difficulty in making reliable comparisons between pure and mixed stands outside a formal replicated experiment. In 1960, a trial-survey of mixed stands, located through Census Records, emphasised these difficulties and led to the conclusion that the work should proceed on two lines, viz. (a) Establishment of replicated mixture experiments for provision of evidence in the future, and (b) Efforts to elucidate mutual effects by the examination of individual trees.

Wind Stability Studies

There have been two main developments during the year. Firstly, a system of notification has been introduced, whereby windblows are reported as they occur, with brief details of the crop and the extent of damage. So far, this is only in operation in three Conservancies, but it is hoped to extend it to the whole country. The object is to find out how much windblow is occurring and what species, size of crop, and environmental conditions are most concerned. Where desirable, detailed investigations will be made before any of the circumstances have become obscured.

Secondly, a series of 'tree pulling' trials have been carried out in Kielder and the Forest of Ae, using the technique briefly described in the *Report on Forest Research*, 1960. The investigation was carried out on Sitka spruce 33 years of age, with a height range of 39 to 60 feet, growing on peats varying in depth up to 24 inches, above mineral soils of different characteristics. All these soils were on the heavy side, but varying from a fine sandy-silt to a silty clay; in most cases stones were present. The objects of the trials were to study the effects on tree stability of depth of peat, nature of mineral soil, and drainage.

On these sites it was observed that drainage had produced a considerable increase in the depth of rooting, and a slight increase in the stability of the trees. Most of the trees had rooted to the full depth of the peat, the ultimate depth of rooting being determined by the nature of the mineral soil below. Peat being mechanically weak, it was not surprising to find that the degree of penetration of roots into the mineral soil below had a greater influence on stability than the total depth of rooting. There were indications that for a given height of crop, trees of high basal area tended to be much more stable than trees of lesser basal area.

The studies revealed very great variations in the rooting habit of Sitka spruce, not all of which appeared easily explicable in terms of soil conditions; the observations made will be of much value in planning a more extensive enquiry into the factors influencing stability in spruce crops.

Further work was also done in this general project on the measurement of the actual loads exerted by wind of various velocities on tree crowns. Some observations were also made (by means of balloons and smoke) on the behaviour of wind in and around the forest margin.

Drainage Studies

The drainage of heavy clays under woodland conditions is difficult and expensive, and the provision of an intensive system by hand methods alone is usually regarded as an uneconomic operation for the purposes of forestry. Not till recently have we had much indication of the effectiveness of drainage in heavy clays. The drainage experiment at Bernwood Forest on the Oxford clay, described by Fourt (*Research Report*, 1960), had, however, given some encouragement to extend such work to other types.

Two experiments have been laid down on sites representative of major areas of mineral soil where drainage is a problem, to study firstly the practical aspect of carrying out drainage mechanically under forest conditions and, secondly, the longer term effect of drainage on root development and tree growth.

One experiment is at Halwill Forest in Devon on heavy Culm soils, using 'mole' drainage, it is thought for the first time in British Forestry. The experiment is a direct comparison of 'mole' drainage and no drainage, superimposed on normal single-furrow ploughing. The treatments have been successfully completed, and observations on the water level and rate of removal of water will be made using observation bore-holes over the next few years.

The second experiment is at Kerry Forest in mid-Wales, where a system of open drains, 2ft. 6ins. deep and spaced at intervals of 2 chains (132 feet), has been laid down at a small angle to the contour in stump-covered ground. The technique used was to remove stumps along pegged drain lines with an 'International Drott' digger, and then to dig the drains with an excavator mounted on a crawler tractor. A total of about 40 chains (2,640 feet) of drains have been made in about six acres, and here again comparisons will be made with the undrained plots of soil water levels, rate of water removal, growth and root development of the tree crop.

These experiments are essentially trials of methods, and now that experience has been gained, further work will be done to study intensity of drainage, optimum depth, and the effect of drainage on soil structure and root development.

Weed Control in the Forest

Total Weed Control

Until recently, work on total weed destruction was restricted to investigation of the use of non-selective herbicides in uncropped areas, i.e. fire-breaks, fence-lines, etc. Results of these trials were published in the *Research Report*, 1960. In 1961 work was centred on the problems of total weed destruction in regeneration areas, both before and after replanting.

Weed growth of grasses and herbaceous species develops rapidly after tree-felling, and it seems that there might well be an important use for herbicides for application at this stage, before weed growth becomes established. A number of experiments were laid down at Thetford Forest in spring 1961, testing soil-acting herbicides, notably triazine derivatives (propazine, atrazine and simazine), as non-selective residual herbicides and 2-6-DBN (2,6-dichlorobenzonitrile), as an active seed-toxin, applied to newly clear-felled sites. Surface accumulation of organic-matter in such sites tends to buffer and reduce the effectiveness of herbicides, so combined cultivation and herbicide treatments are being tested in several experiments.

Control of Grass Weeds

Experiments on the use of chemicals for controlling established grass weeds in planting areas were continued with special emphasis on dalapon, simazine, and more recently Diquat and Paraquat. Results of numerous experiments since 1959 with dalapon confirm that this compound can give a high degree of grass control when applied at rates of eight to 10 lb. per acre as an overall foliage spray. The persistence of control varied according to the type of sward from two to three years on pure *Molinia* and Downland grasses (*Bromus, Dactylis, Festuca* spp.), to six to 12 months on certain woodland grass types.

Most of the 1960 experiments were concerned with assessing the susceptibility of tree crops to treatment, and it has been shown that sprays applied in the growing season, even as directed inter-row sprays, can cause serious crop damage, particularly to young oak, hemlock and Norway spruce. However, damage has been negligible following dormant-season inter-row sprays, i.e. September–March, at rates not exceeding 8 lb. dalapon per acre. Application in narrow strips along planting lines in this way provides good grass-control at a half to three-fifths of the material cost of overall treatment. Spraying before planting has been very successful on several grass-types, and providing planting is delayed some six to eight weeks after spraying, there seems little risk of toxic residual effects.

All these tests have been made at high volume, i.e. 40 to 50 gal. spray per acre, which may not always be easy to apply in practice. 1961 trials include tests on the effectiveness of low-volume spraying at five to 10 gal. per acre, using mist-blowing equipment.

The experiments have also been extended to include grass control following felling in regeneration areas.

In some situations, especially woodland sites, the practical value of grass control is reduced because of the ensuing vigorous growth of herbaceous and sometimes woody species. In such cases the effect of dalapon has been to transform a predominantly grass-weed problem to a predominantly broadleaved-weed problem. In an attempt to obtain more complete weed-control, current trials include combinations of dalapon with simazine, Diquat, Paraquat and Amino-triazole, to reduce the rate of development of broadleaved weed species. Simazine is too costly for overall treatment at effective rates, and tests have been confined to 'spot' treatments around individual plant positions before the weed crop develops. Results suggest this may be a practical method, as applications up to 10 lb. simazine per acre of sprayed ground, shortly after planting, have had no residual effect on the tree crop.

Control of Woody Weeds

Work has started on summarising the results of trials and practical experience with herbicides on woody species. This has involved a survey, by questionnaire, of private and commercial, as well as Forestry Commission, use. The year was notable for a marked expansion in the use of chemicals for controlling woody species in Commission forests, particularly in basal bark spraying for reducing hardwood cover in planted areas, and large-scale application of foliage spraying techniques for controlling birch and gorse scrub before or after planting. Stump treatment for prevention of coppicing after felling of hardwoods was also more widely used.

Experimental work was concentrated on methods of controlling woody species in planted areas for selective control of undesirable species. Thus, at Croft Pascoe, Land's End Forest, Cornwall, gorse was effectively controlled with 2,4,5-T ester at 2 lb. (acid) in 50 gal. water per acre applied as an inter-row spray in early autumn. The tree species, some 15 different kinds in species-trial plots, were apparently unharmed. Similarly, at Wareham Forest, low-volume mist-blower application of 2,4-D ester at 5 lb. (acid) per acre in August in 'checked' Scots pine, has given useful control of *Calluna* with negligible damage to the pine. These results add support to indications from earlier experience, that most conifers are relatively resistant to phenoxyacetic acid sprays once shoot elongation has ceased. This could open the way to the practical use of such compounds for weeding in young conifer crops.

Application difficulties, particularly when volumes of 50 to 150 gal. spray per acre are involved, are great in many forest areas, and several trials have been made with knapsack-type mist-blowers in an effort to obtain uniform distribution at low volumes of five to 15 gal. per acre. Results of such trials on bramble under larch have given good results, comparable with 100 gal. per acre applied with conventional spraying equipment. An effective 'spray-marking' additive to the spray is an important requirement in controlling distribution. Dyes, such as methyl violet, malachite green, etc., have proved ineffective, but encouraging results have been achieved with fine aluminium flake added to the spray solution.

In 1960, a large-scale experiment was laid down to examine the use of 2,4,5-T sprays, applied by helicopter, for controlling and opening up high mixed hardwood scrub, which had been thinned and underplanted with a variety of species. 2,4,5-T at 2 to 4 lb. (acid), in five gal. oil: water emulsion, all per acre, has given good initial control of oak, birch, poplar, hazel and blackthorn, without apparent damage to underplanted beech and Norway spruce. Costs were low compared with normal methods, and depending on the extent of re-sprouting, the technique could have useful applications for treatment of unmerchantable scrub before planting or for plantation release. Sites would need careful selection on account of the risks of spray-drift on to susceptible agricultural and garden crops.

Further work on basal-bark spraying for control of standing trees and coppice has shown that 2,4,5-T applied as an invert emulsion (i.e., water-in-oil instead of normal oil-in-water formulations) gives good results. This treatment should be cheaper than the normal 2,4,5-T-in-oil sprays because of the saving in costly oil diluent. However, in practice, the inverts were found difficult to handle on account of thickening of the emulsion during use. With further development this type of emulsion could become important for stem and stump treatments.

Large-scale trials of basal bark sprays in 1960, using 2,4,5-T in oil, showed that costs of treatment amounted to about one-half that of hand-clearance.

Little progress has been made on the difficult problem of rhododendron control, but new experiments will include tests of 2,4,5-T and 2,4,5-TP invert-emulsions for treatment of established bushes and sprouting stumps.

Protection of Forest Crops

Protection Against Animals

The serious damage caused by deer in replanted areas surrounded by forest, and the high cost of normal deer-fencing, have stimulated trials of possible effective and cheaper methods of protection. Hopes of an answer in easily-erected nylon netting (6-inch (15 cm.) mesh) were dispelled in 1960, since this type of netting proved liable to entangle deer. Further to this, it was found that the nylon deteriorated after about a year's exposure and became too brittle and weak for use. However, recent trials of an alternative type of netting made in polythene with a small 3 inches (7·5 cm.) mesh have proved more successful; it appears more resistant to exposure, and if erected so that it is quite taut, seems less likely to entangle the deer. Further trials are to be laid down and results will be reported in due course.

There is still interest in the possibilities of animal repellent preparations for protection of young trees, although most materials tested in the past have proved unsatisfactory because of phytotoxicity, or lack of persistence. Promising results have been reported with Thiram as a non-phytotoxic deer and hare repellent, and several trials are being carried out in 1961.

In preliminary tests, spray application of 10 per cent Thiram in 20 per cent bitumen emulsion as an adhesive, has shown good weathering properties and negligible phytotoxicity. Trials of repellent properties following spray application to nursery stock before planting, are now in hand.

Fire Control

Additional trials of fire-retardant materials for fire-proofing vegetation are being made in 1961, and results will be published shortly. Conclusions to date are that sodium calcium borate, bentonite clay and monoammonium phosphate (M.A.P.) solution, are effective fire-retardants. The last is considered the most practical material on the basis of cost, handling and storage characteristics and effectiveness.

M.A.P. solution can be applied through existing standard fire-fighting equipment and its indicated uses include:

(1) Speed and additional safety in controlled-burning operations.

(2) Tactical use in cooling of head-fires and formation of a safe base-line for counter-firing.

(3) Fire-proofing the edges of threatened thicket-stage plantations.

Arboreta

The Committee which is responsible for the management of the National Pinetum at Bedgebury has recently been reconstituted. The new Committee, which has been appointed by the Minister of Agriculture, Fisheries, and Food, maintains the joint interest of the Royal Botanic Gardens, Kew, and the Forestry Commission in the control of the Pinetum. The Director of the former establishment, Dr. George Taylor, has been appointed Chairman of the Committee, and Mr. James Macdonald, Deputy Director General of the Forestry Commission, Vice-Chairman.

At Westonbirt Arboretum, the principal developments during the year have been the provision of propagation facilities and more adequate nursery space. In Part III of this Report, page 166, will be found a note on Westonbirt which describes some of the special problems of this arboretum, and the steps which have been taken to deal with them.

Miscellaneous

De-barking of Hardwood Pulpwood

The problem of de-barking crooked hardwoods remains a bar for utilisation of this class of material as pulpwood. Application of chemicals to standing trees is a possible method of easing subsequent bark-removal, and screening trials of a number of chemicals were completed during 1960. Results show considerable promise with Diquat applied as a 5–10 per cent solution to basal girdles. The data from these trials are presented in detail in Part III of this Report, page 184.

REFERENCE

FOURT, D. F. (1961). The Drainage of a Heavy Clay, *Rep. For. Res.* 1960, p. 137.

SILVICULTURAL INVESTIGATIONS IN THE FOREST: SCOTLAND AND NORTH ENGLAND

By M. V. EDWARDS, R. LINES, S. A. NEUSTEIN, D. W. HENMAN and J. ATTERSON

Artificial Regeneration of Conifer Woodlands

Ground Preparation

Since 1958 several experiments have been established to determine whether ploughing is possible and worthwhile. In all experiments, a hydraulically-mounted tine plough was able to work, although the results of its work were in some instances very rough, and the wear-and-tear on the tractor was considerable. This year, for the first time, an unploughable recently felled area was met with at Lennox Forest, Stirlingshire. The difficulty was apparently due to a combination of closely-spaced stumps and wet, heavy clay on which the tractor tracks slipped easily. Previous experiments, confined mainly to windblown spruce areas, have not as yet shown generally improved growth on ploughed ground.

Species and Size of Plants

It has been noted that the larger transplants (approx. 12 inches tall) have been more successful than smaller ones. Sitka spruce, Western hemlock and Lawson cypress have been readily established on these sites in the Borders.

Other Problems

The optimum size of felling area will be investigated in a new experiment at the Forest of Ae, Dumfries-shire, and it is hoped that information will be obtained on the relative stability of margins of large and small clearings. The possibility of chemical control of re-invading vegetation will be investigated.

Afforestation Problems

Ground Preparation: Peat Shrinkage

Further experiments have been established in a series, begun in 1958, to study the shrinkage and disintegration of peat after single-furrow ploughing and planting. The series is now almost complete, having four experiments on deep (over 24 inches) peat and three on shallow peat. Measurements of vertical and horizontal changes in the peat surface will be made periodically throughout the rotation. Correlation of these changes with chemical and other changes in the peat consequent on afforestation is envisaged.

Ground Preparation: Heaths

Provision for long-term studies of intensity of cultivation of heaths has so far been made only on sites where cultivation has been essential to the establishment of a crop. The initial benefits of cultivation on less limiting sites, amply demonstrated in J. W. L. Zehetmayr's Forestry Commission Bulletin No. 32, *Afforestation of Upland Heaths,* has led to single-furrow tine ploughing becoming standard Forestry Commission practice on most heathland sites in the North, even where satisfactory, though slower, establishment could be expected without ploughing. To compare the long-term effects of single-furrow and complete ploughing with those of direct planting, the first of a new series of experiments has been planned for a site at Inshriach Forest, Inverness-shire using Scots and Lodgepole pines.

Loosening of Trees by Wind on Upland Heaths

During the winter of 1959–60, trees 3 to 8 ft. in height, particularly pine, were loosened by strong wind when growing on ploughed upland heaths. The damage took the form of severe loosening of the rootstock without breaking of roots or stem, with the result that very few trees were killed. As the trees were severely loosened, resulting in a pronounced lean, the end result of this damage is likely to be 'sabre-butted' trees, similar to those damaged by snow.

Assessments of this damage indicated that pine were loosened much more than larch, and that both pine and larch were more liable to loosening when planted in the furrow, than on the ridge, of single-furrow tine ploughing. A subsequent investigation of the root systems of pine and larch on various positions of planting has indicated that larch has more roots than has pine for the same weight of shoot, and that root growth when ridge-planted is partly vertical, but when furrow-planted is wholly horizontal. The small amount of roots in the case of the pine, and the lack of vertical rooting in the case of furrow-planted trees, are the main causes of wind-loosening.

Further sites are being examined to determine to what extent furrow-planted trees always lack vertical roots, and possible solutions to this problem are being sought, e.g. complete ploughing or double- or treble-furrow ploughing may be necessary if wind-loosening is to be prevented.

Draining of Clay Soils

A site on heavy clay soil at Lennox Forest, Stirlingshire, is being used to test some of the findings and theories derived from the drainage experiment at Bernwood Forest, Oxfordshire, described in the *Report on Forest Research,* 1960, Part III, page 137. Intensive drainage (24-inch deep drains at ½ chain spacing) will be compared with undrained ground, and pure Sitka spruce with mixed Sitka spruce/Oregon alder (*Alnus rubra*), with respect to soil conditions and crop development. It is hoped to develop a soil structure in which the main fissures remain open throughout the year, thus enabling deeper rooting and improved stability of the crop.

Trial Plantations at High Elevations

Advisory work and recording of establishment techniques continue. The purpose of the project was described in the *Report on Forest Research*, 1960.

Species Trials

After showing quite promising growth on some deep peat and acid soils, *Pinus peuce* and *Cupressus nootkatensis* were planted in small plots in deep peat at four forests covering a wide latitudinal range from Caithness to Northumberland.

Comparison of Pure and Mixed Crops

A mixture experiment employing Scots pine and birch in varying proportions, similar to that planted last year in north Scotland, was planted at Hambleton Forest, Yorkshire, on an upland heath site.

Large numbers of mixed stands were recorded during the Census of Woodlands in 1947, and it appeared that this might be a profitable field for locating and investigating the growth of established mixtures. The Census records for the county of Kincardineshire were examined and all mixed stands listed. A sample area was then selected containing 73 stands in the 31 years-and-over age groups. Later records showed that about one-third of these had been windblown, felled or otherwise eliminated as mixtures. The remaining stands were all visited with intention of making detailed records of their growth and condition, but it became apparent quite early in the survey that in addition to the stands known to be windblown or felled, a high proportion of the remainder were unsuitable for detailed recording. The main reasons were: partial windblow or poor stocking, the mixture being by pure sub-compartments rather than by groups or individual trees, and layout of the stands, a number consisting of narrow strips or belts. In all, only seven stands were classified as suitable for detailed recording and none of these had pure crops of one of the constituent species on similar ground alongside, which could be used for comparison.

Manuring

Two further trials comparing ground mineral phosphate with triple superphosphate, both applied at three different dates after planting, have been established; and a trial of minute and normal doses of phosphate on Lodgepole pine has been laid down to determine when the effects of the initial dose disappear.

A Conservancy trial of a compound fertiliser containing nitrogen, phosphorus and potassium on deep, acid peat at Laurieston Forest in Galloway, has resulted in some remarkable effects. On the fertilised plots, foliage colour of the Sitka spruce and Lodgepole pine has changed from yellowish-green to a lush, dark green, the needles on the current year's shoots are longer and broader, and more lammas growth has occurred. This confirms that elements other than phosphorus may be, or may become, deficient on deep peats. On two other bogs, one in Fife and one in Berwickshire, factorial trials of nitrogen, phosphorus and potassium have been laid down to determine which elements were deficient on these sites.

Weed Control

Five trials of weedkillers to eradicate all vegetation on peat have been established in North Scotland, where several pilot plantations require adequate fire-breaks to facilitate control burning. As this vegetation is growing on deep peat in relatively high rainfall regions, it would be difficult and uneconomic to establish and maintain fire-breaks by ploughing or hand screefing. Also, little, if anything, is known at present regarding the effect of various weedkillers on such sites.

Preliminary results indicate that a mixture of translocated weedkillers (to produce a quick kill) and monuron (to prevent recolonisation) may give the best results. Simazine has so far been disappointing on these sites.

Protection Against Deer

Trials to find methods, cheaper than conventional fencing, of excluding roe deer from newly replanted areas within a forest continued. The series of experiments begun in 1958, using brash in various ways to discourage deer walking through replanted areas, has been concluded. None of the protective measures used gave consistent effective protection. The results of these trials are given in Part III of this Report, page 170. At Glenbranter (Argyll) the nylon netting referred to in last year's report became brittle on the side receiving most direct sunlight, and two types of tar-treated nylon are now being tested in this position. Polythene netting trials in South Scotland are being observed. The effective life of these materials has not yet been tested.

The trials of electric fencing described in the 1959 Annual Research Report have been resumed after initial failure of the equipment. Damage has occurred in the unprotected controls, but none to plants within the fence.

PROVENANCE STUDIES

By R. LINES and J. R. ALDHOUS

Scots Pine

The Scots pine provenance experiment planted in 1932–34 at Thetford Forest, Norfolk, was thinned for the third time in 1960. This experiment has been described in the *Reports on Forest Research* for 1949, 1950 and 1957. Measurements of the main crop after thinning showed that the mean height in all plots had increased by six to eight feet since the previous assessment; the order of the various provenances by height has changed little from the previous assessment shown on p. 57 of the *Report on Forest Research*, 1957. The two north German plain provenances (Potsdam and Allenstein) have dropped two places, and the Cawdor (1932 planting) and Trentino provenances have each gone up three places; but otherwise there is no change. The most vigorous provenances continue to be those from Central Germany and the middle Rhine, while the plots planted with stock raised from seed collected in East Anglia come next in vigour, and are clearly faster growing than all of the Scottish provenances represented at Thetford, except that from Cawdor.

Experiments at Laiken Forest, Nairn (a fertile, low-elevation site), Glen Isla, Angus (moderate fertility and exposure) and Glenlivet, Banff (upland heath at about 1,400 ft.) were assessed at six years of age. These experiments compare progeny from 12 selected seed stands in North-East Scotland. There were appreciable differences in height between provenances at all three sites, but these were significant only at Glen Isla. The provenances which showed their best growth at the highest site (Glenlivet) originated from low-elevation stands (Crathes and Glentanar), while two provenances originating from high-elevation stands (Rannoch and Ballochbuie) showed their best relative growth at the low-elevation Laiken site. Despite these results, there was a highly significant relation between height at six years and elevation of seed source in the Glenlivet experiment. During the winter of 1959–60 there was a certain amount of damage by wind-sway, which was worse on the taller provenances.

Pinus nigra

Two experiments planted in 1951 at Clocaenog, Denbigh, and Newborough, Anglesey, each comprising four provenances of *P. nigra*, were assessed in early 1961. (*See Report on Forest Research*, 1957.)

At Clocaenog, on an exposed site 1,200 ft. above sea level, the provenance from Calabria continues to be most vigorous and uniform in rate of growth, while the provenance from Cuenca, Spain (*P. nigra* var. *cebennensis*) is the slowest. The provenances from Corsica and from Corsican pine growing in East Anglia are intermediate in height, both exhibiting widely varying rates of growth. At Newborough, on fixed sand dunes just above sea level, the provenances from Corsica and from East Anglia are both more vigorous than the Calabrian provenance. The Cuenca provenance is again the least vigorous.

To supplement the information on the response of provenances of *P. nigra* to atmospheric pollution, an experiment, similar to that planted in the spring of 1960 at Wharncliffe, was planted at Cawthorne, near Wakefield, which is also in the South Yorkshire Forest. Eleven provenances were planted, including provenances from Austria, Calabria and Corsica.

A similar set of provenances was used in an experiment at Thetford, Norfolk, where the previous crop on the site had been heavily infected with *Fomes annosus*. This site is intended to test the resistance of the various provenances to *Fomes* attack.

Lodgepole Pine

The large experiment planted in 1938 at Wykeham has been thinned for the second time and samples of the thinnings have been sent to the Forest Products Research Laboratory for examination of their timber properties.

Height assessment of six-year-old experiments at Watten, Caithness, and Kielder, Northumberland, showed that the slowest provenance was Haines, Alaska, at both sites; while Hollis, Alaska, was the tallest at Watten, and Lulu Island the tallest at Kielder. There was considerable game-bird damage at Kielder during the early years, so later assessments may show a change in the position. Hollis was noted as having the best general health and appearance.

A series of experiments planted in 1957 at Achnashellach, Wester Ross; Elchies, Morayshire; and Ceiriog, Denbighshire, have been assessed for height after three growing seasons. The Welsh experiment has grown the fastest. Sixteen provenances are included; six from stands in the Irish Republic, eight from British stands, and two directly imported from America. Generally speaking, it appears that the second generation pines, that is, the progenies of stands growing in Britain and Ireland, are growing at the same rates as the same provenances directly imported from North America.

The order of rate of growth is much what we have come to expect. Provenances originating in the coastal regions of the U.S.A. are growing faster than those from the coast of British Columbia, and the slowest provenances are those from the northern interior of British Columbia and from Alberta. These differences were highly significant at all sites. There was a certain amount of variation in growth rate of the different provenances at the three sites, but in each case the provenance directly imported from Fort Fraser, in the northern interior of B.C., made the poorest height growth.

Three additional experiments were planted in 1961 to supplement those planted in 1959. The new experiments contain the same provenances, together with four extra ones which need evaluation, and the sites, which have been selected to fill gaps in the present cover of Lodgepole pine provenance trials, are at Wark, Northumberland, Selm Muir, Midlothian, and on Rannoch Moor, Argyll.

Pinus banksiana

An experiment with 20 provenances of the Canadian Jack pine, *P. banksiana*, was sown in 1959 at Tulliallan nursery, and lined-out the following year. This collection was made primarily for selecting the best individuals and provenances for use in the inter-species crossing programme of the Genetics Section, but the surplus plants have been used in two small-scale provenance trials. The provenances cover a latitudinal range of 12° and a longitudinal range of 46° (from Alberta in the west to New Brunswick in the east).

In the nursery there were highly significant differences in both height and number of seedlings, though it is difficult to relate these differences to latitude and longitude. The transplant heights generally followed those of the seedlings closely. The group of provenances which has shown the best growth lies along the St. Lawrence river and its tributary the Ottawa, but two provenances from South-West Ontario also grew well. The provenances at both ends of the species range, e.g. Allardville, New Brunswick, and Winter Harbor, Maine, in the east, and McMurray, Alberta, in the west, have all grown poorly. The western provenances developed purple coloration of the foliage during the late autumn, which is similar to the colour characteristic of far inland provenances of Lodgepole pine.

Two experiments have been planted with these 20 provenances and an inland origin of Lodgepole pine at Inshriach, Inverness-shire, on Spey Valley river gravels, and at Broxa, Yorkshire, on upland *Calluna* heath.

Sitka Spruce

In 1958, seed of 12 provenances of Sitka spruce was sown in the research nurseries. Most of the stock raised has now been planted, and this collection is now represented on a number of sites from Cornwall, through Wales, to the North of Scotland; a difference of latitude of just over seven degrees. Experiments have been planted on a full range of site types for the species, including specially exposed and frosty sites. The highest site is at Mynydd Ddu in South Wales, where planting has been carried out at 2,300 ft. None of the experiments planted in 1960 had suffered appreciable losses by the end of the first season. Slight autumn frost damage occurred at one or two sites, but this was of no importance, even on the two sites specifically selected as being likely frost hollows.

A small number of plants of each provenance were planted in small phenology trials in the spring of 1959 at four sites: Newton, Morayshire; Bush, Midlothian; Wykeham, Yorkshire, and Alice Holt, Hampshire. There has so far been only slight difference in the time of flushing between provenances originating from as far apart as North-West Alaska and Southern Oregon. There have, however, been pronounced differences in the pattern of growth and especially in the time of bud formation. This was particularly noticeable during 1960, which was characterised by a mild autumn with little frost before the end of the year. The southerly provenances had not fully hardened off until well into November or even December, whereas the northern provenances in some cases had fully-formed terminal buds in the third week of July, and had almost all ceased growth in September.

A full account of the performance of these provenances in the nursery is given in Part III of this Report, page 147.

Douglas Fir

At the end of their sixth growing season, experiments at Laiken, Glentress, and Sunart were assessed for height. No significant differences between provenances at Glentress or Laiken were found; only at Sunart were there highly significant differences. The results agree quite well with those of the experiments in England and Wales. The fastest growing provenances are those from Washington in the region just behind the Coast Mountains (Elma) and the foothills of the Cascades (Enumclaw and Ashford). In addition, the extreme coastal provenance from Hoquiam is tallest at Sunart, but is also among the best for height growth at the other sites. In England, Hoquiam is one of the slower provenances.

When they were either six or seven years old, these experiments were assessed for date of flushing and incidence of *Adelges cooleyii.* There was a considerable measure of agreement between the sites as to the order of flushing, though there were also notable exceptions. Early-flushing provenances were Shuswap Lake (interior of British Columbia); Upper Santiam River and Sweet Home, Oregon; and Tenino, Washington. Late-flushing provenances were Elma, Ashford and Forks, all from Washington. The differences were much more marked at Laiken than at Glentress.

There was considerable variation in attack by *Adelges* on the different provenances, but little agreement between the results from the three sites. Only the Shuswap Lake provenance consistently showed appreciable resistance to Adelgid attack. It was noted that infestation was heaviest in plots which had grown most rapidly and were closing canopy.

Western Hemlock

At the end of the second year in the nursery, transplants of the 18 provenances of Western hemlock sown in 1959 continued to show the same clinal trend of growth vigour with latitude seen in the seedlings at the end of the first year; i.e. the southern provenances, with the exception of one from high elevation, grew significantly faster than the northern ones.

Observations on time of growth cessation, made at Benmore during the autumn of 1960, showed that only the Alaskan provenance formed terminal buds markedly earlier than all the others. Fifty per cent of these plants had formed terminal buds by mid-September; the other northern provenances (and the high-elevation provenance) followed about the middle of October, while terminal buds did not form on 50 per cent of the plants of the remaining provenances until the end of October or even early November. The wet, mild autumn may have prolonged growth. At Wareham, the more southerly provenances were damaged by frost in late November, while the more northerly provenances were more or less unaffected.

Plants were put out in forest experiments at six Scottish sites in the spring of 1961 and further experiments will be planted next year, so as to cover the range of sites on which Western hemlock shows promise.

Western Red Cedar

Little is known about the differences in behaviour under British conditions attributable to provenance of seed. Seed was obtained from 14 different localities in the range of the species in 1959, and sown at Tulliallan Heathland nursery, Fife, and at Kennington nursery, near Oxford. Eight of the provenances came from British Columbia, four from Washington, one from Oregon and one home-collected seed lot from Hampshire. The latitudes of origin range from 54° 33′ N (Terrace, B.C.) to 45° 50′ N (Vernonia, Oregon). At Tulliallan, but not at Kennington, there were significant height differences between provenances from Vancouver Island. The best of these were from Ladysmith and Sooke, while that from Alberni was much smaller. At this stage the more southerly seed origins have not grown faster, though this happens commonly in provenance experiments with North-West American species. Some of the Tulliallan seedlings were lined-out at Strathyre, Stirlingshire, adjacent to *Didymascella* infected stocks, to see if any connection could be found between provenance and susceptibility to the Keithia disease.

European Silver Fir

Seed of 35 different provenances has been received from nine countries, covering the major part of the range of European silver fir. Germination varied from 56 per cent to nil but averaged about 10 or 12 per cent. There was also a considerable range in the weight of the seeds. This collection was sown in a replicated nursery experiment using the same number of viable seeds per square yard for each provenance. The Forestry Commission is grateful to all who supplied seed so generously for this experiment.

POPLARS AND ELMS

By J. JOBLING

I. POPLARS

Varietal Studies

Varietal Trial Plots

Only 12 plots were planted during the winter, of which 10 were to replace plots which had failed at existing trials. The other two plots were sited on ground which had previously been occupied by a short-term establishment experiment. Planting was carried out at Quantock Forest, Somerset; Hallyburton Forest, Angus and Perth; Stenton Forest, East Lothian; Garadhban Forest, Stirling and Dunbarton; and Dyfnant Forest, Montgomery. A stage has been reached when no further ground is available at the poplar trial areas. However, since a number of varieties remain to be planted, either because they have only recently been introduced or because they are not yet properly represented on a range of sites, present policy is to site them on ground vacated by plots which have failed, or where the first planted variety is of no further interest and can be replaced.

A second planting was carried out at Ledbury, Hereford Forest, of clones of the Grey poplar, *P. canescens*. Five clones were used, bringing the total at the site to 11. These are the first plantings in which plants raised from rooted summerwood cuttings of the Grey poplar have been used on any scale, and it was interesting to note at the end of the growing season that trees planted in 1960 had survived satisfactorily.

Varietal Collection

Of the five clones introduced during the year, two are selections from the Himalayas for inclusion in the populetum, two have been obtained for identification and possible trial on a small scale, while the fifth, a Grey poplar, is for use in the trial of *P. canescens* at Ledbury. With these selections the varietal collection now contains 394 clones, although over one-third of these are represented only in the populetum. The collection is maintained in a stool bed, each clone being represented by six stools. During the past winter the transfer of the stool bed from a nursery at Holt Pound, about one mile away from the Research Station, to a new nursery within the Station's grounds at Alice Holt, has been completed.

Populetum

Thirteen clones were planted during the winter, bringing the total to 261. Over 200 of these have been in the populetum three or more years, and are now properly established. Each clone is represented initially by a group of three trees; during the summer the best specimen tree in a few of the earlier-planted groups was chosen for retention and the two unwanted trees removed. The selection will continue until each clone is represented by only one tree.

Silvicultural Experiments

A number of short-term establishment experiments, on planting methods and treatments, have been closed during the past season, and reports on the results obtained from them have been prepared. Most of the experiments which have been maintained and assessed continue to be informative.

Methods of Pit Preparation

In the two experiments in which the behaviour of trees in holes prepared by explosive is being studied, the effects of method of planting are still apparent. At Alice Holt Forest, Hampshire, where three quantities of explosive were used, namely 1·6 ounces, 4·0 ounces and 5·6 ounces of gelignite, trees in holes prepared by the largest quantity of explosive were 22 per cent taller than trees in hand-dug pits after six seasons, while at 4·0 ounces they were 17 per cent taller, and at 1·6 ounces they were 5 per cent taller than the control trees. At Lynn

Forest, Norfolk, where only 1·6 ounce and 4·0 ounce cartridges were used, trees in holes prepared by the larger quantity of explosive were 12 per cent taller than trees in hand-dug pits after four seasons, and at the smaller quantity they were 7 per cent taller than the control trees. Although the differences in growth due to planting method are significant, even the best trees are not vigorous by normal standards, due to the difficult soils on which the experiments are sited, and further observations are required before any clear conclusions can be reached on the benefits to be obtained by planting in holes prepared by explosive.

Planting Treatments

Experiments planted in 1957 at Gaywood, Lynn Forest, Norfolk, and Creran Forest, Argyll, comparing different types and quantity of mulch, maintained for varying periods from planting, were again assessed. At Gaywood Forest particularly, a number of interesting differences in tree behaviour due to treatment were evident. All mulch treatments had improved tree growth during the four years from planting, with a similar response for each of the three materials used. These were cut vegetation, bark peelings and fertiliser bags. The assessment showed additionally that by increasing the thickness of mulch from 6 inches to 12 inches, with both cut vegetation and bark peelings, a further improvement in growth occurred. It was also apparent at the time the assessment was carried out that – up to four years at any rate – the longer the mulch was maintained the greater was the benefit.

An assessment was also carried out at Gaywood in an experiment in which an application of nitrogen, in the form of ammonium sulphate, was combined with mulching as a planting treatment. All trees are mulched with bark peelings, to different diameters and thicknesses. Growth trends in this experiment are not so apparent, as it is only three years old, but all mulch treatments have improved growth over the no-mulch control. The effects due to application of nitrogen are varied, but there is a suggestion that the presence of the fertiliser, applied to the soil surface before mulching, produces a further benefit.

Spacing

The results of the second assessment carried out in the spacing experiments at Gaywood and Blandford Forest, Dorset, became available during the past year. These confirm that at the end of the seventh year at Gaywood, and at the end of the sixth year at Blandford Forest, no reduction in growth had occurred due to planting at the close spacing of eight feet, although in some plots crowns of adjacent trees had come into contact. The other spacings in these experiments are 14 feet, 18 feet and 26 feet. It was useful to note also that in an experiment at Somerset Forest in Northern Ireland, identical to that at Gaywood, both using *P.* 'serotina', no differences in growth due to spacing had been detected at the end of the fifth season.

Mixtures

During the winter, planting was started at Bradon Forest, Wiltshire, of a second experiment to study the growth of poplar in mixture with alder. The first, sited at Mildenhall Woods, Thetford Chase, Norfolk, and planted in 1956, is now virtually established. The experiment at Bradon Forest is on a heavy clay soil which formerly carried mixed coppice, including a proportion of alder, and for these conditions *P.* 'laevigiata', a hybrid black poplar, and *P. tacamahaca* x *trichocarpa* 37 have been selected. The former variety is one of the most outstanding in a poplar trial on a heavy clay soil at Yardley Chase, Northampton.

Nursery Experiments

Experiments were again undertaken in the poplar nursery at Alice Holt and at Kennington Nursery, Oxford, on the use of herbicides in cutting-beds. The main interest was in the effects of applications of simazine on the young rooted plants of poplar. This work is discussed under the section "Nursery Investigations", page 19.

Large-scale propagation was again carried out of clones of *P. canescens* and of the European aspen, *P. tremula*, and its related hybrids, using the mist technique for rooting softwood cuttings. On this occasion, the cuttings were rooted in perishable peat pots, so that the plants were more easily handled whilst being removed from the frame and lined-out in the open nursery. Rooting the cuttings in pots may also result in improved plant quality.

Distribution of Cuttings

Although some 30 separate demands for cuttings were received during the winter and early spring, the total number distributed, of eight standard varieties, was only 11,567. This compares with the despatch of 31,543 cuttings in 1960 and 43,036 in 1959. The demand for all varieties fell, particularly for those which have been available since the distribution scheme started. As might be anticipated, the greatest interest was shown in *P.* 'robusta' and in the three recently recommended varieties, namely *P.* 'laevigiata' and clones 32 and 37 of the cross *P. tacamahaca* x *trichocarpa*. Despatches to private estates, trade nurseries and Forestry Commission nurseries are shown separately by variety in Table 2.

Table 2

Distribution of Cuttings of Standard Varieties

	1	2	3	4	5	6	7	8	TOTAL
Forestry Commission	100	—	—	185	—	150	650	—	1,085
Private estates	1,227	120	2,100	1,130	120	2,075	550	60	7,382
Trade nurseries	450	—	500	1,000	—	850	300	—	3,100
	1,777	120	2,600	2,315	120	3,075	1,500	60	11,567

(1) *P.* 'eugenei'
(2) *P.* 'gelrica'
(3) *P.* 'laevigiata'
(4) *P.* 'robusta'
(5) *P.* 'serotina'
(6) *P. tacamahaca* x *trichocarpa* 32
(7) *P. tacamahaca* x *trichocarpa* 37
(8) *P.* 'berolinensis'

Gifts of cuttings of non-standard varieties were made to research workers in Germany, India, New Zealand and Pakistan, while cuttings were sent to several persons interested in poplars in this country, including research workers at the Universities of Aberdeen, Cambridge and Wales (Aberystwyth). In addition, rooted plants surplus to requirements were made available to various research stations and university departments, as well as to Forestry Commission Conservancies.

Bacterial Canker Investigations

Some 180 clones were planted during the winter at Fenrow Nursery, Rendlesham Forest, Suffolk, prior to their inoculation with bacterial slime in the early summer of 1961. The comparative trial of methods of inoculation and assessment jointly undertaken with the Phytopathologisch Laboratorium "Willie Commelin Scholten", Baarn, Holland, was continued, and involved the exchange of plant material of clones with a range of susceptibility to bacterial canker.

II. ELMS

Further progress has been made in the selection of 'plus' elm trees, and during the past season a number of fine hedgerow and roadside specimens were noted for propagation. Several of these were forms of the Huntingdon elm, *U. hollandica* var. *vegeta*, which was found growing extremely well on a wide range of sites in different parts of the country, and selections were made of the hybrid in counties as far north as Yorkshire.

A number of woodlands were visited during the growing season to obtain information on the behaviour of different elms in pure stands and in mixture with other hardwoods, but as most included only Wych elm, *U. glabra*, and occasionally English elm, *U. procera*, no useful conclusions could be reached on the growth of the less common species and hybrids in woodland conditions. However, the visits led to the location of some fine Wych elm, especially in the South of Scotland, and one stand in particular has been noted as a seed source. In the East of England, the smooth-leaved elm, *U. carpinifolia*, or a related form, was seen in small stands, but these were mostly too young to be informative. Forms of the Dutch elm, *U. hollandica* var *hollandica*, were located in woodlands in East England and will be included in the clonal collection.

During the winter a start was made on the study of the behaviour of age-types of planting stock, when root-suckers of English elm were collected at Badbury Forest, Berkshire, and lined-out in a nursery at the Research Station. These will be subjected to different nursery treatments and compared in the field with other forms of planting stock. Although over 700 rooted cuttings, representing some 30 clones, were raised in the mist frame during the summer, there were considerable losses of material due to a temporary failure of the 'mist' mechanism, and efforts to raise a selected clone in large quantity for age-type experiments were unsuccessful.

Work in Elm disease trials was limited to the replacement of failed trees in otherwise established clonal plantings in areas of heavy infection.

FOREST ECOLOGY

By J. M. B. BROWN

Ecology of Corsican Pine

The general survey of the performance of Corsican pine in Britain was concluded with visits to certain forests in Wales where the tree has been planted up to an altitude of 1,000 feet or over, and by further study of the course of disease in some forests in North East England where outbreaks of die-back had previously been observed. In the Welsh forests diseased and dead trees were a regular feature of plantations above about 1,000 feet, but the general incidence of die-back was considerably less than in North East England, where in some instances (e.g. Dalby, Allerston Forest, in North Yorkshire) disease has appeared at lower altitudes.

All stands not seriously affected by disease have provided records of height and diameter growth; these and the data previously assembled are now being prepared for analysis.

In October 1960, Mr. D. J. Read, a graduate botanist of Hull University, took up the study of the serious die-back of Corsican pine in Allerston Forests in the North Riding of Yorkshire. Close contact has been maintained with Mr. Read, who will probably give particular attention to the microclimatic factors in relation to disease and to the role of pathogenic fungi. There is evidence from all parts of Britain where disease has appeared that the local stand climate, as affected by altitude, aspect and slope, the height and density of the pines, the occurrence of gaps and the character of the surrounding plantations, if any, exercise a marked influence on the severity of disease. In the dissected topography of Allerston Forest there are good facilities for collecting the relevant climatic data which we have lacked hitherto.

The status of the fungi associated with disease in Corsican pine, in particular the part played by *Crumenula abietina* Lgbg. (syn. *Brunchorstia destruens* Erikss.), has for long been a subject of dispute. In Britain, foresters, ascribing the decisive role to physical factors of the environment, particularly temperature, have been inclined to discount the virulence of *Crumenula*: whereas in some parts of Europe, in Switzerland, Germany and the Scandinavian countries, many accept the evidence, for the most part circumstantial, that *Cremenula abietina* is pathogenic and a cardinal factor in the occurrence of outbreaks of die-back. Should this prove to be the case in Britain, it will be necessary to take account of an additional environmental factor, namely the proximity of sources of infection, in assessing the liability to disease of plantations of Corsican pine, some of which are remote from other stands of susceptible pines.

In connection with the investigation of disease in Corsican pine, a short visit was paid in July 1960 to some forests in Holland and the Belgian Campine. Grateful acknowledgement is due to Dr. van Vloten, former Director of the Stichting Bosbouwproefstation in Wageningen, and to Professor M. Boudru, Institut Agronomique de Gembloux, who very kindly provided guidance and information. It was ascertained that the die-back of tips associated with *Crumenula* (*Brunchorstia*), which is the disorder of widespread importance in British uplands, generally played a minor part in the wave of attack between 1940 and 1943 in Belgium and the Netherlands. Cambial death and canker development, most often occurring on the main stem within a few feet of the ground, were the characteristic symptoms in those outbreaks: another species of *Crumenula*, *C. pinicola* Karst., was usually involved, but it was regarded as purely secondary, the cause being sought in the abnormally low winter temperature experienced in those years. Shoot die-back, associated with *Crumenula abietina*, has nevertheless been reported from both countries in recent decades.

Other aspects of Corsican pine ecology which have received attention during the year under review concern the recovery of stands affected by disease, the influence of environmental conditions on cone production, and the behaviour of the tree on calcareous soils.

In the Belgian Campine the excellent recovery of most of the stands affected by disease in 1940–43 is scarcely relevant, inasmuch as the symptoms were different. In Britain, however, examples of good recovery after the loss of 5 to 20 per cent of the trees, have been observed in several forests and it seems that the stand need not be written off unless losses are high. It is believed that this impetus to resist further attacks may be bound up with alterations to the 'stand climate'. In some cases, however, losses have been intolerably severe and accordingly suitable methods of restoring such stands to full productive capacity are being examined.

The outstandingly dry, warm and sunny summer of 1959 resulted in abundant flowering of Corsican pine in 1960, at least in some districts, and the opportunity is being taken to carry out a rapid survey of expected cone yields in relation to geographic location, topographic factors, age of stand and thinning treatment. Particular notice will be taken of stands on marginal upland sites, where seed from trees which had resisted or survived disease might prove of special value, but representative stands on lowland sites in England are also being examined. In the course of this survey a very encouraging example of Corsican pine natural regeneration was located in Thetford Chase, East Anglia, adjacent to the prehistoric flint mines known as Grimes Graves.

In the establishment of beech on chalk grassland, it has been customary to use a pine nurse and Corsican pine has recently been preferred, on account of its indifference to the associated soil and air drought and its superiority, as against Scots pine, in accommodating itself to the alkaline soil. Several cases of lime-induced chlorosis have, however, been observed among Corsican pine plantations on the chalk and it is clearly not a tree which can be relied on to grow to maturity on soils of pronounced alkalinity. An obvious alternative is the Austrian pine, but it is not a tree which has much else to commend it. The possibility of discovering a provenance of Austrian pine, which, while accommodated to calcareous soils, shows superior growth rate and stem form, is being looked into. In this, as in the search for provenances tolerant of atmospheric pollution, or better adapted to the upland climate, liaison is maintained with the silviculturists responsible for provenance trials.

Restoration of Derelict Mining Lands

An area of 25 acres at Aberpergwm in the Vale of Neath, forming part of Coed Morgannwg Forest, Glamorgan, was exploited for coal by the open-cast or strip-mining system between 1948 and 1953 and, after restoration, was replanted in 1954. A variety of conifers and broadleaved trees was used, so that the results might be applied in further planting of similar derelict mining land on a larger scale. Early in 1961 the need arose to clear the plantation in view of the resumption of strip-mining operations, and the opportunity was taken of excavating the root systems of representatives of several species of tree and thus supplementing the appraisal of general results carried out by Mr. John White, District Officer, in 1959.

The site of this plantation is at 550 to 650 feet, with a general slope to East; but restoration left it with so-called 'hill and dale' configuration, so that aspect and slope vary much from place to place. The annual average rainfall is between 50 and 60 inches and the winters are mild. The slabs of black shale, which formed the general basis of renewed soil development in 1954, had by 1960 weathered to fine flakes on the surface, but the main rooting medium was still comparatively large fragments, sometimes loosely aggregated, with, in several of the profile pits, considerable admixture of clay derived from the original soil cover. pH values showed a range, in the 48 samples collected at 20 cm. depth, from 4·8 to 7·7, but 32 gave values between 6·5 and 7·5. The lower values were clearly due to local pockets of original soil.

The results of this enquiry are being written up, but it is clear that the very large number of variables (topographic position; physical character of the soil; pH value; species of tree; method of establishment by planting or sowing, with or without fertiliser) will make the interpretation difficult. There are, however, indications of at least four environmental factors which have an important influence on the variable performance of the several trees tried.

(a) *Topographical position.* Most species have grown better on the slopes than on the flats, where compaction by machinery may in some cases have aggravated the effects of poor site drainage.

(b) *Erosion.* On the steep slopes, however, erosion has been an adverse factor and failures, due partly perhaps to excessive drainage, have been relatively frequent.

(c) *pH value.* The near-neutral raw shale is in this respect more favourable to alders than to spruces and other sensitive conifers.

(d) *Nitrogen supply.* The outstanding performance of species with the property of nitrogen fixation – Common alder (*Alnus glutinosa*), Grey alder (*Alnus incana*), robinia (*Robinia pseudoacacia*), and broom (*Sarothamnus scoparius*) (sown in some plots as soil improver) – coupled with the yellowish colour of the needles of some of the conifers, suggest that nitrogen deficiency may be a limiting factor for some time, wherever the raw shale preponderates in the rooting medium.

FOREST SOILS

By W. H. HINSON

Facilities for analysis of needle samples from fertiliser trials on conifer crops have been improved during the year, as the equipment mentioned in the 1960 *Report on Forest Research* has been brought into use, and new staff have been trained in analytical routines. This work, now involving some 2,000 samples annually for comprehensive analysis, had increased over the last few years, resulting in long delays in producing the results; but little further increase in demand is anticipated, and it should be possible to complete work on samples in hand before the next collection of material.

Regarding results of the foliar analysis, little generalisation is yet possible. Satisfactory improvement of the foliar level of phosphorus as a result of soil applications, whether to plantations at establishment, to crops in a checked condition, or to crops in the pole stage, seems to be the rule. Nitrogen applications in several forms have resulted in substantial uptake of this nutrient, with increased levels in the needles for several years at least. Applications of other nutrients seem far less satisfactory; for example, lime and potash applications to a Scots pine site at Bramshill Forest do not appear to have influenced the uptake of these cations. At this site, magnesium has produced a growth response in the presence of applied nitrogen, but the change in level of the foliar magnesium is not significant.

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

This important project, mentioned in the 1960 *Report*, has regrettably been left in abeyance, owing to the priority given to foliar analysis of the fertiliser experiments.

Water Relations of Forest Crops and Drainage

The importance of rooting habit, in relation to the stability of crops against wind-throw and the continued vigour of stands some 20 to 30 years after planting on heavy soils and peat, has directed attention to questions of soil drainage and crop transpiration. Visits have been made to a number of sites, including Lennox Forest in mid-Scotland where spruce is suffering serious wind damage and exhibiting slow growth 30 years after planting, despite early promise. The soil is a heavy boulder clay which has not been intensively drained, and the root systems of the spruce are extremely shallow. However, there is evidence that former hardwood growth had rooted this soil in depth. Tightly closed fissures can be seen on close examination of the profile, and these can only be interpreted as being due to the drying-out of the clay by the transpiration of forest cover in former times. It is proposed to test the effect on the profile of intensive drainage in a spruce/alder mixture. Alder is able to root very deeply on this site, and the effect of drainage and the use of this species as a nurse may so improve the rooting habit of the spruce that its own transpiration will eventually be sufficient to maintain the soil structure in depth after the alder is cut out or suppressed.

The Soils Section has continued its collaboration with Dr. A. J. Rutter, of the Imperial College of Science and Technology, London, in his studies of the hydrological relations of forested and grass-covered soils at Crowthorne, Bramshill Forest, Berks. (Rutter, 1959). Records of moisture tension, rainfall, etc., have been maintained on several sites during Dr. Rutter's absence in Pakistan.

Gypsum soil moisture blocks, inserted at depths down to 8 feet, have shown that in 1960 the transpiration of the pine continued to dry out the zone from 2 feet to 5 feet 6 inches in depth during the period from April to November, building up high moisture tensions by the late autumn. The highest tensions, and latest dates of re-wetting of these zones, were associated with taller and older stands. The readings were taken weekly and the results are remarkable in view of the fact that the surface layers were usually moist from the exceptional summer rains.

A pair of lysimeters, similar to those described by F. H. W. Green (1959) for the observation of the potential evaporation of grass cover, have been installed at the Alice Holt Climatological Station. Soil moisture instruments have been added to assist in the maintenance of suitably moist conditions, without waterlogging.

Techniques

The determination of calcium and magnesium by atomic absorption has proved to be much more satisfactory than other techniques previously tried.

The magnesium determination is virtually free from any interference, but the calcium absorption is suppressed by small traces of phosphate at levels which do not affect its emission in the same flame. The method cannot therefore be recommended for calcium unless phosphate is rigorously removed. A solution to this problem using ion exchange resins is the subject of a separate publication (Hinson 1962).

The design of an exceptionally simple portable alternating current resistance bridge for the measurement of soil moisture has been completed. (Practical details for construction are available in duplicated form.) Improvements have also been made to the design of the gypsum soil moisture blocks. It has been found that graphite-coated silver electrodes are immune from capacity effects, which are a source of difficulty with other electrode materials, save platinised platinum.

A relatively inexpensive apparatus for recording instrument readings by lapse-time photography has been assembled and tested in the laboratory. Field tests will follow.

Facilities for the photometric determination of the mean area of cell wall material in stained wood sections has been devised at the request of the Pathology Section.

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FOREST GENETICS

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

The Survey of Seed Sources

The object of this survey is to locate suitable seed sources 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 1960 was done in Wales and Southern England, and 40 additions were made to the Register of Seed Sources for England and Wales.

Following the good flowering of many species in spring 1960, it appeared certain that good seed crops of many species would be available for collection in the autumn of 1960. An interim Register of Seed Sources for Britain was therefore prepared and distributed early in September. This register contains 403 classified seed sources totalling 7,261 acres. Table 3 summarises the entries for those species which are represented in the register by more than 90 acres of classified seed sources.

Table 3

Area of Registered Seed Sources in Scotland, England and Wales[1]

Species	Classification	Distribution by Countries			
		Scotland	England	Wales	Totals
		(acres)	(acres)	(acres)	(acres)
Scots pine	Plus and almost Plus	964	424	0	1,388
	Normal	1,523	105	0	1,628
Corsican pine	Plus and almost Plus	0	999	0	999
	Normal	34	56	0	90
European larch	Plus and almost Plus	395	5	0	400
	Normal	234	20	12	266
Japanese larch	Plus and almost Plus	33	0	0	33
	Normal	26	29	3	58
Hybrid larch	Plus and almost Plus	124	0	0	124
	Normal	6	0	0	6
Norway spruce	Plus and almost Plus	0	0	0	0
	Normal	102	19	0	121
Douglas fir	Plus and almost Plus	124	175	40	339
	Normal	40	165	6	211
Western red cedar	Plus and almost Plus	11	22	0	33
	Normal	15	58	2	75
Sessile oak	Plus and almost Plus	5	12	0	17
	Normal	26	17	35	78
Pedunculate oak	Plus and almost Plus	149	0	0	149
	Normal	17	18	0	35
Beech	Plus and almost Plus	4	104	0	108
	Normal	10	987	0	997

(1) The principal species omitted from this summary are Lodgepole pine, Sitka spruce, Serbian spruce, Western hemlock, sycamore and ash, for which less than 90 acres of seed sources have been classified and registered.

The survey of seed sources is to be completed by the end of 1961. The next step in the process of improving the genetic quality of seed collected in Britain is to convert the best seed sources into seed stands, or seed production areas, in which all the phenotypically poorer trees are removed, thus leaving isolated the crowns of the finest trees for seed collection purposes. This conversion of seed sources into seed stands has been proceeding slowly since 1953, but the work is now being speeded up. During the year a series of seed collection courses sponsored by the Forest Tree Seed Association of England and Wales were conducted by members of the Genetics Section and there are now trained seed collection teams in each Forestry Commission Conservancy throughout the country.

The 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 2,959. Only 20 new trees were found during the year and it is evident that a high proportion of the potential Plus trees in the older woods, plantations and arboreta in Britain have been located (by 'older' woods and plantations is meant those which are more than 30 to 40 years of age). More Plus and Special trees will, of course, be found as the younger woods and plantations grow older and the search for such trees will continue.

Most of the Plus and Special trees have been found and selected during the course of the survey of seed sources, and Table 4 shows that the greatest number of trees were found in the period 1954 to 1956 when the survey parties were working in Scotland and Northern England. Seed sources and Plus trees have still to be selected in South Wales and this will be done during the summer of 1961. It will thus be possible to present a country-wide summary of the register of Plus trees in the 1962 *Research Report.*

Table 4

Number of Plus Trees Selected

Year Ended 31st March	Number Selected During the Year	Accumulated Totals	Regions in which most of the trees were selected(¹)
1949	27	27	England and Eastern Scotland
1950	41	68	,, ,,
1951	37	105	,, ,,
1952	205	310	Eastern Scotland
1953	314	624	Northern Scotland
1954	424	1,048	Western Scotland
1955	504	1,552	Southern Scotland
1956	450	2,002	North West England and Scotland
1957	70	2,072	Eastern England
1958	390	2,462	Southern England
1959	288	2,750	North East England
1960	189	2,939	Southern England and Wales
1961	20	2,959	Wales

(¹) Most of the trees have been selected during the survey of seed sources. It is therefore possible to indicate the regions from which most, but not all, the Plus and Special trees were selected in each year.

The 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, beech and certain other species continued during the year, and 1,443 clones have now been planted. The Plus and Special trees are represented in these tree banks by clones of grafted plants or rooted 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 collections, one for England and Wales and the other for Scotland.

The planting of the tree banks began in the spring of 1957 and Table 5 shows the progress of the work since then. By maintaining the present rate of planting, the Plus and Special trees will be fully represented in tree banks in five or six years' time.

Table 5

Progress in the Formation of Tree Banks

Year Ended 31st March	Plus and Special Trees		
	Selected and Registered	Propagated Vegetatively	Planted in Tree Banks
1957	2,072	1,051	585
1958	2,462	1,359	816
1959	2,750	1,581	1,075
1960	2,939	1,771	1,229
1961	2,959	2,011	1,443

Vegetative Propagation

As in previous years, grafting, the rooting of cuttings and layering were used to raise clonal material for inclusion in tree banks, field tests and seed orchards. The final total of grafts attempted during the spring of 1960 was 13,373 and the number of successful grafts surviving to the spring of 1961 was 9,060, representing 473 parent trees. The overall success was 68 per cent.

Just over 23,000 cuttings were inserted in the propagation frames at Alice Holt, Grizedale, Bush and Kennington nurseries, most of these being clones of X *Cupressocyparis leylandii* and Western red cedar. During the spring of 1961, 4,800 rooted cuttings, principally X *C. leylandii*, were distributed for planting in field trials and tree banks.

Controlled Crossing and Progeny Testing

Controlled crosses are made for several purposes and the nature of the crossing pattern employed changes with the object of the work. Controlled crosses between individuals of the same species are done to identify those selected Plus and Special trees which combine well with others to produce good progenies, that is, those which possess good combining ability. Another object of crosses between individuals within a species is to determine the heritability of the characteristics desired, heritability being defined as that portion of the variance observed in the progenies which is due to genetic factors. The controlled crossing work done in seed orchards is intended to identify trees with good combining ability and to permit estimations of the heritability of the important characteristics included in the breeding programme. An example was given for larch in the *Research Report*, 1960.

Inter-provenance Crosses

A second broad type of crossing work concerns the crossing together of different provenances within a species which may lead to the production of within-species hybrids which combine the good characteristics of the parent provenances. An example of this kind is provided by the inter-provenance crosses made in two experiments on Lodgepole pine at Allerston Forest in Yorkshire. In the experiment at Harwood Dale are plots of trees from six widely separate populations of Lodgepole pine which straddle the main area of natural distribution of the species. The plots represent three provenances from British Columbia and one each from Washington, Oregon and Idaho in U.S.A. One of the British Columbia provenances is from a coastal locality; the other five provenances are all from inland areas. In 1959 seven to 10 of the best dominants were selected in each plot and the crowns of the trees were isolated by thinning to allow sunlight to reach them and make them accessible for controlled pollination. The warm, dry and sunny summer of 1959 resulted in good flowering in spring 1960, and 34 of the possible 36 inter-provenance crosses were made using balanced pollen mixtures from the seven to 10 selected trees to represent each provenance. The first results of this work will be seen in mid-1962, by which time the seed will have been sown and seedlings should be appearing.

Assessment of Survival

Assessment of survival after planting of the larch progenies raised from crosses made in 1956 in the Hybrid larch seed orchard at Newton, Morayshire, and planted out on four sites in 1959, showed that in general the losses were so few as to give little indication of important differences. On the main site in the Forest of Dean, Gloucestershire, survival was virtually complete. There were, however, losses of up to 45 per cent in three of the Japanese larch progenies planted on two upland sites in Wales and Northern Ireland. On these two sites four Japanese parents yielded progenies which survived well after planting, while two others yielded progenies having a lower field survival after planting.

The Formation and Management of Seed Orchards

Seed orchards consisting of clones of grafted plants derived from Plus trees of Scots pine, Lodgepole pine, European larch, Douglas fir and beech have been 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 have also been planted to produce seed of the first generation Hybrid larch, *Larix* x *eurolepis*. Forty-five acres of seed orchards planted for the production of Hybrid larch will, in due course, produce sufficient seed to satisfy the foreseeable demands for seed of this hybrid.

Small quantities of seed are now being harvested from seed orchards in Britain. The larch seed orchard at Newton, Morayshire, produced the second crop of seed in autumn 1960. Twelve pounds of seed were collected from four acres, the yield thus being 3 lb. per acre in the ninth growing season after planting. A beech seed orchard at Alice Holt planted in 1951 and one acre in extent yielded 11½ lb. of beech nuts in 1960. Another beech seed orchard at Hemsted Forest, Kent, was planted in 1957; this produced ½ lb. of filled nuts which are being sown in a small beech progeny test, together with most of the nuts from the Alice Holt orchard.

The older Scots pine seed orchards are also now coning freely, but male flower production is only just beginning. Controlled crossing programmes will begin in these seed orchards as soon as sufficient pollen becomes available. The planting of a series of Lodgepole pine seed orchards has so far been delayed by the lack of suitable Plus parent trees. Sufficient grafts have, however, been made to plant the first orchard of this species at Newton in the spring of 1961.

Maintenance of Seed Orchards

Now that some 150 acres of seed orchard are established in various parts of Britain, the work of managing them is growing each year. An experiment set up in a seed orchard containing 20 clones of Scots pine situated in Bradon Forest, Wiltshire, is designed to compare the effects of mulching, fertilisers and weed suppression by polythene sheets and three chemical weedkillers (simazine, dalapon, and pentachlorphenol) on the growth rate and flowering of Scots pine grafts. This experiment is being run for three years.

Larch Seed Production

Observations on the relative dates of male and female flowering of European and Japanese larch clones have been made in two larch seed orchards at Newton Nursery, Morayshire, and Mabie Forest, Dumfries-shire. These two seed orchards contain a total of 37 clones of grafted plants, two of which are represented at both sites. The majority of the Japanese larch clones shed their pollen some 14 days before most of the European larch do so, but the female flowers of the European larch clones are generally receptive when the Japanese larch pollen is flying. Thus, as a general rule, most of the cones collected from the European larch will contain seed of Hybrid larch (i.e. *Larix decidua* x *L. leptolepis* = *L.* x *eurolepis*) and the cones of the Japanese larch clones will produce Japanese larch seed. The principal object of the two seed orchards at Newton and Mabie is to produce seed of Hybrid larch. It is evident that the production of such seed is dependent on the number of female flowers and cones produced by the *European larch* grafts. It has also been observed that most of the Japanese larch clones produce copious quantities of pollen, and it appears that a suitable proportion of European to Japanese larch grafts is three or four to one. The demand for seed of Japanese larch has fallen in recent years and seed orchards consisting entirely of Japanese larch clones are probably unnecessary. It is probable, on existing evidence, that useful quantities of Japanese larch seed will be produced in seed orchards consisting of clones of European and Japanese larch.

A small seed orchard has been planted in which grafts of the two species are represented in the proportion indicated by these observations: i.e. one Japanese larch pollinator to four European larch seed bearers.

The Technique of Tree Breeding

Pollination Bags

During the past 10 years several kinds of pollination bags have been tried for isolating the female flowers of the pines, larches, Douglas fir and beech. Until recently most use has been made of two greaseproof paper bags, the first to isolate the female flowers and the second put over the first after pollination was completed. These bags have relatively low strength and poor weather resistance; in particular, prolonged rain causes them to disintegrate. Moreover, the temperature inside the bags is often 10 to 15 degrees higher than that outside.

In 1959 and 1960 a number of lightweight plastic materials were tested. Polythene bags proved unsuitable because of heating and condensation inside, but bags made of a non-woven Terylene fabric were shown to be sufficiently porous yet pollen-proof and appeared to stand up well to the weather and the abrasive action of pine needles. These Tereylene bags (Plate 3) are light in weight, dry off quickly after rain and there is little or no build up of heat and condensation inside. The addition of a small polyvinyl chloride window permits easy observation of the developing female flowers. Only one bag is required instead of two, and they can be used again after heat or chemical sterilisation. These non-woven Terylene pollination bags are now in general use and will replace the greaseproof paper bags as soon as possible.

Physiology of Flowering

Work continues on the physiology of flowering in forest trees, in collaboration with Professor P. F. Wareing and his colleagues at the University College of Wales, Aberystwyth. Their work is described in Part II of this Report, page 114.

Size of Graft

The probable importance of size of graft, and the accompanying development of a complex lower branch system, for the production of male flowers by grafts of Corsican pine, may be inferred from the performance of a group of grafts of this species at Alice Holt Research Station. Eleven clones were produced in spring 1950 by grafting scions from mature Plus trees of Corsican pine on to three-year-old rootstocks of pine. The grafts first produced female flowers in 1956, when they were seven years old and has reached a height of eight to nine feet. Male flowers did not appear until 1958, by which time the grafts were 12 to 13 feet tall, and these male flowers were borne on the weaker shoots in the lower three feet of the crown, where the branch system had become complex and rather short and partially shaded branchlets were numerous. Since 1958 the male flower-bearing region has extended upwards and these grafts have produced male and female flowers each year.

Rootstock Trial

In 1953 a small rootstock trial was planted at Rendlesham Forest, Suffolk. scions from a single mature Corsican pine tree (*Pinus nigra* var. *calabrica*) were grafted in 1951 on to seedling rootstocks of Corsican pine, Austrian pine (*Pinus nigra* var. *austriaca*), Lodgepole pine, Mountain pine and two origins of Scots pine, one from Eastern Scotland and the other from a local source in Eastern England. The experimental layout consisted of five ransomised blocks, each combination of rootstock and scion being represented by a single tree in each block.

An assessment of height growth in 1957 revealed highly significant differences between the mean heights of the scions on the various rootstocks, the scion-growth on Austrian pine and Corsican pine rootstocks being significantly greater than on Lodgepole and Mountain pine rootstocks. The difference in scion growth on the two origins of Scots pine was striking, scion growth on the Eastern Scottish origin was significantly or appreciably poorer than on any other rootstock, whereas growth on the local Eastern English origin was significantly better than on any other rootstock.

By August 1960 the tallest grafts had reached a height of 10 to 12 feet. The order of scion growth was similar to that in 1957, but two of the grafts on Eastern Scottish Scots pine had died. The count of one-year-old developing cones showed best female-flowering on Eastern English Scots pine (the mean number of cones per graft being 20) and Mountain pine (14 cones per graft). The mean number of cones on the other rootstocks were Austrian pine, seven per graft; Corsican and Lodgepole pine, three per graft; and Eastern Scottish Scots pine, two per graft. The further development of this small trial holds considerable interest since it appears that a very crude choice of rootstocks has affected the growth, survival and cone production of the scions. But it is necessary to stress that similar results may not have been obtained if other Corsican pine trees had been used as the sources of scion wood and studies of the performance of a number of clones on different rootstock species must continue.

Other Work

The flow of enquiries from Forestry Commission and outside sources continued, some 143 being dealt with during the year. Most of these concerned vegetative propagation by grafts and cuttings (advice given included the design and construction of two large propagation frames for the mass production of Leyland cypress cuttings), the layout and management of seed orchards and the selection and treatment of seed sources. General enquiries on the organisation of tree breeding programmes increased markedly. Technical advice was given to the Scottish Forest Tree Seed Association and the Forest Tree Seed Association of England and Wales.

FOREST PATHOLOGY

By J. S. MURRAY

A notable event was the study tour on the fungus *Fomes annosus*, in June 1960, arranged under the auspices of the International Union of Forest Research Organisations. Over 20 delegates from nine countries took part in discussions and saw examples of damage in various forests in North and East Scotland. This fungus is of increasing seriousness in all the countries represented, notably in the U.S.A. where invasion of new plantations is being observed with disquiet. The discussions were very fruitful, for the majority of those attending were actively employed in research on *Fomes*. The response to the meeting was a good measure of how seriously the disease is regarded abroad and why accounts of it have bulked so large in recent Forestry Commission *Reports on Forest Research.*

In contrast to the 1959 season, the summer of 1960 was cool and extremely wet. The most obvious effect as far as pathology is concerned was waterlogging and death of root systems of nursery stock, leading in some cases to establishment losses. This was the cause ascribed to several cases of dying in newly-planted Japanese larch. In the Wareham area, *Dothistroma pini* caused severe needle loss on nursery pines. This fungus, which has been known in Britain for only the last five years, seems to be favoured by wet summers and suppressed by dry ones.

Fomes annosus

Field investigations confirmed that the limitations of *Fomes* development on ex-hardwood sites are temporary. With the exhaustion of the hardwood material and its associated fungal flora, and with the multiplication of conifer thinning stumps, invasion and spread by the fungus are accelerated. The only sites with apparently lasting resistance to invasion by *Fomes* fungus are those where the main rooting zone is in peat. For these reasons creosote stump treatment has now become general practice in most parts of the country. Work on testing alternative materials to creosote has continued.

Experiments on chemical and mechanical treatment of *Fomes*-infected crops, before and after clear-felling, in order to reduce the incidence of disease in the following crop have been laid down. So also have trials of species and provenances to investigate their relative susceptibility to infection, both by butt-rot and killing attacks. These are becoming increasingly important aspects of disease control, as clear-felling and replanting, and enrichment of selected crops, become more common.

Further work on infection of wounds on standing trees during extraction of produce has confirmed that although infection does occur in a number of species, only a small proportion of wounds lead to serious progressive decay. This finding relates only to stands up to 40 years of age.

Keithia Disease of Western Red Cedar, Thuja plicata

Nurseries in England, Scotland and Wales in which it was proposed to carry out rotation sowing of Western red cedar were inspected. As a result, the rotation sowing programme already started in Scotland was modified, while rotation sowings are being started in 1961 in England and in Wales.

Small-scale experiments indicate that infection by the causative fungus, *Didymascella thujina*, is not carried over from one season to the next in nursery soil which has previously carried infected *Thuja*, nor in litter formed beneath infected plants. If all *Thuja* plants are removed from a nursery following the outbreak of the disease, re-establishment of the disease on future *Thuja* crops will depend on deposition of spores carried with the wind from a distant source of infection, or on the importation into the nursery of infected *Thuja* stock. It is on these premises that the principle of rotation sowing is founded.

Trials have commenced to test control of *Didymascella* with sprays of the systemic antibiotic 'Acti-dione' and to assess the phytotoxic effect of various concentrations of this substance on *Thuja* foliage.

Botrytis cinerea

An attempt was made to correlate the temperature and humidity conditions occurring over nursery seedbeds with the onset of infection by this fungus. This was carried out in 10 nurseries scattered over England, Scotland and Wales, using *Sequoiadendron giganteum* as the test species. Preliminary examination of the data obtained indicates that local temperature and humidity records are of little value in forecasting the onset of infection.

During the growing season of 1960 the general climatic conditions throughout the country were those which are assumed to favour infection by *Botrytis*. Despite this, no reports of serious *Botrytis* damage have been received. This has emphasised our sparse knowledge of the general biology of *Botrytis* in forest nurseries, and it is hoped to initiate fundamental studies in the near future.

Group Dying of Conifers Caused by Rhizina undulata

Observational work was confined to an area where group development has been followed since fires were first lit in healthy Sitka spruce in 1955. Spread of *Rhizina*, and death rate of trees, decreased considerably in 1960. Some abnormal thickening and colouration of *Rhizina* fructifications was found for the first time, but the cause of this was not determined.

Dying of Norway Spruce

Detailed work on this disease in unthinned stands on the East and West coasts of Scotland was started. There was some evidence that increasing exposure of the crown might have played a part in the damage, but measurement of growth differences between healthy and diseased trees has revealed that climatic conditions in particular years are probably important factors in the disease.

Die-back of Oak

An investigation into death of oak in young stands in East Anglia was completed. Relative exposure to winds prevailing during drought was found to have been a decisive factor in initiating the damage.

Melampsora pinitorqua

Infection of the test bed of aspens and pines, first achieved in 1957 after attempts had been made for three years, has declined. Only one *Pinus pinaster* shoot was affected in 1960. Whatever its effects elsewhere, the disease appears to be innocuous in the test bed.

Cronartium ribicola

Observations were continued on the trial plot of currant species, *Ribes* and pine species. *Pinus griffithii*, the Himalayan pine, has not yet produced any blisters, though swellings have appeared on some stems. A resinous swelling appeared on one of the grafts of resistant Weymouth pine, *Pinus strobus*, clones from America, and the plant died.

Elm Disease Caused by Ceratocystis ulmi

Collection and propagation of British clones for testing continued in co-operation with the Silviculture Section. The unfavourable spring caused serious losses among the new grafts, and progress was further retarded by a failure of the mist propagating unit.

Wound Protectants

In the trial on beech at Westbury Forest, Hants., Arbrex has proved the best substance tried for protecting and stimulating cambial growth, but Rito, standard grade (a thick bitumen), appears to give the most durable cover. On large wounds a combination of Arbrex round the edges and Rito over the main area would probably be better than either alone.

Advisory Work

As usual, advisory work occupied a good deal of the time of the section.

FOREST ENTOMOLOGY

By D. BEVAN

Pine Looper Moth, Bupalus piniarius

Pupal Survey

Three additions were made to the areas surveyed in 1960 – Edensmuir in Fife, and Hambleton and Allerston Forests in Yorkshire.

Little change in population is recorded from most forests, though six units in Scotland show slight increases. Only in the case of Cannock is the density of the insect above endemic figures, but the rise in numbers in Culbin and Tentsmuir deserve mention owing to these forests' previous history of infestation.

Cannock Chase – In the count made in the winter 1959–60 a forest average of 7·6, and a highest compartment mean of 33·2 pupae, both per square yard, were reported. These two statistics for the winter 1960-61 were 7·1 and 25·4. The overall population average has thus dropped and nowhere has the density of population reached so high a maximum as it did in the previous year.

The threatening population of 1959–60, it appears, was largely controlled below infestation level by parasitisation of the pupae by *Cratichneumon nigritarius* (*see* Part III, page 176). Pupal parasitism found by examination of pupae collected during the winter 1960–61 is again quite high, and it will be interesting gto see how reliable a control measure this insect proves to be during the comin spring and summer.

Culbin – The values for forest average and highest compartment mean were 1·2 and 2·9 pupae per square yard in the 1959–60 survey, followed by 2·6 and 8·2 pupae per sq. yd. in the winter 1960–61. The compartments showing the highest densities are all those which bore a relatively high pupal count during the winter of 1953–54 (previous to the aerial spraying carried out during the summer of 1954).

Tentsmuir – At this forest the values for forest average and highest compartment mean were 0·1 and 0·4 in 1959–60, and 1·8 and 7·6 pupae per sq. yd. for 1960–61. The rate of increase is therefore 20-fold in this forest.

The development of these populations will require watching.

Fpidemiological Investigations

The main object of these studies has been to investigate the mechanism causing density fluctuation in Pine looper. Work has continued since 1956 in a study plot at Elveden, Thetford, a site thought, at the time of selection, to have a high infestation risk. Unfortunately, from the research point of view, no part of Thetford has ever contained even a mildly threatening population, and although the plot has provided a good trial ground for the development of sampling techniques, little information on the process of outbreak has been forthcoming. For this reason a further study plot was established in 1959 at Cannock Chase, a forest known to be subject to population fluctuations and with a record of infestation.

Owing to the shortage of specialist labour required for summer sampling, this kind of work had to be confined to stages in the insect's life-cycle which could be done by trapping methods, employing local staff to make collections.

The main results of this were that no data could be gathered on the critical egg and larval stages, though details of interest on pupal, adult and last-stage larvae were obtained in this way.

Apart from these two study areas, much additional information has been gathered from the short-term investigations initiated whenever a potentially damaging population has cropped up in any of the Forestry Commission's pine plantations. These have usually lasted for one year only and have either finished in a control operation, as at Tentsmuir in 1957, or with an almost complete natural subsidence of population, as at Rendlesham in 1959. The work involved on such occasions has been directed primarily to the needs of the minute, viz. in establishing whether or not artificial controls were needed. At the same time, of course, certain observations, mainly of research interest, upon these higher density populations has been possible. However, at no time has it been possible to obtain a complete sequence of observations throughout any fluctuation of size, until the spring of 1960, when pupal counts at Cannock revealed that a great increase in numbers had taken place and that a population high enough to cause defoliation was present. Thus for the first time a situation requiring investigation, owing to high Pine looper density, had arisen in a forest already under special surveillance. As described in Part III of this Report, page 176, the information gathered from the work that followed was of considerable interest. This 1960 Cannock population, in spite of having been kept below infestation level naturally during the summer, had by no means completely collapsed by the time the pupal stage had been reached. The time seemed right, therefore, to transfer the main effect of *Bupalus* work to Cannock, a forest which appears to provide the necessary conditions for an epidemiological study of this nature. Observations will continue at Elveden along the lines of those previously carried out at Cannock, but the more intensive studies of adult, egg and larval mortalities will be concentrated now at the last-named forest.

Anoplonyx destructor, Bens., a Larch Sawfly

Field Investigations

Intensive work has continued in the permanent study plot at Mortimer. Assessments of adults, final-stage larvae and cocoons have again yielded interesting results, and the branch sampling method of counting eggs and larvae, tried for the first time, appears promising. An attempt to speed up the rather tedious and time-consuming business of cocoon counting is also encouraging; here, the larvae, on descending from the crowns for pupation, are allowed to fall into vermiculite-filled trays, making the removal of the cocoons quite an easy matter.

One of the minor difficulties in this project has lain in the positive identification of the cocoons of the three common sawfly species on larch, *Anoplonyx destructor* Bens., *Pristiphora laricis*, Hart., and *Pachynematus imperfectus* Zadd., and it has not, therefore, been possible until recently, to relate the host with the parasites bred from winter cocoon collection. The rather slight differences between the species has only been learned by constant handling, but now almost 100 per cent accuracy of identification has been obtained. With this knowledge it should now be possible to estimate the precise effect of the two most numerous and common parasites of *A. destructor*, *Labroctonus westringi*, Holm., and *Rhorus palustris* var. *nigriventris*, Str.

To the published list of parasites of *A. destructor* must be added this year, from cocoons, a *Trematopygus* sp., a *Rhorus* sp. and *Mesoleius tenthredinidis*, and a *Metasecodes* sp. upon eggs. Of these, only the *Metasecodes* sp. has appeared in numbers.

Feeding by centipedes, staphylinid larvae and nematodes has been observed in the laboratory, but whether any of these general feeders can account for the considerable cocoon loss during the winter months has yet to be investigated. Little difference in cocoon count has been noted between plots protected against small ground game and those unprotected, and no further detailed work is therefore envisaged upon these animals in the immediate future. Data from cocoon collections made at Mortimer on two dates – November 1959 and March 1960 – showed a loss of population of $8\cdot2 \pm 1\cdot9$ cocoons per sq. yd. during this period, leaving $4\cdot8 \pm 1\cdot0$ cocoons in unprotected and $3\cdot3 \pm 1\cdot2$ cocoons in protected areas.

Two species of fungi, *Paecilomyces farinosus* (Dicks ex Fr.) Brown and Smith, and a *Fusarium* sp., have been found active in the field and accounted for some 80 per cent of larvae sleeved on larch branches at Mortimer and Radnor. Whether these losses were due to some slight differences between conditions within the muslin sleeve and the outside, or to injury to these very sensitive insects during transfer to the branch, has not yet been established.

Increment Loss Caused by Defoliation

The intention to lay down a long-term experiment to measure increment loss, following *A. destructor* defoliation, was mentioned in a previous report. The first year's spraying of an 18½ acre block of Japanese larch planted in 1930 at Drumtochty was carried out in June and was successful. A count, made in the autumn, of larvae falling from the crowns for pupation indicated that although a population of about 350 larvae per sq. yd. were present in the adjacent blocks, there were none in the sprayed compartments. If high densities continue at this forest, it is hoped that it will be possible to give an accurate estimate of the financial loss resulting from this insect's activities within a period of 10 years.

Pinhole Borer, Trypodendron lineatum, Ol.

Low levels of infestation have somewhat bedevilled experimentation upon this insect. At least, in part, this has been due to the capricious nature of the species which seems to infest without obvious pattern.

Further trials of insecticides for single log protection were carried out this year at Glenduror Forest in Argyll. Two formulations based on benzenehexachloride, Hexaplus and Protoplus (the latter with added pentachlorophenol), were tested, together with a chemical containing dieldrin, called Dilstan. The first two chemicals, at concentration of 0·75 per cent, applied at the rate of 1 gallon per 100 sq. ft. of bark surface, gave almost complete control.

Biological investigations have included:

(1) An extension of one of the 1959 experiments into the relationship between time of felling of Douglas fir, Japanese larch, Norway spruce and Sitka spruce, and their susceptibility to attack; and

(2) A comparison between stump and log infestations.

In the former, logs were felled at Glenduror, at monthly intervals from November 1959 to April 1960. No preference by the beetles for logs of a particular age or host species could be detected owing to the low level of attack. It is worthy of note, however, that the shortest period between felling and attack observed during the experiment was three weeks. In the second experiment considerable differences were noted in the success of broods in the two types of breeding material. The stump tunnels, which tended to be much longer than those in logs, frequently contained dead larvae and beetle remains, together with slime and detritus; they also harboured many live predatious bettles and larvae, among which *Epuraea obsoleta* appeared most numerous. There was little development of larval tunnels in these stump galleries and it seems that only a few eggs got even as far as hatching. It would appear from this investigation that the risks of stumps acting as reservoirs for the beetles are not very great. Both creosoted and uncreosoted stumps were examined in this investigation, and no differences were noted.

These studies continue to be conducted in collaboration with the Entomological Section of the Forest Products Research Laboratory, Princes Risborough. In 1961 it is proposed to investigate the chemical protection of log stacks, and to obtain further information upon felling-age preference.

Advisory Work

One hundred and sixteen enquiries were dealt with during the year, 64 of these were from Forestry Commission and 52 from private sources.

GREY SQUIRREL RESEARCH

By H. G. LLOYD, J. F. SHILLITO and L. A. TEE

This project is run jointly by the Infestation Control Laboratory of the Ministry of Agriculture and the Research Branch of the Forestry Commission.

The field and laboratory work connected with the Straits Population Study in Alice Holt forest has been completed. Analysis, with K. D. Taylor, of the vast amount of data collected is continuing and a report will be available in 1962.

Poisoning Experiments

Cage tests of Warfarin have been done, and field trials of Warfarin in groundnuts were conducted in Scotland in June and July 1960. The results were very promising and further work, in May, June and July 1961, in Scotland, is at present under way. The current trials are intended to determine the optimum duration of poison baiting during these months and the further development of techniques.

Two other anticoagulants will be tested against captive squirrels during the next twelve months.

Traps

Field trials of baited (approved) humane spring traps are in progress. Preliminary results indicated that although these traps are successful against grey squirrels when baited with maize, cage traps are more efficient. Other considerations such as cost, portability, and ease of concealment have not yet been assessed.

The development of a new cage trap (designed by a Forestry Commission warrener) is being done concurrently with these field trials. The trap is being tested in comparison with the production model single-capture Legg trap.

Plans have been made for an expansion of the research programme in 1962. This will include studies on the degree of protection afforded to susceptible tree crops (e.g. sycamore) by application of various control methods at different times of year. Preliminary studies on the bark-stripping habit of grey squirrels will also begin.

FOREST MANAGEMENT AND WORKING PLANS

By F. C. HUMMEL

The work of the Management Section continues to embrace four main subjects – Economics, Mensuration, Census and Working Plans. As reported last year, no census field work is in progress at present, but a sample survey of the whole country is planned to take place in a few years' time. Meanwhile the maintenance of census statistics and the answering of enquiries arising from them have been made the responsibility of the Economist. For this reason the Economist has entitled his report 'Forest Economics and Census'. In contrast to last year, Mensuration has been made the subject of a separate report this year because a number of new research developments have been started, mainly as the result of the appointment of a new Mensuration Officer and the presence in the Section during the year of a Swiss research graduate. During the previous few years the officer in charge of the Management Section has also acted as Mensuration Officer, although most of his time was necessarily devoted to the development of the newer activities of the Management Section – Working Plans and Economics.

More than half of the Management Section's personnel is engaged on Working Plans, but most of this work is either consultant work on planning problems or in the nature of a service to prepare forest inventories and collect other data required by territorial officers for the preparation of Working Plans. The research content of this part of our activities is low and the subject therefore does not feature prominently in *Report*. Working Plan activities have, however, raised a number of research problems and stimulated investigations to try and solve them. These investigations are mainly of a mensurational or economic nature and are therefore dealt with in the respective reports on these subjects. The Working Plans Officer, the Economist and the Mensuration Officer work jointly as a team on most management problems.

The application of electronic computing to forest inventory, which is a major new development, is the subject of a special paper in Part III of this *Report* (*see* page 196).

An officer was appointed during the year to undertake soil mapping, and investigations into the correlation of site and tree growth, for Working Plan purposes. He is at present undergoing training with the Soil Survey of England and Wales.

Officers of the Management Section, in co-operation with others, revised the new draft for the form of the so-called 'Plan of Operations' which private woodland owners have to prepare if they wish to qualify for grants under the Dedication and Approved Woodland Schemes. This is a simple type of working plan designed primarily to meet the requirements of small estates. The experience gained during the past few years enabled the number of forms to be halved and other simplifications to be introduced without sacrifice of any information that is essential, either to the owner of the woods for their efficient management, or to the Forestry Commission to meet its statutory obligations.

A number of training courses and a discussion group were organised by officers of the Management Section in co-operation with the Education Branch. They included Mensuration courses for foresters and District Officers, a survey course for Working Plan personnel, for which we were fortunate in securing the services of an Ordnance Survey Officer as an instructor, and a three-day discussion group for Divisional Officers on forecasting yields and on economic appraisals of alternative courses of action.

MENSURATION

By R. T. BRADLEY, J. M. CHRISTIE and A. M. MACKENZIE

Permanent Sample Plots

Since the last comprehensive review of sample plots 10 years ago the tolat number of permanent plots has trebled and now stands at about 800. This total, however, includes plots given a standard treatment, series of plots subject to a range of treatments, race, species and spacing experiments, and replicated thinning experiments.

The main object of the review of sample plots was to ascertain whether, within the limits imposed by management costs, our existing plots covered the range of treatments and sites to which each species is currently, and to some extent might in the future be, subjected to in this country. The results of the analysis have shown that changes in the relative number of plots within each species will have to be made in view of the changes in relative importance and the amount of information already available for each species. It will also be necessary to increase slightly the total number of plots during the next 10 years, after which the rate of establishment of new plots will decline very considerably. This decision to a large extent arises from the need for a wider range of treatments and less emphasis on the standard form of treatment.

The total number of plots in each species at the time of the review (January 1961) and the proposed number of plots in 1970 are given in Table 6. The totals for 1970 are a compromise between the present position and the number of plots which seem to be desirable on theoretical grounds.

It is intended that more detailed investigation of sample plot data will be started this year and will take the form of studies on the growth of individual trees in an attempt to characterise stand development in terms of more basic growth factors.

The Bowmont Norway spruce replicated (4 x 4 latin square) thinning experiment, established in 1930, received its seventh measurement this year and the mean volumes produced under the four treatment types are summarised in Table 7.

The differences in total production between treatments are slightly less than at the last measurement but, when the differences between 1930 volumes are taken into account, are still highly significant. The slight reduction in average increment under the 'D' grade treatment may be due to the fact that the trees

Table 6

Numbers of Permanent Sample Plots by Species at 1.1.61

Species	Total 1960	Proposed Total 1970
Sitka spruce	93	115
Norway spruce	59	70
Scots pine	87	80
Corsican pine	64	65
Douglas fir	66	75
Japanese larch	106	70
European larch	69	60
Total, Major Conifers	544	535
Lodgepole pine	14	30
Western hemlock	16	30
Hybrid larch	14	25
Abies grandis	11	20
Abies procera (nobilis)	9	15
Western red cedar	8	15
Lawson cypress	3	10
Other conifers	23	35
Total, Minor Conifers	98	180
Oak	48	50
Beech	19	20
Other hardwoods	50	55
Total, Hardwoods	117	125
Mixtures	16	25
Underplantings	13	25
Total	29	50
Grand Total, All Plots	788	890

Table 7

Bowmont Norway Spruce Thinning Experiment

(Average volumes per acre – Hoppus feet, over-bark)

Thinning Treatment (Grade)	B	C	D	LC
Volume of standing crop	6,414	5,172	3,390	3,553
Total thinning yield to date	916	2,710	4,524	4,088
Total volume production to date	7,330	7,882	7,914	7,641

are no longer able fully, to utilise the site as the number of trees in these plots is nearer to that usually associated with an 'E' grade thinning.

A recent study of the experiment (Mackenzie, unpublished) has revealed the interesting fact that the total surface area of the crowns is the same in all treatments, i.e. approximately three times the ground area of the plots, despite the large differences in numbers of trees. Economic analysis has shown that although none of the plots is yet financially mature, the 'D' grade thinning has already yielded a return of £70 per acre more than the 'B' grade. Under the 'B' grade treatment the rotation which yields the maximum financial return has nearly been reached at the age of 50 years, while that for the 'D' grade treatment will not be reached for a further 20–25 years, during which time the differences in value yield will increase in favour of the heavier thinning.

Yield and Increment Studies

Multiple yield tables for four different thinning grades or intensities have been prepared for the first time in Britain. These tables are for Sitka spruce which, although no more important than Scots pine in terms of area of standing crops, is the most important species in terms of volume production at the moment. The existing yield table for Sitka spruce (*see* Forest Record 24, *Revised Yield Tables for Conifers in Britain*) has been slightly revised, and the age range extended from 50 to 80 years. The pattern of treatment assumed in this table has been used as the basis for the multiple yield tables and comprises the 'standard' thinning regime. The other three tables are for thinning treatments characterised by the basal area of the standing crop after thinning, namely, 120 per cent, 80 per cent and 60 per cent of that given in the 'standard' or 100 per cent table. Although these tables have necessarily been constructed on the assumption of a type of thinning which is a compromise between the extremes of strict low or strict crown thinning, the considerable range of intensities covered make it possible, by interpolation, to derive the probable course of stand development under other types and patterns of treatment.

Graphical methods were again used to construct these tables and some subjective extrapolation was necessary, particularly in the lower quality classes, and no data were available beyond 25 years, for the 60 per cent table. A loss of total production increasing to a maximum of about 15 per cent at a height of 110 feet has been assumed on theoretical grounds in the 60 per cent table; otherwise it has been assumed that thinning treatment does not affect total volume production. This latter assumption is supported by the evidence from a large number of remeasurements of plots thinned to the other intensities. It is not claimed that the pattern of thinning intensity with time, especially in the heaviest thinning, is necessarily the ideal one, and it is certain that it could be improved upon from the financial point of view.

Work on the conifer stand tables has now been extended so that the tables will show the percentage volume distribution by girth classes and by assortments as well as the percentage distribution by numbers of stems. These tables should be applicable to standing crops or thinnings, and samples of standing crops or thinnings (e.g. as in tariff estimation), provided that the girth distribution is 'normal' in the statistical sense.

The analysis of Sitka spruce data has shown that about 45 per cent of the number of trees in a stand have girths larger than the girth of the tree of mean basal area, and that these trees contribute approximately 60 per cent of the volume.

Further work has been carried out on the use of the general tariff tables and the results are about to be published in a revised version of Forest Record No. 31 (*Tariff Tables*) now in the press. The text of this has been completely rewritten, although the tables themselves remain unaltered. The new text indicates how the tables may be used for hardwoods, and for conifers beyond the originally specified top height of 80 feet; it describes the most efficient and most economical means of organising the work; it gives the various checks of accuracy that may be employed and it shows how the difficulties most commonly encountered in practice (e.g. irregular stands) may be surmounted.

Methods of increment determination, particularly for working plan purposes, have provided a major commitment and work has been concentrated on two different approaches; further refinement of yield tables and, secondly, direct estimation of increment.

Using the first approach, the precision of estimates of future yield and increment can be improved by subdividing the total production range, which in the present yield tables is defined by top height alone, and in this way still retain the advantages of height as the prime indicator of volume yield. Once the complex problems of computing yield tables have been solved, the use of electronic computers will speed up the preparation of such modified tables for use in those areas to which the general yield tables are not directly applicable. This method of estimation is most useful in younger stands where it is still possible to obtain an estimate of total production to indicate the extent of the divergence of the local pattern of growth from that depicted in the general yield tables.

Work carried out during the year on direct measurement of increment, using increment cores, suggests that reliable estimates of crop volume increment may best be determined by sampling the girth increment of the largest-girthed trees only.

Direct Reading Caliper

Estimation of growing stock value and increment should be greatly facilitated by the development of a prototype caliper (Plates 4 and 5). This uses 5-hole punch tape, a common medium for introducing data into electronic computers, and incorporates a Creed teleprinter punch unit by means of which measurements are transferred directly on to tape, with no intermediate manual recording or manipulation. The use of 5-hole tape limits the number of different characters available to 2^5, or 32, whereas 7-hole tape, which will probably be used in the final version, permits 2^7, or 128, character combinations.

Stem diameter readings are registered while the caliper is still in the measuring position by giving a half turn to a handle that moves the caliper arm and carriage along the rack. This rack, carrying the 32 class-interval selectors, can be moved along the slide, and the inch-girth classes used in this model can be set so that automatic registering starts and extends 32 inches beyond any chosen minimum girth. Reduction gears and small pointers are used for the measurement of increment cores, which are recorded in $\frac{1}{8}$-inch girth classes by the same rack selector system.

Other information is recorded using sequence coding for combinations of the 32 registering positions. A convenient layout for the recording of enumeration data is shown below (Fig. 1).

Trials of the instrument and method have demonstrated that enumeration work can be speeded up, costs reduced, and errors in recording, summarising and transferring data can be avoided as far as the summarising, by the computer, of the processed information.

Further development and refinement of the prototype and extension of its application is planned.

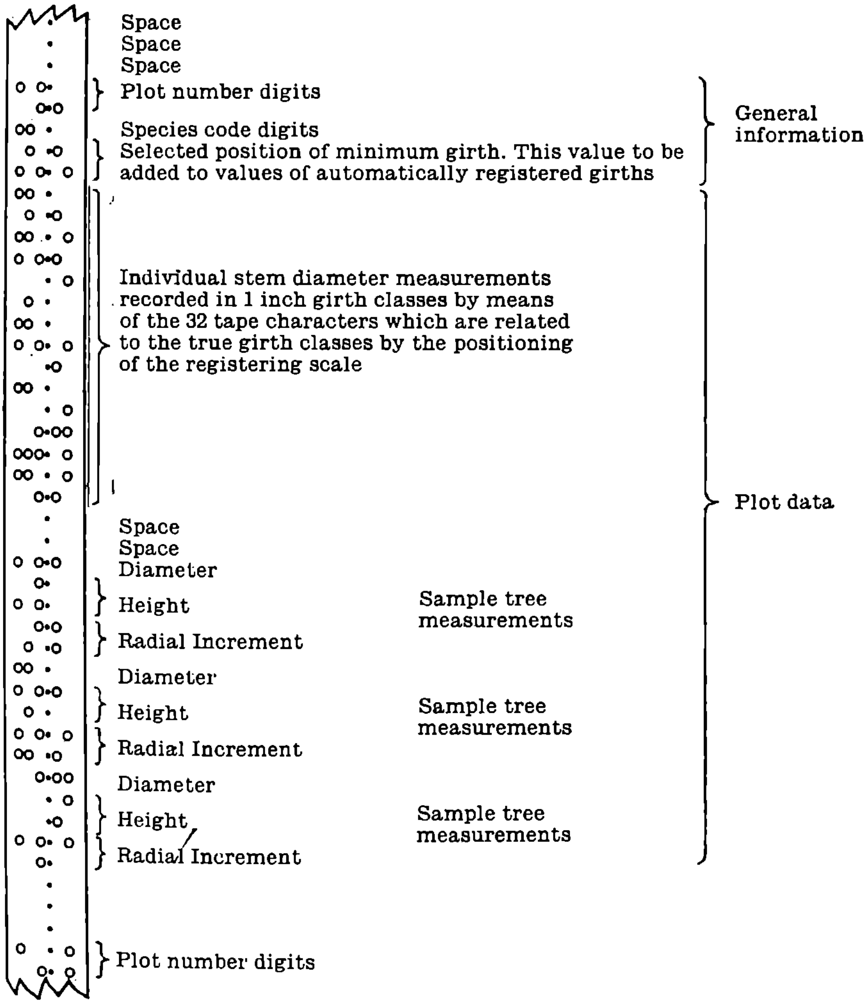

Fig. 1. Layout for Data on the Direct-reading Caliper.

FOREST ECONOMICS AND CENSUS

By A. J. GRAYSON

Organisation

In the course of the year, responsibility for the maintenance of census data has been passed to the Economist. Thus information of a census nature (woodland area, volume, increment, woodland size distribution, etc.) is currently being maintained along with statistics on timber production, consumption and trade, as well as relevant statistical data on prices, costs and levels of activity in major wood-using sectors.

Development of the Forest Economy

The review of methods applicable to broad studies of future trends in timber prices and consumption has continued. Work on this important aspect is expected to take up an increasing proportion of effort in economic research as the Second Timber Trends Study (1960 to 1975) for Europe gets under way. As a contribution to the supply side of the timber trends question, information on the quality-class distribution of major species by area has been compiled from working plan forms for forests which have been enumerated. Using particular rates of interest, it is possible to determine average costs of production of roundwood for each combination of species, rate of volume yield and operational cost, and hence to build up a hypothetical model of the height and shape of the aggregate supply curve for softwood and hardwood roundwood.

Assessments have been made of the volumes of roundwood, in particular assortments available for use in developing industries, while increasing attention has been paid to the economic consequences of alternative methods of providing stipulated volumes. For example, clear-felling within a compact area has been compared with thinning over a larger zone. The introduction of economics more explicitly represents an important advance on earlier practice, which restricted the appraisals conducted to the provision of forecasts on data for volume yields alone.

Economics in the Management of Forests

The definition of the objects of management for particular forests, and the broad methods of achieving them, have become progressively more important economic problems as working plans are prepared in larger numbers. In addition a number of questions arising in the normal course of planning and management have been dealt with *ad hoc*. Economic evaluations of alternative courses of management have been made, adopting a uniform criterion of profitability. Reference was made in the *Report on Forest Research*, 1959 to the criterion of maximising present worth, valuing future revenues and expenditures at a fixed rate of interest. This measure of profitability, using 3½ per cent as the real (not monetary) alternative rate of return to be used in discounting, has now been adopted as the generally applicable method in Forestry Commission working.

Uses of the criterion fall into two classes. In the first place there are some matters of local management concern which must stem from decisions taken for the whole country or a particular region of it. Thus several working plan areas may, at the intermediate stage of planning after a broad decision of policy has been taken, be linked quite closely in their methods of working. Two studies of the implications of different clear-felling regimes applied to two large areas (in one case involving some changes in species representation) have been carried out, using the criterion of achieving the maximum sum of future net revenues discounted at 3½ per cent. These have demonstrated the flexibility of the approach. Flexibility is a convenient property of the principle which must be emphasised, and this feature stands whether the alternatives analysed refer to whole forests or single stands. Thus the commercial returns of any given course may be compared with effects on such imponderable aspects as the degree of normality achieved over the area, the variation in the labour force required for forest work and exploitation, etc., and thus monetary and other consequences are confronted. It is hoped to evolve more refined techniques for the evaluation of net discounted revenues under different courses of management: linear programming may come to be employed in this sphere. If any constraint is applied within which several alternatives exist, then not only may the economic optimum under the imposed condition be evaluated, but also the difference can be calculated between this and the theoretical optimum achieved when the particular constraint does not apply. Hence a measure of the opportunity cost (i.e. the implied cost of foregoing the maximum economic return) may be derived. This principle has been applied to the assessment of the opportunity cost of fellings before or after the rotation of maximum discounted net revenue, and the cost of retaining a certain species where other, more profitable, trees might be favoured.

Secondly, in specific fields, economic evaluations on the basis of computations for a model acre have been made. Using the existing British yield tables and reasonable assumptions as to the steepness of price rise with increasing girth, rotations of maximum net discounted revenue have been calculated for the major species.

In lower Quality Classes, especially with pines and Norway spruce, the values of net discounted revenue are not very sensitive to changes in rotation. The most profitable rotations are usually found to be close to the age when mean annual volume increment culminates. For a given relationship between breast height quarter-girth and price, there will be one such optimal rotation for each species and Quality Class. The breast-height quarter-girth of the mean tree may then be read from the yield tables. It is found that for the major conifers, the range in size of final crop tree, from the highest to the lowest quality class within one species is between 2 and 4 inches. With heavier thinning regimes than those implied in the published yield tables, and with steeper price-size curves, the most profitable rotations will always be longer, and also the spread of tree sizes produced on these rotations will be wider still over the range of Quality Classes.

Until recently, calculations have been based on yield tables which assume no loss in increment potential of the stand compared with the maximum obtainable. However, with the aid of the new tables constructed by the Mensuration Section, it has been possible to assess the effect of a grade of thinning ('E') which, it has been assumed, reduces stocking so far that at 50 years in Sitka spruce, for example, total yield is approximately 85 per cent, in Quality Classes I and II, of that obtained under both 'C/D' and 'D' grade thinnings. A gentle rise in price with size, namely at a rate of 1d. per hoppus foot over-bark per 1 inch of breast-height quarter-girth between 11 inches and 18 inches, has been assumed, and a rate of 3½ per cent has been used in discounting. It is then found that owing to the rather heavy reductions in total yield at quite early ages (20 to 25 years) the net discounted revenue rises to rather lower values than those calculated in the 'D' grade and even the 'C/D' grade. Thus it appears that with such shallow price-size curves the enhanced girth increment and the consequent larger value increment on the main crop is insufficient to offset the reduced volume yields adopted in the 'E' grade tables. In other words, the profitability of heavier grades of thinning in Sitka spruce under the conditions noted is quite sensitive to the loss of yield involved once the heaviest grade capable of sustaining maximum volume increment has been surpassed.

In order to demonstrate the effect of diverging from the calculated optimum rotation, the convention has been adopted of assessing the range of rotation lengths within which net discounted revenue does not fall more than £5 per acre below the maximum achieved. Investigations of treatments yielding highest returns include the following cases:

(a) Production of telegraph poles from Scots pine.

(b) Production of pulpwood from spruce.

(c) Time of replacement of Sweet chestnut by conifer crops.

In all applications of the profitability criterion so far dealt with, it is relatively easy and usually desirable to demonstrate the effects of changed assumptions of volume yield, costs and prices.

Economics of the Private Forestry Sector

Further progress has been made on the project, noted last year, concerned with the evaluation of overall cash expenditures and receipts in private woodlands. Enquiries are proceeding jointly with the Economics Section of the Forestry Departments at the Universities of Oxford and Aberdeen, and with representatives of the private woodland owners' organisations.

Two studies are singled out for comment here. With the compartment cost data collected by the Oxford survey team, an attempt has been made to assess the variation of unit cost of planting in England and Wales in relation to various recorded factors. The costs concerned were obtained by correcting the compartment costs for labour and plants used in planting, by means of a wages index, in order to bring the results of five years' costing to a more comparable basis. Compartment cost thus corrected was divided by the area planted to give a unit cost for each compartment. A regional split was then made, and multiple regressions of unit cost on estate and compartment factors calculated. A regression was also run for the pooled observations (505 in number).

While a certain amount of variation in unit costs over all compartments could be significantly related to such factors as numbers of plants per acre, area planted and maximum altitude of estate woodlands, the proportion of total variance explained was disappointingly low at 15 per cent. (The individual regions, or pairs of regions, yielded regressions on a variety of factors which accounted for up to 75 per cent of total variance, but the structural interpretation of some of these were not clear.)

On the whole it appears that a certain amount of variance can be reasonably 'explained', but the factors recorded are not sufficiently closely related to the real causes of variation of planting costs between compartments, estates or regions. On the other hand, the range of unit costs of planting is not high (averages for the regions dealt with varied between £20·8 and £25·7), and the precision of these means was usually better than 10 per cent, while the precision of the overall mean for 505 compartments was as high as 2 per cent.

Secondly, regression analysis was applied to round log prices as reported to the Forest Economics Section at Oxford for sales in 1955. The basic purpose of this study was to determine what factors (such as mid-quarter-girth, volume in an individual sale, quality of log) could be associated with variation in price. If price variation could be explained in this way, allowance could be made for changes in proportions of species, assortments and so on in comparing annual data.

In oak, Scots pine and Norway spruce (the two latter species being lumped together since their price variation could jointly be explained by a single relationship) some success was achieved using mid-quarter-girth and a simple quality grading (fair and poor). In other species data were either too scanty or the important causal factors were not identified.

WORK STUDY

By J. W. L. ZEHETMAYR

Introduction

Since this is the first report on work study, an outline of the subject and of the method of working will be given before details of current work are discussed.

Work study has been defined as an intensive enquiry into management to ensure the best possible use of human and material resources in carrying out a specified activity. It is a tool of management used to find out how jobs are carried out in practice and to work out better methods. To find out the best method usually requires time-study, to measure the time taken under a variety of conditions, and this provides an ideal basis for the development of incentive schemes, payment being related to the amount of work in each job.

Work study must operate at all levels in an organisation, because it will throw up proposals relating to various grades – labour, supervisory and managerial. It must be undertaken on an advisory basis, otherwise it usurps the function of management; hence co-operation at all levels must be the aim, obtaining results by persuasion and proof rather than the exercise of authority.

Up to the beginning of 1959 the Forestry Commission Work Study Section had largely been engaged on exploratory work at the Forests of Ae, Kershope, Coed y Brenin and Dovey. The year 1959–60 has seen a great deal of this work brought to fruition by placing the organisation, piece rates and control of production operations in a number of forests on a work-studied basis under the control of local forest management. The task in 1961 is largely to round off work on production and start the study of forest maintenance.

Organisation of the Work

The Work Study Section is led by a Divisional Officer responsible to Director (Headquarters). Its staff in the last year has consisted of one Senior Executive Officer, four District Officers, two Executive Officers, two Foresters, and three Assistant Foresters.

The Work Study Section provides four teams each with a leader and usually with two other members. Team leaders have been given formal training in work study, and serve as assistants before taking over a team themselves. A mixture of grades in the teams is intentional so that 'forest level' experience and 'executive' experience is available in each team, besides the managerial experience of the leader. Work Study Section's headquarters are in Edinburgh, where a District Officer works on machinery trials and the establishment of standard times.

Each team is given an assignment in a particular forest, district, or conservancy, and up to now this has always been in broad terms – "to study the conduct of production operations from marking to despatch". Work starts with a survey of all the relevant features of production; all operations are observed in the forest; control and payment procedures are recorded, and the financial accounts analysed. A formal survey report is then presented to the Conservator and the lines of action to be taken are agreed. Work then starts in earnest with method improvement and time studies designed to assist in setting piece rates. Costings are undertaken, and often at this stage development work is needed if it is desired to alter methods substantially, as by the introduction of new equipment. As work on the various points raised in the survey is completed, reports are made to the Conservator, often linked with meetings at which future policy or action is decided. It is the job of the head of the section to see that the objectives set out at the start are in the main covered, that changes in direction are approved and agreed by all, and that effort is not lightly diverted into other investigations.

Assignments

The assignments in progress in 1960 are shown in Table 8.

Table 8

Work Study Assignments

Conservancy	Forests	Completion Date	Main Products
North Wales	Gwydyr Coed y Brenin Dovey Kerry	August, 1960	Spruce pulpwood for Bowaters' Ellesmere Port mill. Poles of other species sold at roadside.
North-East England (Border District)	Redesdale Kielder	September, 1960	Peeled lineal pitwood.
West Scotland (Cowal Districts)	Glenbranter Glenfinart Benmore Ardgartan	April, 1961	Logs for Cowal-Ari sawmill, Strachur. Tops sold sold at roadside for pitwood.
South Wales	Ebbw Wentwood Coed Morgannwy (Rheola)	September, 1960 " " December, 1960	E.: Poles and tonnage pitwood. W.: Hardwood pulp for Sudbrook Mill. C.M.: Tonnage pitwood.

With experience gained on production of chipwood and stakes, etc., at previous assignments at the Forest of Ae (South Scotland) and at Kershope (North West England), the section has some knowledge of the production of most major types of produce and a particular knowledge of industrial wood - pulpwood, chipwood and boardwood.

Fields of Work Covered in 1960–61

Not every one of the following items is investigated by each team, but they all find it necessary to do some work on the majority of them. All teams contribute to providing lecturers and instructors for Northerwood and other courses.

Tools and Methods

The first approach to any of the manual jobs which form the basis of production work is to see that workers have good tools, know how to maintain them, and use efficient and safe methods. A new tool list has been issued throughout the Commission, incorporating Work Study findings in the field of production. Information is fed to the Forester Training Schools and to Tool Instructors in the Conservancies. Some instruction on the job is given by members in the course of study, and in certain cases the Work Study team has trained a production team in better methods, resulting in higher output and earnings to everyone's satisfaction.

Equipment

During the year final designs for several items of equipment have been produced, among them the Border sledge, the log jack, and the roller-topped stand for saw benches.

A new item which is promising is a 'wheeled towing arm' working on the 'tug-lift' principle to assist in moving machine saws and bark-peelers on rough roads and verges. All these items will be incorporated in a publication now in draft on "Aids to Handling and Converting Thinnings".

Machinery

(a) Chain Saws: During the year considerable attention has been devoted to chain saws. The indications from Work Study are that chain saws should be owned by forest workers, that they should be used by a small group led by the owner, that hand-saw rates should be paid to such worker-owners, that there should be a guarantee of the availability of work before men are encouraged to purchase such saws, and that training and workshop maintenance facilities should be provided.

Experience in Britain on this matter agreed with the much greater experience in Sweden that this division is logical, workable and fair to all.

(b) Testing of New Items of Equipment: Forest testing of production equipment developed to the 'user trial' stage by Machinery Development Officer is carried out by the section. Items tested or under test are:

(1) *Isachsen Double-drum Tractor-mounted Winch for Extraction.* This Norwegian equipment has suffered under test from mechanical faults. The principle is however excellent for heavy fellings on difficult ground. The problems in Britain are to apply the machine to thinnings, and to use it on much narrower roads and more confined spaces than is customary in Norway.

(2) *Single-strand Ropeway.* Trials of this equipment showed that it may be of value to 'salvage' silviculturally essential thinnings, but that it could not, under the conditions of these trials, otherwise extract timber economically.

(3) *Shawnee Poole Timber Hauler.* This equipment offers great promise for direct hauls from stump to mill, thus combining extraction and haulage and eliminating intermediate unloading and reloading. Over limited distances (under 35 miles) it offers substantial savings, but the difficulty is to find sites where the quantity being transported justifies the high initial cost of the equipment.

Piecework Schemes

During the year all the previous work was put into a practical form with the development of a basic piecework system, which can be expanded to cover all forms of work suitable for piecework. Booklets for timber production operations in North Wales and for the Border area of North East England are in use within the Forestry Commission, while a draft is under trial for the Cowal districts of West Scotland.

Rates are set for a great variety of jobs under varied conditions. Between them the booklets cover:

Thinning (and felling, hand extraction, etc.).
Extraction by horse.
Machine and hand crosscutting.
Machine and hand peeling.
Loading.

The main features of the booklets are:

(a) *Tables of Standard Times* are the essential foundation. The standard times, expressed in minutes for each job, each size of tree, length of haul, etc., provide a measure, derived from time-study, of the amount of work in each job. They are based on the time taken by the average worker working on piecework, and presume good methods and the correct tools.

(b) The conditions under which each table of standard times applies are defined, together with a specification of the job to be carried out, tools to be available, etc.

(c) Additional work or altered conditions are allowed for by a series of adjustments.

(d) The conversion of standard times to money in a logical manner is set out. The calculation of the 'price per standard minute' is based on current rates of pay and conditions, the skill required by the job, and locality conditions. Once determined for a particular forest, the price remains constant until conditions of service change.

This system follows broadly that developed by Work Study in industry in Britain, and in forestry in Sweden, and is based on the experience of the section over the past four years. After a further period of trial it should be possible to integrate the various regional schemes into a comprehensive guide to piece rates.

Forest Organisation and Management.

Arising out of observing how jobs are performed, there are inevitably recommendations as to how they should be organised and controlled. These may be specific to an area or related to a particular job, e.g. that one junior supervisor should be able to control the despatch of 3,000 tons of pulpwood per year, this to be worked by three teams of four men each, with horse and chain saw. Much more general is the production of Labour Control figures which have only occasionally been produced by existing management routines. Working from existing records the following facts are obtained:

(a) *Piecework Ratio.* The proportion of available working days spent on piecework. This rarely exceeds 50 per cent for all operations in a forest. The attainment of a higher figure would be the greatest single contribution that could be made to the reduction of costs.

(b) *Piecework Performance.* The ratio of piecework earnings to timework earnings.

(c) *Days-wet per Man-year.* This figure, in conjunction with actual and average rainfalls, is the only logical method of comparing wet time between different areas.

Costing

Three separate types of work have been in hand:

(a) **Compartment Costing.** The investigation of methods, labour control, produce control and costs on an area make it possible to draw up a balance sheet showing not only costs and return from the operation, but also output, which can be converted to productivity. A system for such compartment costings has been under widespread test and has been adopted in some Conservancies. It is admittedly more suited to ride-side working and quick turnover than to depots or pitwood operations which require long seasoning. The results derived from the costing of some 30 compartments producing pulpwood are being written-up.

(b) **Costing of Different Sizes of Pole and Piece.** Time-study makes it possible for the first time to cost the individual rather than the average tree or specification. Results stress the very high costs associated with small dimensions, and suggest adoption of thinning techniques to eliminate high-cost produce when high-price markets are not available. In one extensive area, changing the thinning regime resulted in a virtual doubling of the average size of spruce tree cut at first thinning, from 0·9 hoppus feet in 1959 to 1·6 hoppus feet in 1960.

(c) **Costing of Different Specifications of Pitwood.** The complexities of the different specifications, prices and production costs make it almost impossible to choose, even where there is a choice, what should be produced. A report has been drawn up which provides a guide to relative profitability, based on an expected conversion loss and despatched hoppus-foot volume per ton, taking into account the varying cost of production of the various specifications.

Produce Control

A vital factor in produce operations is to compare estimates of standing timber with outturn, and to establish realistic conversion losses and conversion factors for various specifications of produce. Detailed examination in 1960 of some 40 compartments mainly producing pulp has led to:

(a) Recommendations for simple methods of checking standing volume estimates on the basis of volumes of produce, and for the calculation of conversion losses on various types of produce.

(b) Recommendations on the simplest method of controlling pulp operations.

Project Organisation

This might be taken to include the whole of Work Study, but it is mentioned to illustrate that in the case of pulpwood information has been gathered on:

(1) The basic principles which should control the operation.
(2) Working organisation and methods.
(3) Piece rates to cover all foreseeable conditions.
(4) Produce control.
(5) Costing of compartments over a wide variety of conditions.

All these have been separately noted above: together they form the basis for a comprehensive report on the "Production and Control of Tonnage Pulpwood", now in preparation.

Training of Staff and Publicity

Three courses on Work Study have been run for District Officers and Foresters, and three courses on Tool Use and Maintenance for Tool Instructors. In addition, talks on Work Study have been given at other courses. Demonstrations or exhibits were provided for three agricultural shows.

UTILISATION DEVELOPMENT

By E. G. RICHARDS

Home-grown Pitprops

The investigation at the Forest Products Research Laboratory, Princes Risborough, into the compressive strengths of home-grown pitprops from England, Scotland and Wales, which was referred to in the *Report on Forest Research*, 1959, ended with the testing of pitprops from Wales. Both seasoned and unseasoned commercially-prepared pitprops were tested.

Statistical examination of the experimental data has confirmed that home-produced pitprops, provided they are properly manufactured and well seasoned, are suitable for use as timber supports in the mines.

Properties of Home-grown Timber

A comprehensive programme of study of the properties of home-grown timber began in 1959 with the field sampling and laboratory examination of the timber of Sitka spruce. This programme also is a joint undertaking with the Forest Products Research Laboratory. The past year saw the completion of the laboratory examination of the Sitka spruce samples.

A report on this investigation is being prepared.

Samples of timber from thinning operations in provenance plots of Lodgepole pine at Beddgelert and Clocaenog Forests in Wales were sent to the Forest Products Research Laboratory for examination; the work is being continued with samples from 15 provenances of Lodgepole pine from a provenance experiment at Wykeham Beat of Allerston Forest.

Work has also begun on the timber properties of home-grown Japanese larch. Hybrid larch will also be examined if suitable material of true 'Hybrid' is found during field sampling. Timber from European larch from the same sites is also being examined as a basis for comparison.

Determination of Specific Gravity and Moisture Content of Freshly-felled Conifers

The field sampling of 20- to 40-year-old crops of the major coniferous species, referred to in the *Report on Forest Research*, 1960, was completed during the year.

Altogether some 22,000 samples were examined by the Forest Products Research Laboratory and their specific gravity and moisture content determined. The seven species concerned were Scots and Corsican pines; European and Japanese larches; Norway and Sitka spruces; and Douglas fir.

The statistical analysis of the data shows a wide variation in both moisture content and specific gravity; this variation can be attributed to differences between sites, differences between trees on the same site and differences between billets from the same tree. The factors responsible for the differences between sites have not yet been identified.

Further analyses of the data are planned. A report of the results so far obtained is being prepared.

Thetford Winter-Seasoning Experiment

At Brandon Produce Depot, Thetford Forest, an experiment was laid down to investigate the amount of drying which might be expected in close-piled stacks of peeled material during the winter months.

The experiment has also been designed to show if there are any differences between the rates of drying of Scots and Corsican pine and to show the effect of providing stacks with roofs.

Freshly felled and peeled logs of Corsican and Scots pine, 6 feet 6 inches long and 3 to 7 inches in top diameter, were stacked, both with and without roofs, on three separate dates during the winter of 1960–61.

The Forest Products Research Laboratory are assisting with this project.

Fence-post Trials

Field assessments have continued on the fence-post trials which were mentioned in the *Report on Forest Research*, 1960. As expected, no failures have occurred in posts treated with preservative, but already, after two to three years, some untreated posts of birch, Scots pine, Sitka spruce, alder and ash have rotted sufficiently at ground level to break off when a horizontal pull of 50 lb. was applied to the top of the post.

Home-grown Thinnings Bungalow

Reference was made in the *Report on Forest Research*, 1960, to a bungalow which it was planned to build of home-grown timber from thinnings. This bungalow has now been built at Alice Holt (*see* Plate 1).

Home-grown Sitka spruce from the West of Scotland was used for the framing, cladding and roof trusses, and home-grown Scots pine from the New Forest for the joinery work. Ceilings are of insulating board, manufactured from home-grown softwood thinnings, and treated with a factory-applied flame-retardant paint.

The freshly-sawn green timber was treated at the Forest Products Research Laboratory by diffusion impregnation, using a borax salt which was applied in a 'spray tunnel'. No difficulties were encountered and excellent penetration was achieved.

One feature of the bungalow is that the internal partition walls are not load-bearing, so that one basic design allows a varied internal arrangement of rooms according to the requirements for accommodation at any particular site.

MACHINERY RESEARCH

By R. G. SHAW

Tractors

There is a tendency for increasing use to be made in the forest of four-wheel drive in place of comparatively expensive tracked tractors. Tests are being undertaken in the application of four-wheel drive to many forest operations. The possibility of hydraulic transmission becoming a commercial proposition is being carefully watched, and contact is being maintained with all organisations known to be working on this project. The infinitely variable speed provided by this form of transmission is likely to prove invaluable for forest use, particularly in nurseries.

Transport

Methods of moving timber from the stump to road-going vehicles are still under active investigation. The wide variety of conditions that must be met provides the greatest problem and is, in fact, a subject of Work Study as much as mechanisation. A new device for transporting heavy loads of long logs using standard agricultural tractors has been devised and it is now undergoing practical trials. This device is known as the 'Alice Holt Logger'.

Contact is being maintained with the makers of the Hovercraft, since a load-carrying model is being produced which would travel over soft ground, and this might be a possible vehicle for extraction of produce over soft peat.

Loading

The transfer of loads to long-distance road vehicles is a vital link in economic extraction costs, and the problem is always under review. Lorry-mounted loaders are tested as they become available, but as quantities to be transported increase, central loading in mobile depots may prove the most economical method. Trials of the various alternatives are being undertaken as a Joint Work Study and Machinery project.

Ploughing

Experiments have been undertaken in the placing of fertiliser automatically under the furrow as the plough progresses. This is a long-term project as it will take some years to form a definite opinion on the results.

Winches

Trials of the Norwegian Isachsen winch have shown that twin-drum winches have great possibilities in the extraction of thinnings under difficult ground conditions for ranges up to 150 yards.

Trials of the Boughton hydraulic-drive winch have indicated the value of this type of drive in giving sensitive control and added safety, through ability to limit the maximum pull that can be applied.

In view of the success of these two trials, it is probable that a winch combining the twin-drum principle and hydraulic drive will be designed for further experiments.

Drain Cleaning

The problem of cleaning forest drains is still without a complete solution. Many machines exist which will deal with some of the conditions, but none will clean a drain 18 inches deep for less than 2s. a chain. Most, in fact, are far in excess of this figure. The flail machine mentioned in the last *Report* has progressed, and was awarded a bronze medal in the Royal Agricultural Society of England forest-drain cleaning competition in March 1961. The shape of the drain cut by this machine is not yet considered entirely satisfactory, so modifications are being introduced.

Bark Peeling

No solution has been found to the problem of peeling crooked hardwood logs to make them acceptable for pulp. There are, however, indications that chemical treatment of the standing tree will loosen the bark sufficiently for adequate peeling to be achieved by drum-barking. This investigation is being pursued.

Power Saws

A large number of saws are now available on the British market. New models continue to appear, giving a welcome increase in cutting speed and an equally welcome decrease in weight. Performance trials based on the F.A.O. Testing Schedule continue to be carried out in conjunction with the Forest Products Research Laboratory.

DESIGN AND ANALYSIS OF EXPERIMENTS

By J. N. R. JEFFERS

The work of the Statistics Section has continued to be that of providing advice on the design and analysis of experiments and surveys, undertaking the analysis and interpretation of collected data, and carrying out research into the application of statistical methods and digital computers to problems of forest research and management. The staff of the Section has been strengthened by the appointment of an Experimental Officer and an Assistant Experimental Officer, both of whom are engaged on the advisory work of the Section and in the interpretation of numerical data, and by the appointment of one District Officer who has been mainly concerned with the interpretation of data arising from studies of the utilisation of home-grown timber. Two students of the Ministry of Aviation have also been attached to the Section for six months' periods for training in practical applications of statistical methods.

Electronic digital computers have continued to play an essential part in all the work of the Section, making it possible to undertake a heavy programme of analytical work with a relatively small staff of computing assistants, who are almost entirely concerned with the preparation of data for the computers. Two computers have been in major use, the Ferranti Pegasus computer at the nearby Royal Aircraft Establishment, and the Ferranti Sirius computer at the London Computer Centre. Both of these machines have been found to be very suitable for the work of the Section. A little use has also been made of the Pegasus computer at the Northampton College of Advanced Technology.

Advisory work on the design and analysis of forest experiments has also been undertaken for a number of Overseas Forest Departments, notably those of Rhodesia and Cyprus, and for other organisations and research stations interested in forest problems, particularly for the Forest Products Research Laboratory.

An important commitment in the past year has been that of providing talks on information theory, statistical methods, and electronic computing to a wide range of the staff of the Forestry Commission, outwith the Research Branch.

The importance of this aspect of the work cannot be over-estimated, since the acceptance and use of these new methods will very largely be a function of the amount that is known about them by all levels of the Commission's staff.

Design of Experiments and Surveys

Advice on the design and analysis of experiments and surveys remains as the most important function of the Section, designs being required for more than 100 investigations throughout the year. For designed experiments, the usual diversity in complexity and scope has been evident, though the emphasis has generally been towards a smaller number of complex experiments, in each of which a number of variables have been measured. In combination with the more powerful methods of multivariate analysis made possible by the use of electronic computers, such complex experiments have been found to be more informative than a larger series of simpler experiments.

Design of surveys and of investigations concerned with the management of forests, as distinct from research problems, has increased markedly, and now forms a very large part of the effort of the qualified staff of the Section. This trend emphasises the increasing importance and awareness of the part that modern computing and statistical methods can play in the management of so extensive an enterprise as that of forestry. Some of the more important of these investigations have been concerned with forecasts of production from Commission forests, with the determination of the basic properties of timber grown on a wide variety of sites, with the wastage and turnover of labour in Commission forests, and with the estimation of insect populations. Special emphasis has continued to be placed on the problems of forest enumeration, and particularly of the further use that is made of the basic data collected during such enumerations.

The Forest Service of the United States Department of Agriculture has instituted a handbook of research planning-factor data, the purpose of which is to compile, in a readily available form, information regarding experimental or sampling errors essential for the planning of an efficient experiment or survey. The Statistics Section of the Forestry Commission Research Branch was invited to co-operate in the compilation of this handbook, and has done so readily. There is little doubt that this is an important step towards greater efficiency in the design of forest experiments and surveys. As a start, the records of the efficiency achieved in the wide range of experiments and surveys conducted by the Research Branch have been made available to the Forest Service, and a scheme for recording and compiling this information automatically, in precisely the form in which it is required for the handbook, has been organised.

Analysis of Experiments and Surveys

The demand for the analysis and interpretation of numerical data has continued at an ever-increasing rate, and more than 6,000 separate analyses were completed in the year under review. About one quarter of these analyses have been routine analyses of intermediate assessments of long-term experiments, the remainder being special analyses of important immediate problems, some of the more interesting of which are outlined below.

A number of important sets of data on the basic properties of the timber of Sitka spruce, and of other conifers of economic importance, became available during the year, and extensive analyses of these data were carried out. One of the most important of these was concerned with the variation in moisture content and specific gravity of freshly-felled conifers. In these analyses, the relationships of moisture content and specific gravity to identifiable factors were found to be very much more complex than has been indicated in previously published literature, and work on these data is continuing.

Forecasts of the production of timber arising from thinning and felling operations in Forestry Commission plantations also became available during the year, and were the subject of a critical analysis, first, to test the accuracy of the estimates, and, second, to obtain a balanced picure of the future production in a way in which it can most readily be used as a basis for management decisions. Use has been made in this analysis of recent methods for the construction of mathematical models of practical situations, and it has revealed the value of such techniques, both in their ability to describe a practical situation, and in that of predicting the consequences of certain defined courses of action.

Several investigations of economic problems were undertaken during the year, the most interesting of which, from a statistical point of view, was an investigation of the cost of establishment of plantations. This investigation, based on a survey carried out in 1959, attempted to relate costs of establishment to basic physical factors, such as the size of the area established, the length of drains and fences created, the species planted, etc., and to a number of variables designed to measure the experience of the staff of the forest and the local supervision available. The surprising results of the analysis were that, despite the high level of apparent variability in the cost of establishment in individual units, almost all of this variability was accountable by a small number of simple physical factors; and, if a few simple measures of experience and supervision were included, less than 3 per cent of the variability in cost remained to be accounted for by the wide variations in other site factors which are generally claimed by the field staff to be the main reason for the varying costs.

Many of the designed experiments which have been received for analysis in the current year have been concerned with the inter-relationships between fertiliser applications, the uptake of nutrients into the foliage of the trees, and their subsequent growth. The most important of these were the pole-stage manuring experiments, designed as partially-replicated factorial experiments and described in earlier reports. Special methods of analysis were evolved for the interpretation of these data, and the results have shown the effort involved in the establishment and conduct of these complex experiments to be well worth-while.

Working plan enumerations have formed a large part of the computing effort, using the programme described in last year's *Report*, and further modifications of that programme. For each enumeration, two sets of calculations are required, those for the pilot survey, on the results of which are based the estimates of the numbers of sample plots required in the final survey, and those for the completed enumeration. It is fair to say that the new methods of computation, and the fact that they can be carried out while the field staff are still engaged on measuring at the forest concerned, has done much to contribute to the success of the large programme of enumerations that has been carried out.

Computer Programming

The use of two different computers, Pegasus and Sirius, has been made possible by the fact that the Section decided, at an early stage in the transfer of their computations to electronic computers, to write the basic flow-diagrams of all new programmes in Pegasus Autocode. Not only does this procedure enable the basic flow-diagram to be tested at the earliest possible stage, but, because the Pegasus Autocode is also acceptable to Sirius, at least one version of the programme is available for running on either machine. This has made possible a certain flexibility in the use of computers which would not have been possible if time could have been hired on only one type of machine. It has also enabled a direct comparison to be made between the relative advantages of the two different computers.

Most of the general-purpose programmes required for the analytical work of the Section were already in existence at the beginning of the year, and the programming effort has, therefore, largely been directed towards the production of a number of special-purpose programmes required for particular analyses. Improvements have however been made to a number of the general-purpose programmes, notably to the 'single classification analysis of variance' programme, which has been extended to cover hierarchial classifications, to the Latin square and Graeco-latin square programmes, and to the Working Plan enumeration programme. The general programme for the analysis of variance of non-orthogonal data, with two or three constraints, has virtually solved the problem of the analysis of a large class of experiments.

The special-purpose programmes which have been written included those for the compilation and analysis of the production forecasts of the Commission's forests, and these have given the staff of the Section an insight into some of the problems involved in the setting up of automatic data-processing systems for a range of information arising from the day-to-day work, in particular into the problems of ensuring that the basic data are correct before they are used in the advanced computations required for the analysis of complex situations. A special programme has also been written for the calculation of stand tables, giving the distribution of volumes of individual stands by diameter classes. This programme was based on the probit transformation, and involves a probit transformation sub-routine of general applicability. Others include a programme for estimating the population of squirrels and other small mammals, or of insects, from trapping records; and the calculation of the net discounted revenue from plantations, allowing for variable inputs in the form of costs of establishment, protection and maintenance, and of variable prices for the timber produced. A programme to compute the efficiency of individual nurseries has formed the basis of a more extended, though at present preliminary, investigation into the simulation of the planning, growth, and allocation of nursery stocks. Finally, among these programmes developed over the last year should be mentioned those written to analyse the growth curves derived from vernier tree bands, involving weekly measurements of the girths of trees, with the purpose of detecting small differences in growth over the year, and differences in the seasonal pattern of growth.

International Union of Forest Research Organisations

Work on the standardisation of measurements for the Working Party of Section 25 of the International Union of Forest Research Organisations, and on the compilation of information and tests on instruments used in forestry, has now been completed.

The Panel of Forest Statisticians, of which the Statistician is a member, has been actively considering the ways in which the panel can be of the greatest use to forest research. A report on the conclusions reached is to be presented to the forthcoming Congress of the Union.

LIBRARY AND DOCUMENTATION

By R. M. G. SEMPLE

Towards the end of the year a start was made on the extension and reorganisation of the library premises. This will take some months to complete, but will provide better facilities for library and Alice Holt staff in general, and enable both library and documentation work to function more efficiently, for the benefit of the Commission as a whole.

Library

The number of books in the library on 31st March, 1961 was 3,666, an increase during the year of 181; of these, 95 were purchased, the remainder being received as gifts or by exchange. 880 books are now on permanent loan to Sectional libraries. Other loans of books increased from 952 to 1,032. 222 publications were borrowed on behalf of Commission staff from outside libraries. 42 volumes of periodicals were bound, bringing the total of (bound) periodicals to 1,468 volumes. The above figures represent, of course, only a part of the use which is being made of the library's facilities; the trend is even more apparent in the increased daily use of the library for private study, and it is hoped that when the new reading room is completed a much greater increase will occur. The present rather cramped and noisy quarters are not an inducement to serious reading.

Documentation and Information

A considerable quantity of material has been added to the information files, each item being indexed and cross-referenced. Even with the most careful selection, this valuable collection of typescript reports, translations, reprints, pamphlets and similar material of special interest, now forms an extensive archive section, and arrangements are being made to house it in a more fitting and accessible form.

There has been steady but rather slow progress in the work of documentation, but it is hoped that in the coming year this can be speeded up by making a much fuller use of the title cards supplied by the Commonwealth Forestry Bureau. The card catalogues now hold some 91,000 cards. This is an apparent decrease on the previous year, but a number of irrelevant categories have been excluded from the count; there has, in fact, been an effective increase of some 3,000 cards, representing about 1,000 references. The Subject catalogue now contains about 45,000 cards; the Geographical about 9,000.

No major bibliographies were prepared during the year, although one on the afforestation of industrial waste lands is under preparation. There has been, however, a very definite increase in the number of special bibliographies asked for and prepared, and in requests for information generally. A gratifying feature has been that a high proportion of these requests now come from officers in the field and even from sources outside the Commission; enquiries from Forester Training Schools also appear to be on the increase. It is to be hoped that this trend will continue, and that knowledge of the facilities available at Alice Holt will become more widely known throughout the Commission.

The bibliography of British forest literature up to 1950 was virtually completed by Mr. Kitchingman before his retirement. Some 10,000 items are now catalogued on cards, in the order in which they will appear in the bibliography. Some minor additions have still to be made, but otherwise the work has reached the stage in which the next step is the consideration of the form in which it shall be presented to the printer.

Translations

The more important translations completed were noted in the April, 1961 Library Quarterly. These now total 118. A number of more specialised translations were also prepared – generally partial translations for specific aspects of research work in progress. Copies of these are held in the information files. The library is a participating member of the Commonwealth Translations Exchange Scheme, and an extensive list of translations available to members of this scheme was given in the Library Quarterly of July, 1960. The list will be added to by circulating in subsequent Quarterlies lists of translations of special interest, prepared by other members of the scheme.

PHOTOGRAPHY

By I. A. ANDERSON

Photographic Collection

The total number of photographs in the official collection is now 24,757. Great use continues to be made of the collection, but the number of slides loaned for lecture purposes, 12,765, shows a slight drop from the 1959–60 figure of 13,421. Under present conditions this was to be expected, since, although the number of new slides added to the collection compared favourably with previous years, out-dated material is not being replaced quickly enough.

1,184 prints were produced for exhibition or for sale, and a further 1,015 were loaned for various purposes.

Films

A film on the Pine looper moth was completed and has been well received. Film distribution has again increased, 230 films being loaned during the year, but there is a clear demand for more films on forestry subjects.

General

The Photographic Section is now responsible for controlling the work done by the Illustrator, and is thus able to co-ordinate all illustrative work.

PART II

Research Undertaken for the Forestry Commission, or With Its Assistance, by Workers at Universities or Other Institutions

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RESEARCH ON SCOTTISH FOREST SOILS

By W. O. BINNS

Macaulay Institute for Soil Research, Aberdeen

Fertiliser Trials on Sand Dunes

Trials of inorganic fertilisers at Culbin Forest, Morayshire, have been in progress since 1954. On the high dunes, 5 cwt ammonium sulphate per acre increased the height growth of young Corsican pine by about 30 per cent for three years only, and 2 cwt ground mineral phosphate has increased it by 10 per cent for four years so far, whereas 2½ cwt potassium chloride increased it significantly only in the fourth year after application. Magnesium sulphate at 2½ cwt per acre had no direct effects.

Trials of inorganic fertilisers have been started on one of the areas of eroded dunes in the North East of the forest, where growth of Corsican pine is poor.

Fertiliser Trials on Deep Peat

Results of trials on Lodgepole pine and Sitka spruce at the Lon Mor, Inchnacardoch Forest, confirm the need of both species for additional potassium on this site. Foliage analyses of Sitka spruce planted in 1929, and of Lodgepole pine planted in 1946, both of which were treated with 2½ cwt potassium chloride per acre in 1957, show that foliage potassium levels in the treated plots reached a maximum in 1959, and fell slightly in 1960. Girth increment of the spruce, and height increment of the pine both continue to be significantly greater in the treated plots.

Foliage analysis of Lodgepole pine planted in 1929, to which potassium chloride was applied in April 1960, shows that uptake of potassium has been slight in the first year, and that levels are still low in all plots.

In a nitrogen-potassium trial laid down in April 1960 on 14-year-old checked Sitka spruce, both rates of nitrogen have raised foliage nitrogen contents to a satisfactory level, and restored foliage colour. The uptake of potassium has been appreciable, but foliage levels are still rather low.

Foliage analysis of Japanese larch and of Sitka spruce, planted in 1939, from a nitrogen-phosphorus-potassium fertiliser trial, to which, repeat dressings were applied in 1960, has shown the different requirements of these two species for nitrogen. Foliage nitrogen contents of the larch are satisfactory without added nitrogen, while for the spruce extra nitrogen is essential. In the absence of repeat dressings of these nutrients, both species have low phosphate and potash levels.

The fertiliser trials at the Lon Mor in recent years have shown that all species need added phosphorus and potassium. Sitka spruce usually needs extra nitrogen as well if it is to close canopy, and even then its further growth is still problematical.

Tree Growth and the Chemical Composition of Deep Peat

Analyses of the top foot of the peat from nine sites, ranging from Spadeadam Forest in Cumberland to Strathy Forest in Sutherland, have been completed. There seems to be no fundamental difference between the chemical composition of peat from raised bogs and that from blanket bogs. The total potassium content of the peat at the Lon Mor is as high as, or higher than, that found at seven of the sites examined, while the total phosphorus content there is about halfway between the highest and lowest levels encountered.

The peat in part of Rumster Forest, Caithness, where Sitka spruce has shown remarkable early growth amid luxuriant heather, *Calluna vulgaris*, has very high ash and total nitrogen content; the natural vegetation gave no indication that this was a potentially fertile site, due presumably to an over-riding phosphorus deficiency.

Further analysis of samples, from good *Molinia caerulea* grass peat and from the poorest raised bogs, will be necessary before it can be decided how useful peat analysis will be for forecasting fertiliser requirements.

Nitrogen Mineralisation in Deep Peat

The work at Wauchope Forest in Roxburghshire (*Research Report*, 1959) is being followed up at Glentrool Forest, Kirkcudbrightshire, by Dr. J. Keay, who joined the Macaulay Institute staff in July 1960. In the first experiment, the effect of fresh deep and shallow ploughing on nitrogen mineralisation and tree growth is being examined. As yet very little accumulation of mineral nitrogen has been detected, but ammonium ions added as ammonium sulphate to the interface of ridge and peat surfaces rapidly disappeared under the deep ridges, but persisted for several months under the shallow ridges. Since moisture contents of peat samples from both ridge types did not differ significantly, it is thought that a chemical reaction is involved. It is possible, however, that this reaction is irrelevant to the mineral nitrogen content of each type of ridge later on.

Under the conditions at Glentrool it seems that, even if nitrogen mineralisation occurs, there are processes removing mineral nitrogen just as rapidly, probably by chemical action rather than by leaching or microbiological agencies. It is expected that as the peat dries, the balance will turn towards the accumulation of ammonium ions.

Sand Culture Experiments

Introductory experiments on the sand culture of Sitka spruce and Lodgepole pine have been started with a view to studying mineral nutrition of these species. It is hoped to extend the work to study the distribution of nutrients throughout the tree, under conditions of suboptimal supply.

NUTRITION EXPERIMENTS IN FOREST NURSERIES

By B. BENZIAN
Rothamsted Experimental Station

Long-term Rotation Experiments

In 1951, two long-term rotation experiments of about 350 plots each, cropped with Sitka spruce seedlings or transplants, were laid down in nurseries at Wareham, Dorset, and Kennington, near Oxford. (Their design and lay-out is described in *Rep. For Res. For. Comm.*, **53**, pp. 84–100.) The experiments compare, on the one hand, continuous conifer cropping with, on the other hand, a rotation in which one conifer crop in three is replaced either by bare fallow or else by a 'green crop' (rye, ryegrass or yellow lupins); they also compare annual applications of compost made from bracken and hop-waste with a mixture of "Nitro-chalk", superphosphate, potassium chloride, and magnesium sulphate. Over eight seasons, there has been no advantage, at either centre, from interrupting continuous cropping with conifers by any of the three green crops, but at Kennington bare fallow improved growth. At both centres, fertiliser-grown seedlings have been 20 to 30 per cent larger than those having compost.

In a supplementary experiment on continuously-cropped seedbeds, compost and fertiliser each increased seedling height; at Wareham the unmanured crop failed completely. At *Kennington* compost and fertiliser applied together were no better than fertiliser applied alone, but at *Wareham* the two manures applied together produced larger plants than either material applied alone. This result might indicate that compost had other functions besides supplying nutrients, but there is no present evidence that this is so. The fertiliser-grown plants suffered from copper deficiency (*Nature*, Lond. (1956), **178**, 864), and in several seasons also showed potassium-deficiency symptoms. During wet seasons compost plots, as well as fertiliser-treated plots, pass through periods of nitrogen deficiency, and these periods are rarely coincident on the two kinds of plots. Therefore plants grown with compost plus fertiliser have received a steadier supply of nitrogen, and have been less subject to either potassium or copper shortages. The experiments are being modified to eliminate, as far as possible, differences that may come from lack of nutrients in the fertiliser.

The Problem of 'Worn-out' Nurseries

In some of the Forestry Commission's nurseries (mostly those started on farming land between 1920 and 1940) some conifers, such as Sitka spruce, Western hemlock and Lodgepole pine, remain small and stunted, even with ample plant nutrients applied either as compost or fertiliser. This stunted growth normally occurs on soils with high pH, but there are exceptions, such as failures on acid soil at Ringwood. In several nurseries stunting is associated with root damage caused by fungi and, at Ringwood, with root-parasitic nematodes as well. Root damage of either kind is greatly decreased by 'partial soil sterilants' such as formalin and chloropicrin; but these materials are also of benefit where no effects from pests and pathogens have yet been recognised. Improvements have even been observed in highly productive nurseries like Wareham, where growth seems normal.

It is difficult to isolate the factor or factors responsible for stunting, and for the dramatic improvement in growth with 'partial sterilisation' of the soil; members of several departments at Rothamsted are working together on the problem. Materials like steam, formalin and chloropicrin not only profoundly change the soil flora and fauna, but chemical changes in the soil may alter nutritional conditions, such as producing and maintaining a higher concentration of ammonia. 'Partial sterilants' and acidifying agents both tend to increase the amount of manganese in seedlings, and the untreated plants may well suffer from manganese and/or iron deficiency. Manganese, as well as iron, chelates have been tested as foliar sprays, but so far without success in the nurseries, and only very slight benefit from manganese chelate in pots.

As stunting is confined to older nurseries, it is important to discover whether, with modern manuring, cultivation and weed control, nurseries can remain fertile indefinitely. The two long-term rotation experiments mentioned above will indicate problems that may come from intensive conifer cropping. Although during the first eight seasons there were no signs of deterioration in growth resembling the troubles encountered in 'worn-out' nurseries, size (1959) and plant number (1960) were much decreased on many compost-treated plots in Kennington. In 1959 the Wareham plots suffered from an attack of *Fusarium* wilt, which was much more severe with compost than with fertiliser. The future will show if these failures are isolated occurrences or if they are the first indications of a gradual deterioration.

Test on Soil Diluents

Most recent work on partial sterilisation has been done at Ringwood and Old Kennington Nurseries; at both, but particularly Ringwood, poor soil structure is likely to have contributed to stunted growth. Close packing may interfere with supplies of water and air, as well as with drainage, and may obstruct growing roots and so favour attacks by parasites. To open up the soil, two materials were incorporated into the top six inches a few weeks before sowing: 12 lb./sq. yd. of coarse-grade sedge peat, and 100 lb./sq. yd. of quartz grit from St. Austell, Cornwall. At Old Kennington the diluents were tested together with formalin; at Ringwood bad weather made this impossible. In the Old Kennington experiment, peat applied alone increased height by 40 per cent, and formalin applied alone by 70 per cent. With formalin, peat improved growth only slightly; and with peat, the response to formalin was lessened. Bad physical conditions may have aggravated attacks by pathogens. However, in the very wet 1960 season part of the benefit from peat may have been from a slow release of nitrogen. At Kennington, there was no response to St. Austell grit. At Ringwood, peat improved growth, but, in contrast to Kennington, the nutritionally inert quartz grit gave a slight benefit.

Note: This article has previously appeared in the *Annual Report of the Rothamsted Experimental Station*, 1960.

PROTEIN-FIXING CONSTITUENTS OF PLANTS

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

Dyson Perrins Laboratory, Oxford University

Introduction

The 1960 *Report* described attempts to isolate the condensed tannin present in heather, *Calluna vulgaris*, from an aqueous or aqueous acetone extract of shoots of the plant by:

(a) adsorption on hide powder,
(b) column chromatography on Perlon powder or cellulose.

Further attempts to isolate the tannin from an aqueous acetone extract by salting-out, followed by solvent extraction or precipitation with ether, have led to successful methods of isolation. Quercetin has also been isolated from the extract.

Isolation of Tannin

(a) Solvent Extraction

An aqueous acetone extract of *Calluna vulgaris* was saturated with sodium chloride and extracted continuously with ethyl acetate in a liquid-extractor. The ethyl acetate extract was concentrated to a volume of about one-tenth and poured into excess of ether. A cream-coloured flocculent precipitate formed which was separated by centrifugation. The average yield of this product from dried *Calluna* shoots was 0·2 per cent.

The product was examined by two-way paper chromatography and was detected on paper by a number of reagents giving colours with phenols. It had R_F = 0·0 in n-butanol/acetic acid/water (4:1:5 v/v; upper phase) and ran as a streak R_F = 0·0–0·6 in 2 per cent aqueous acetic acid. It could be completely precipitated from aqueous solution by the addition of 1 per cent aqueous gelatine, and behaved identically with the streak material (*Rep. For. Res.*, 1959 p. 104) present in crude *Calluna* extracts.

(b) Precipitation with Ether

Aqueous acetone *Calluna* extract was saturated with sodium chloride and allowed to stand. The mixture separated into two layers. The upper layer was removed, diluted with twice its volume of ethanol, and treated with excess of ether. A cream precipitate formed which was separated by centrifugation. The product contained sodium chloride.

Sodium chloride was removed by treating the above product with freshly distilled dimethylformamide. The insoluble sodium chloride was removed by centrifugation and the clear supernatant liquid treated with an equal volume of acetone followed by excess of ether. A pale brown solid was precipitated which was separated by centrifugation. The product gave a negative silver nitrate test, but contained a small amount of inorganic residue.

Found, C, 49·59; H, 5·00; residue, 0·95 per cent
C, 49·34; H, 5·00; residue, 1·50 per cent

The properties of this material agreed with those of the product obtained in (a) above in that it is precipitated with gelatine and adsorbed by hide powder. The two specimens both gave cyanidin chloride on hydrolysis with boiling methanolic hydrogen chloride. Alkali fusion gave phloroglucinol and protocatechuic acid.

Methylation of the tannin was difficult. The use of diazomethane in methanol/ether or of dimethyl sulphate/potassium carbonate in acetone yielded a product which gave a positive ferric chloride test. The use of dimethyl sulphate in cold aqueous alcoholic potassium hydroxide under nitrogen yielded a product which gave a negative test with ferric chloride/potassium ferricyanide. The methoxyl analysis of this product varied between 15·1 per cent and 17·9 per cent. The infrared spectrum showed the presence of hydroxyl groups.

Acetylation of the tannin with acetic anhydride in pyridine in the cold gave a product which showed no hydroxyl band in the infrared spectrum. The acetyl content was determined in two ways:

(i) by saponification: found, Ac, 33·0 per cent
(ii) by oxidation (Kuhn-Roth): found, Ac, 45·5 per cent

The acid hydrolysis and alkali fusion experiments indicate that the tannin is based on a flavonoid type of structure with the cyanidin hydroxylation pattern. However, the observed methoxyl and acetyl contents of the methylated and acetylated tannin are not consistent with the tannin being a simple polymerised 3′:4′:5:7 tetrahydroxy-flavan 3:4 diol (leucocyanidin).

$C_{15}H_{10}O_3(OCH_3)_4$ requires $4OCH_3$, 34·3 per cent
$C_{15}H_{10}O(OAc)_6$ requires 6Ac, 46·2 per cent

The discrepancy between the two methods of acetyl determination indicates that there are C-methyl groups in the acetylated tannin other than those present as acetate radicals. The low observed methoxyl content indicates that the tannin contains equal numbers of a leucocyanidin unit and a non-phenolic unit of approximately equal molecular weight. No evidence concerning the nature of this other fragment has been obtained.

Non-Tannin Constituents Present in Calluna Extract

Quercetin has been isolated from aqueous acetone *Calluna* extract (Perkin and Newbury, 1899) and identified by comparison of the pigment obtained from *Calluna vulgaris* with authentic quercetin. The two materials were identical in chromatographic behaviour, melting point and ultra-violet spectra. There was no depression of melting point on admixture. The acetates of *Calluna* pigment and of quercetin were identical in melting point, infrared, and ultra-violet spectra. There was no depression of melting point on admixture and the acetate of *Calluna* pigment gave good analytical results.

REFERENCE

PERKIN and NEWBURY, 1899. *J. Chem. Soc.*, 75, p. 837.

BIOLOGY OF FOREST SOILS

By G. W. HEATH
Rothamsted Experimental Station

The studies in rate of change in weight of decomposing leaves described in last year's *Report* were continued. Leaf discs were punched out of the lamina of labelled leaves at fortnightly intervals, and no loss in weight per unit area of lamina had occurred 12 months after leaf fall. Sampling was continued until October 1960, by which time all material was exhausted. It was concluded that under the conditions of the two sites used in this experiment, the lamina of fallen leaves underwent no decomposition or decay measurable as a loss in weight. Portions of the labelled leaves did disappear from time to time so that the whole leaves would show a loss in weight, but this experiment was specifically designed to follow changes in weight per unit area of lamina. It is emphasised, however, that no attempt was made to ensure that the marked leaves were kept in any particular strata of the litter layer, but nevertheless they appeared to be on the surface for the greater part of the time. The suggestion from last year's experiment was that fragmentation or skeletonisation of leaves is an extremely important and perhaps initial stage in the process of decomposition, and this year's experiments are particularly concerned with the elucidation of this point.

During the period of leaf-fall in 1960, leaf discs of oak and beech, one inch in diameter, were placed in the litter layer of an oak-dominant mixed woodland, and also in a young pure beech woodland. Discs were placed at roughly three levels during the period of leaf-fall, i.e. at the bottom of the litter layer, in the middle and on top. Since October, samples of the discs have been collected at weekly intervals, and it is intended to continue this sampling until leaf-fall, 1961. So far it has appeared that not only do those leaf discs at the bottom of the litter disappear more quickly, but they become more fragmented and skeletonised than do those in the middle and these latter are more fragmented than those on top. Oak discs disappear and are fragmented more quickly than beech discs, but this may be due to the different ages of the two woodlands. The most important agents of fragmentation appear to be earthworms and larvae of the Tipulidae, although other Dipterous larvae occur in quite large numbers in the oak litter. In both sites the earthworm populations are mainly composed of *Lumbricus rubellus* Hoff. and *L. terrestris* L. with a few specimens of *Allolobophora terrestris* f. *longa* Sav. and *A. caliginosa* Sav.

Methods of analysis for total carbon and hydrolysable carbohydrates have been investigated, and these quantities, in addition to the loss in weight, are being determined on the leaf disc samples.

Where leaf discs have been placed at the bottom of the litter, and in contact with the soil, half the oak discs have disappeared within the first six months of the experiment, but less than a quarter of the beech discs have disappeared.

In both experimental sites, leaf traps to estimate the size and composition of the litter were put out at the time of leaf-fall. Table 9 gives the results; in the mixed woodland the litter was divided up according to the component species.

Table 9

Results of Litter Trapping

(Dry matter weight in grams/4 sq. feet)

	Trap 1	Trap 2	Trap 3	Trap 4	Trap 5	Trap 6	Mean (wt/4 sq. ft.)
Mixed Woodland							
Oak leaves . . .	105·8	112·3	86·8	91·4	106·8	92·8	99·3
Hawthorn leaves .	4·8	11·8	6·6	22·5	14·7	11·2	11·9
Ash leaves . . .	1·2	10·2	1·7	7·2	9·7	5·0	5·8
Birch leaves. . .	3·6	10·9	2·6	6·0	11·3	17·6	8·7
Twigs, all sorts. .	17·1	17·8	17·7	20·7	38·1	8·0	19·9
Acorns, seeds, etc. .	0·1	1·1	1·7	0·9	0·6	6·1	1·8
Beech Plantation							
Beech leaves . .	116·4	98·6	90·1	116·2	110·5	107·7	106·6

The electrolytic respirometer mentioned in the 1960 *Report* has now been adapted and connected to a 'Cambridge' recording milliameter. It is proving suitable for measuring the respiration rates of soil animals such as millipedes and Isopods. Small cores of soil, with a volume of about 15 ml., can be accommodated in the respirometer, and their rate of respiration measured. With such small samples, however, a good deal of variation occurs. It seems that a better system would be to have soil samples of about 1 litre in volume, and by means of atmosphere transference to monitor either the oxygen or the carbon dioxide concentration. Such a system has been investigated and it appears that when carbon dioxide concentration increases to a high level, some soil animals are better able to withstand these conditions than are others, for instance Orabatid mites survive longer than Enchytraid worms or earthworms. This may be because Enchytraid worms live in a water film whilst mites do not, and that at high CO_2 concentrations the proportion of oxygen to carbon dioxide in the soil water is much smaller than it is in the soil air.

SOIL FAUNA RESEARCH

By D. R. GIFFORD

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The comparison at Ae Forest of the mite fauna of *Molinia* grass moorland with that of a Sitka spruce plantation on a similar site was completed during the year. It has been evident during the sampling programme that the bulk of the mites are found in the uppermost horizons of the litter and humus, and although three samples, each 1½ inches deep, were taken at each site, the third contained a very few mites, and can be ignored in assessing the mite population.

It has also been evident during the sampling programme that the fauna of the Sitka spruce litter bears, in the area investigated, a strong resemblance to the fauna of the upper *Molinia* litter, and must be derived from it. However, one major difference is the reduction in the population of Trombidiform mites in the coniferous litter.

In order to assess the relationship of the Sitka litter fauna to faunas developed in natural woodland, and those developed under very old plantation conditions, some sampling was done during 1960–61 in three other sites: in deciduous oak-hazel-alder woodland at rather lower elevation (650 feet) at Ae Forest, Dumfries-shire; in a Scots pine plantation at Rachan, near Broughton, Peebles-shire, 180 years in age; and at the Black Wood, Rannoch, an area of aged natural Scots pine-birch woodland in western Perthshire.

It is unfortunate that these supporting investigations were in rather diverse conditions, but the results obtained at once confirmed that a number of features in the species composition were common to all the well-developed faunas of these old or natural woodlands. Although the steep slope topography and mull soil of the deciduous woodland at Ae gave entirely different pedological conditions to any of the other sites (all podsols of various kinds on soils of glacial origin), there were considerable resemblances between its mite fauna and that of the Rachan Wood, and also to that of the Black Wood. The Sitka spruce litter was, on the other hand, much poorer in species than any of the other sites. An interesting confirmation of this was obtained in sampling a small area of Sitka spruce by a quarry on steeply sloping ground, near the area originally investigated at Ae, where there are indications that some birch woodland was present before tree-planting was done (about 1930). Here the soil is a shallow podsol, with only 3 inches of peat, and a highly localised fauna strongly resembling that of Rachan Wood was found, with a number of species of Belbids only otherwise collected at Rachan, but in addition one or two *Oribatid* species which were found in none of the other sites. This fauna does not seem to have spread into the surrounding plantations, in which conditions differ to some extent in the compaction of the current litter profile, since on the aberrant site the *Calluna*-Mosses vegetation was hummocky, and now rather deep litter of the spruce is suspended on spongy masses of persistent remains of the former vegetation.

On none of these sites was sampling done on the detailed quantitative basis of the two principal sites at Ae.

While it is not difficult to characterise the faunas of these sites, and, with persistence, to map the distribution of particular faunas, it is much more difficult to obtain useful information on the reasons for the distribution of many of the species. Studies on food preference and habitat requirements, and on the position of the various species in the complex of litter destruction, are essential for an understanding of the mites' ecology. The current investigation aims at helping to elucidate the role of mites in the breakdown of forest litter, and thus in the development of soil profile and circulation of nutrients, but until a start is made in working out the relationship between the Acarina, the other groups of animals present, and the lesser plants and bacteria, little will be achieved. Due to the immaturity of the litter profile at Ae Forest, this site is no longer considered suitable for working on these relationships, and work has been transferred to the Black Wood, Rannoch, on to a number of knolls which appear to have supported pure Scots pine for many centuries; preliminary faunistic studies are already available as part of the Ae investigation, and work is now directed at determining the stratification of the mite population. This is being combined with a preliminary sampling of the other animals present in the organic horizons, and it is hoped to begin work on the fungi towards the end of the season.

A detailed account of the work of the past four years at Ae Forest is in course of preparation, and this will present a discussion of the development of the fauna in young plantations.

STUDIES IN SOIL MYCOLOGY, V: MYCOSTASIS IN SOILS

By C. G. DOBBS and D. A. GRIFFITHS

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Conclusion of the Germination Assay

The monthly germination tests on 12 forest soils, with estimations of the contents of reducing sugars, were continued until July 1960. Figure 2 shows the results from March 1960, continuing Figure 3, p. 88, in the *Report on Forest Research*, 1960. It will be noticed that the germination levels during April, May and June, 1960, had returned almost to zero for the first time since the summer of 1957; also that in May 1960, as in May and September 1959, a slight rise in 'sugar' content was not associated with a similar rise in the germination curve.

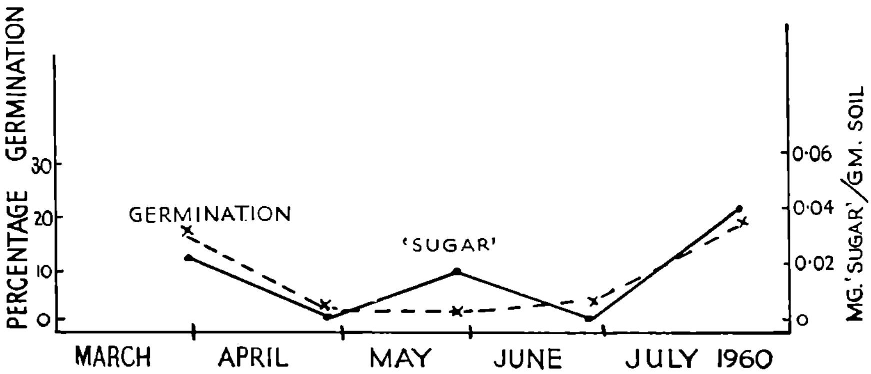

FIG. 2.—Percentage germination (broken line) in relation to sugar concentration (full line). This continues Fig. 3, p. 88, in the *Report on Forest Research for* 1960.

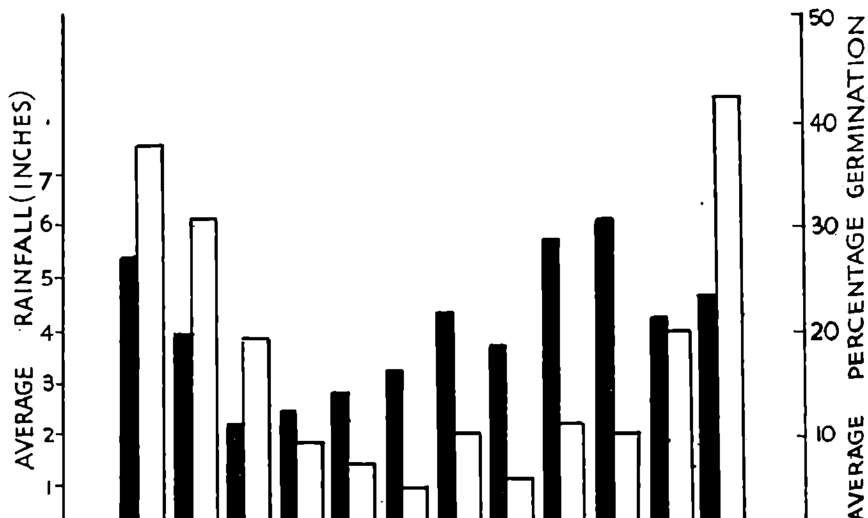

FIG. 3.—Average percentage germination for the months of the years 1957–60 covered by the assay, with average monthly rainfall in inches (solid black columns).

Figure 3 shows the germination averages for all soils for the months of the year, based upon the whole assay – a continuous monthly record from November 1957 to July 1960, with some less regular records from March 1957, making 438 separate assays in all. In general, the germination level has not shown any convincing relationship with the weather records, apart from the broad inverse relationship with the seasonal temperature; but the average monthly rainfall (also shown in text Figure 3) shows some correspondence during two periods of the year: January to March, and July to September. The first is likely to be coincidental, since moisture is rarely limiting in the soil at that time of year, but experience suggests that the second may indicate some causal connection, especially the slight rise in July. It is at this time of year that a condition of soil-dryness, which often develops during the earlier part of the summer, is liable to be broken by rainfall. In this connection the observations of Miss M. G. Hay (now Mrs. D. J. Anderson) while demonstrator in mycology at Bangor (1958–60) are of interest. Using a method of making cellulose acetate 'pulls' of soil and litter surfaces, she succeeded in demonstrating germination of fungal spores in the litter layers on several occasions after rain. This was most marked in September 1959, two days after the long drought of that year broke.

Differences Between Sites, Species and Soil-layers

A partial analysis of the germination data, for which thanks are due to the Statistics Section at Alice Holt Research Station, showed certain differences to be significant at the 1 per cent level.

In each of the soil-layers, there was significantly more germination under the beech-oak mixture at Church Island than there was under the same species at the higher and more exposed site at Marian y Winllan. At Church Island, only the litter layer showed a significant difference between the tree species, with more germination under the beech-oak mixture than under the pine.

At both sites and under all the tree species, the litter layers consistently gave significantly higher germination levels than the humus or mineral layers, the difference being greater under the broadleaved trees than under the conifers. The differences between the humus and mineral layers were slighter and less consistent. On the Church Island site the mineral layers gave slightly higher, at Marian y Winllan lower, germination levels than the humus layers. Under the pine at Church Island the difference was not significant; but under the spruce at Marian y Winllan it was significant, and each layer gave about twice the germination of the layer below it.

Reducing-Sugars in the Soils

The monthly estimations of reducing material in the soils (*see* Figure 2) were discontinued at the same time as the germination assay. Further chromatograms (*see Report on Forest Research*, 1960 for methods) were run in December 1960 and revealed the presence of the same sugars, ribose, sorbose and galactose, in the fresh extract of pine humus soil, with the addition also of a spot for xylose, previously found only in the extract from autoclaved soils.

These sugars, when tested for their effect upon the spore germination of the fungus *Mucor ramannianus* in the presence of the inhibitor, gave unexpected results as compared with glucose. A strongly mycostatic garden soil which, when moistened with distilled water, gave zero germination on a test film, and 60 per cent germination with 0·1 per cent glucose solution, gave zero germination when moistened with 0·1 per cent solutions of ribose, sorbose, galactose and xylose. Mixtures of 0·1 per cent solutions of glucose with these 'soil-sugars' also gave zero or much reduced germination. Similar tests carried out with a strongly inhibitory sterile filtered extract of pine humus soil gave similar results. These 'soil-sugars' failed to produce the counter-inhibitory effect of glucose.

At present we do not know how widespread or how permanent is the presence of these particular sugars in forest soils, but the possibility that some of the soil-sugars may actually inhibit some fungal growth and germination, which is suggested by the reduced germination when they are mixed with glucose, needs investigation. This is at present difficult to relate to the broad correlation between germination level and content of reducing-material, although it might perhaps help to explain the fact that, whereas a high germination level (above 50 per cent) never occurred in the absence of 'reducing-sugars', in five isolated assays out of a total of 204, zero germination was associated with an appreciable 'reducing-sugar' content of the soil extract. There is also, of course, the possibility that some of these soil-sugars may inhibit the activity of the mycostatic organisms.

R. M. Jackson (1960), using the less sensitive agar disc method, with test spores of the fungus *Penicillium citrinum*, showed that, in general, monosaccharides have a greater counter-inhibitory effect than disaccharides, and these in turn greater than a trisaccharide (raffinose). Among the monosaccharides tested by him at the 0·1 per cent level, galactose and xylose, though slightly less effective than glucose, nevertheless stimulated germination and had no inhibitory effect. We suggest that the subject of the biological effect of sugars in the soil requires far more attention that it has received.

Attempts to Determine Nature of Inhibitor

Sterile extracts of soils, prepared under nitrogen by the method described in the *Report on Forest Research*, 1960, but using a Group 6 Membranfilter instead of four thicknesses of fine filter paper, have continued to show varying inhibitory effects upon spore germination. Much time continues to be spent in attempts to improve and standardise the spore germination test.

Active extracts, when exposed to the air, lose activity slightly, but variably, in 12 hours, completely after 24 hours. Activity was found to be reduced by 65 per cent after oxygen had been bubbled through the extract for five minutes, and to be lost completely after seven minutes. Although all the extracts tested were thermolabile, their temperature relations were not uniform. Some seemed to be affected by temperatures as low as 30°C, others not until heated to 60°C.

An attempt was made partially to fractionate the extract by shaking with organic solvents: successively with diethyl ether, petroleum ether, benzene, acetone, chloroform. In each case the water fraction was removed and tested against spores by the washed agar method, while the organic solvents were evaporated away under nitrogen gas, and the residues made up with water and tested against spores. In extracts from pine humus soil, activity was confined to the diethyl ether fraction, which produced, at the most, a reduction in germination of about 50 per cent.

The activity of water extracts which had been passed through washed activated neutral charcoal was completely removed, as also was the activity of both water and ether extracts passed through an alumina column.

Finally, an attempt was made to make some estimate of the molecule size by using a range of Membranfilters graded as to pore size, in place of the cellophane in the soil germination test. The inhibition, as judged by the reduction in spore germination on the soil-contact area, passed through all grades of the filters, the finest of which had a pore diameter of 5 $m\mu$.

Calcareous Soils

It has from the first seemed certain that mycostasis in soils is a complex phenomenon, and that a number of inhibitory substances are concerned in it. The behaviour of chalk and chalky soils (*see Report on Forest Research*, 1958) presents some problems distinct from those of the biologically produced inhibition which has been the main object of study. Some of the tests carried out in 1957 and 1958 have been repeated, and the results in general confirm that natural chalk subsoil, when tested with the cellophane spore-film, gives complete inhibition, even after the addition of glucose. In contrast to an earlier result, however, an autoclaved chalk gave 50 per cent germination. 'Analar' laboratory calcium carbonate, on the other hand, though completely inhibiting germination when moistened with distilled water, allowed 40 per cent germination with 0·1 per cent glucose solution. Various samples of calcareous marine sands from surface levels, and also from deeper levels, of the Newborough Warren dune system in Anglesey, continued to show complete inhibition even after chrome-washing, water-washing and autoclaving, although, on occasion, this sand has been found to be compacted together by basidiomycete mycelium.

The observations of R. M. Jackson (1958) on a range of permanent grass plots of differing pH, at Rothamsted, showed a direct relationship between soil pH and inhibition effects. Limed plots showed a greater inhibition than unlimed, and the most acid plots no significant difference from the controls over filter paper. This, however, was with *Penicillium citrinum* and with the agar disc method, which would detect only a fairly strong inhibition. The more sensitive cellophane film method has shown that some inhibition is generally present in acid forest soils, and, indeed, in all soils tested, except where the effect is masked by the presence of soil-sugars. For many fungi there is also some inhibition of growth and germination associated with high pH, but this does not fully account for the effects produced by calcareous soils, which require a separate study.

Fomes annosus

The work of Rishbeth (1950, 1951, 1959) has drawn attention to the relative virulence of the wood-rotting fungus *Fomes annosus* on chalky soils, and to the importance of its basidiospores as agents of dispersal and infection. The existence of a strong inhibitory effect of forest soils on the mycelial growth of *Fomes annosus* and other basidiomycetes has been recorded (*see Report on Forest Research*, 1958, Table 25), and the conidia of *Fomes* have also been tested and shown to be subject to soil mycostasis. Basidiospores, in general (including those of *Fomes*), owing to their less immediate and regular germination, had not hitherto been satisfactorily tested.

Mr. M. S. Johnson, while a Forestry Honours student at Bangor, completed a brief research project on this subject. Sporophores of *Fomes annosus* were collected from pine stumps both in Thetford Chase Forest, on a calcareous soil of pH 7·5, and the Church Island site, near Menai Bridge, Anglesey, on an acid soil, of pH about 4, which has long been used for mycostasis tests. Samples of the mineral soil, at six- to eight-inch depth, were also collected from both sites, and their effect upon the germination of the basidiospores from fruit bodies of both provenances was tested by the cellophane film method. The effect of both soils upon the mycelial growth of cultures derived from these spores was also tested by the agar disc method.

A strong inhibitory effect of both types of soil upon basidiospore germination was conclusively shown, and a similar effect upon mycelial growth was confirmed. The results were too variable, and the replications insufficient, to establish the existence of differences between the inhibitory effects of the soils or the behaviour of the strains of *Fomes*, but they were sufficient to suggest that the alkaline Thetford Chase soil tested may be more inhibitory to basidiospore germination, but less so to the mycelial growth of *Fomes*, than is the acid soil from Church Island.

Changes in Staff

Early in 1961 Dr. D. A. Griffiths left Bangor to take up a lectureship in mycology in the University of Malaya. The work on mycostasis has been taken over by Miss Nancy C. C. Carter, Ph.D.(Cantab.).

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HYDROLOGICAL RELATIONS OF FOREST STANDS

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

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Progress continues in the development of suitable techniques for investigating the various phases of the hydrological cycle in a pole stage plantation of Norway spruce in Bagley Wood, near Oxford. The assistance of Mr. A. E. Ogden, throughout the past year, is acknowledged.

Precipitation Over the Stand

For some months, daily records have been kept of the catch of 16 rain gauges of various types mounted above, and at, canopy level. Differences observed in the catches of these gauges were of the order of a few per cent, and could be largely attributed to the type of gauge used. Comparisons with the catch of gauges on nearby open ground, under standard Meteorological Office conditions, indicated that the 'above canopy' gauges fitted with 60° Nipher shields gave closest agreement; however, much depended on the length of the period on which the comparisons were based and, over short periods, the degree of the divergence in many cases suggested real differences in precipitation over the two areas. In an attempt to assess the absolute precipitation over the stand, the data for the 'above canopy' gauges are being analysed in terms of wind velocity and evaporation conditions to see how far their variable behaviour can be explained by these factors.

Interception and Throughfall

Earlier work has confirmed the superiority of large troughs over standard rain gauges as a means of estimating precipitation reaching the forest floor (throughfall). To facilitate the measurement of the large volumes of water collected by the troughs, these have been made self-recording, using tipping buckets fitted with micro-switches and 'Post Office' counters. The measurement of stemflow has been improved by the use of aluminium coach guttering mounted spirally around the stems.

Evaporation, Transpiration and Soil Moisture

Small lysimeters, filled with humus, have been installed to give an approximate measure of evaporation from the forest floor, and to improve their performance, they are to be fitted with tension plates so as to simulate natural drainage.

From preliminary experiments in the laboratory, a suitable technique has been devised to measure sap flow rates in tree stems, using a heat flow method, and results have confirmed the feasibility of this approach to the measurement of relative transpiration of whole trees. The necessary apparatus has been installed in the stand, and work is in progress in testing a technique for calibration in terms of absolute values. Automatic recording devices on a number of representative trees within the stand are being developed.

As a guide to soil moisture variations, tensiometers and nylon resistance units have been installed at various depths; by locating these instruments along the radius of the tree crown, it is intended to follow changes resulting from the uneven distribution of throughfall below the crown.

SHELTER RESEARCH

By R. BALTAXE

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Introduction

This is the last research report to be submitted for the current three-year period of this project, and it will be appropriate to consider briefly the general direction in which progress has been made.

The most interesting result which has so far emerged is a conclusion about what constitutes significant research on the fundamental aspects of shelter from wind. Broadly speaking, the approach to research on shelter does not seem to have changed since R. Geiger (1951) pointed out the proliferation of 'occasional' research of more or less local interest and the paucity of investigations systematically designed to elucidate the basic principles involved.

From an anlysis of the wind tunnel experiments referred to in the *Report on Forest Research*, 1960, and a critical review of the literature based upon their results, it has been concluded that in many cases the significant feature of air flow in relation to shelter will be the level of turbulence of the wind. It has been recognised by several workers, and demonstrated experimentally by Jensen (1954), that the scale of turbulence in the incident wind is important in determining the flow pattern of windbreaks. It is therefore to be expected that the wide range of turbulence encountered in nature will be reflected in a considerable variation of shelter effect. Therefore to obtain a specific effect, at some critical time for crop growth or soil blowing, a windbreak may have to be tailored to elicit this from the sort of wind which is then critical or dominant. This implies the need for a much more rigorous definition of situations in which it is proposed to apply shelter than has hitherto been considered necessary or worth while.

The available information on the potential effects of shelter, and how to obtain them, appeals to evidence either of a very general or local nature. It is generally admitted that there is as yet no guidance on how to set about obtaining a specific effect, especially in quantitative terms, under given conditions. Now that the significant feature of the air flow-windbreak-shelter effect complex can be stated, it will at least be possible to design investigations to provide this information.

Wind tunnel Experiments

The publication of these experiments is delayed for inclusion in a thesis, but their main features and implications may be briefly described here.

The experiments were concerned partly with observing the direction of flow, by means of a freely rotating vane (Burns, Childs, Nicol and Ross 1959), in the lee of a series of model windbreaks of different permeability. It was observed that when the permeability was high (50 per cent) the leeward flow was steady. The rate of flow at any point in the wake was then the same as the positive horizontal velocity. This can be measured with great accuracy with a pressure-tube anemometer.

When the permeability was reduced, the flow ceased to be steady and exhibited increasing fluctuation, with a concurrent reduction in the positive horizontal velocity component. The observation of these changes showed that they were quite systematic, with a series of models ranging from 50 per cent to 0 per cent permeability. The way in which the flow patterns changed was analogous to the device of delaying or preventing separation of the flow in the lee of bodies generating a turbulent wake, by injecting fast-flowing fluid at the boundary surface (Goldstein 1938 p. 530). This indicates how the flow patterns may be controlled. Their characteristics also indicate the status of the special case of windbreaks in the context of aerodynamics. In effect, the flow patterns they generate are subject to the principles governing the flow around any more or less bluff bodies and therefore principally a function of their form drag. This in turn is governed by their shape and, as has been demonstrated, very considerably by their permeability to the flow, and these two factors may be varied independently.

This conclusion makes it possible to interpret the results of the many investigations on the air flow behind windbreaks in terms of aerodynamics and so to assess their general applicability. It also enables a large amount of evidence, obtained without specific reference to windbreaks, to be drawn upon in predicting their effect on air flow. This constitutes a useful step towards the conclusion of the first phase of the systematic investigation of shelter suggested by Geiger (*Ibid.*), namely the elucidation of the relationship between windbreaks and air flow.

The second phase concerns the significance of the various features of the resultant flow for the factors of the micro-climate, i.e. their effect on the transport or diffusion of heat, moisture and soil particles.

In the wake of a model of low or moderate permeability (0 per cent to ca. 40 per cent), some of the flow was steady and its velocity low, as can be reliably measured with a pressure-tube anemometer. But over much of the wake the direction of flow fluctuated more or less intensely. From the known characteristics of pressure-tube anemometers, it can be inferred that in such flow their response will be virtually limited to the mean positive horizontal velocity component.

PLATE 1. Richards and Holtam: Utilisation Development: Bungalow constructed from Home-grown thinnings, erected at Alice Holt. The cladding timbers are Sitka spruce.

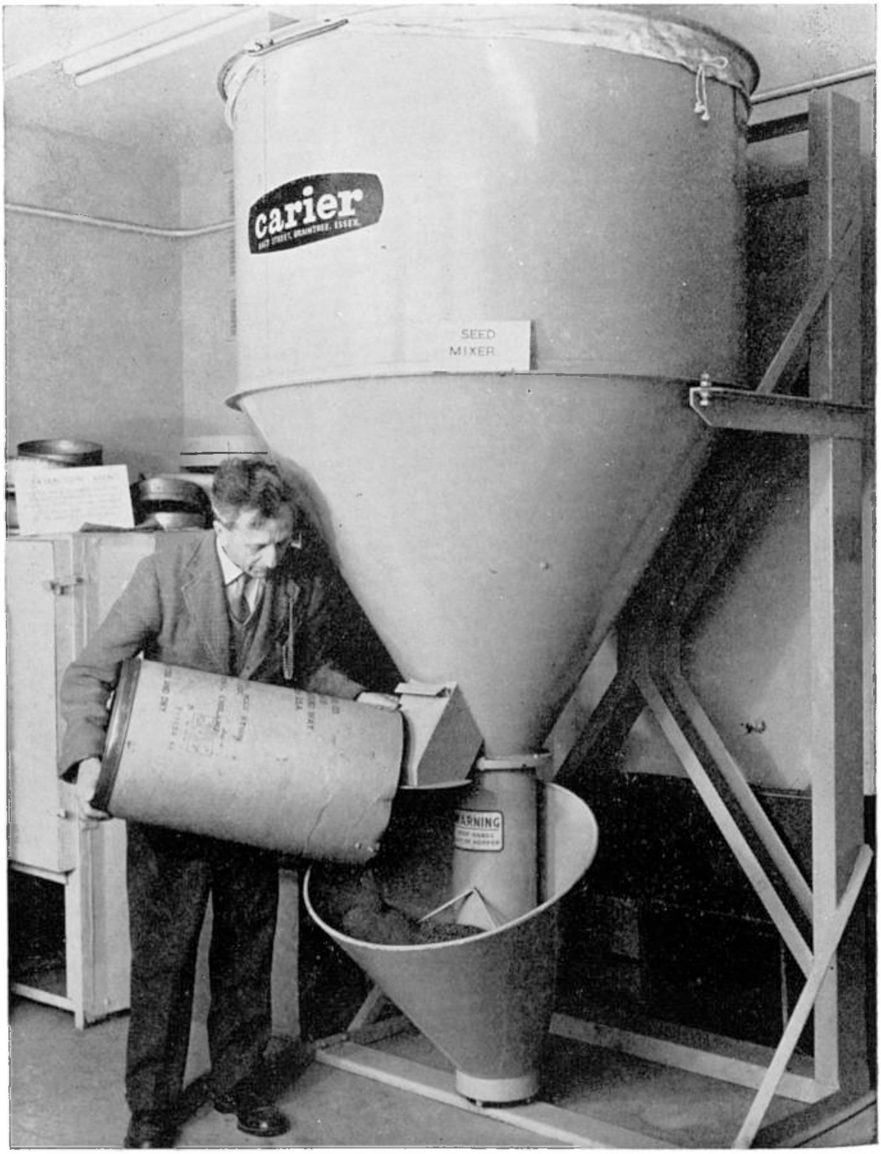

PLATE 2. Holmes and Buszewicz: Forest Tree Seed: Seed mixer, recently installed at Alice Holt.

PLATE 3. Matthews, Mitchell and Faulkner: Forest Genetics: Isolation of female flowers of larch with "Terylene" pollination bag.

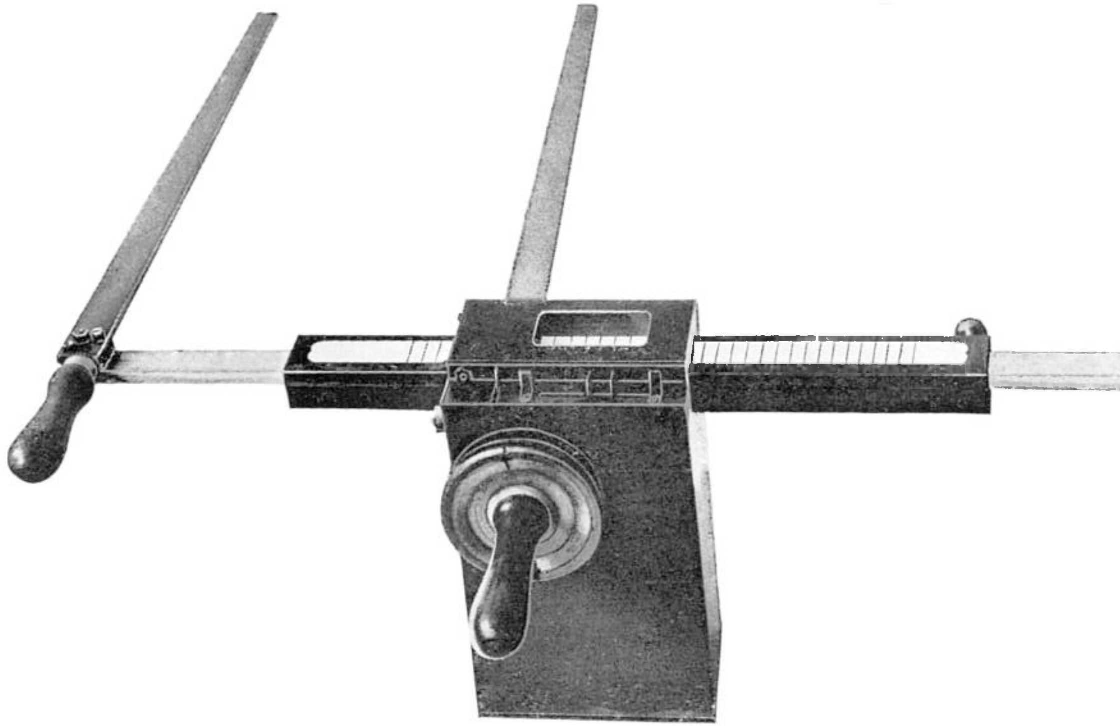

PLATE 4. Bradley, Christie and Mackenzie: Mensuration: General view of prototype caliper.

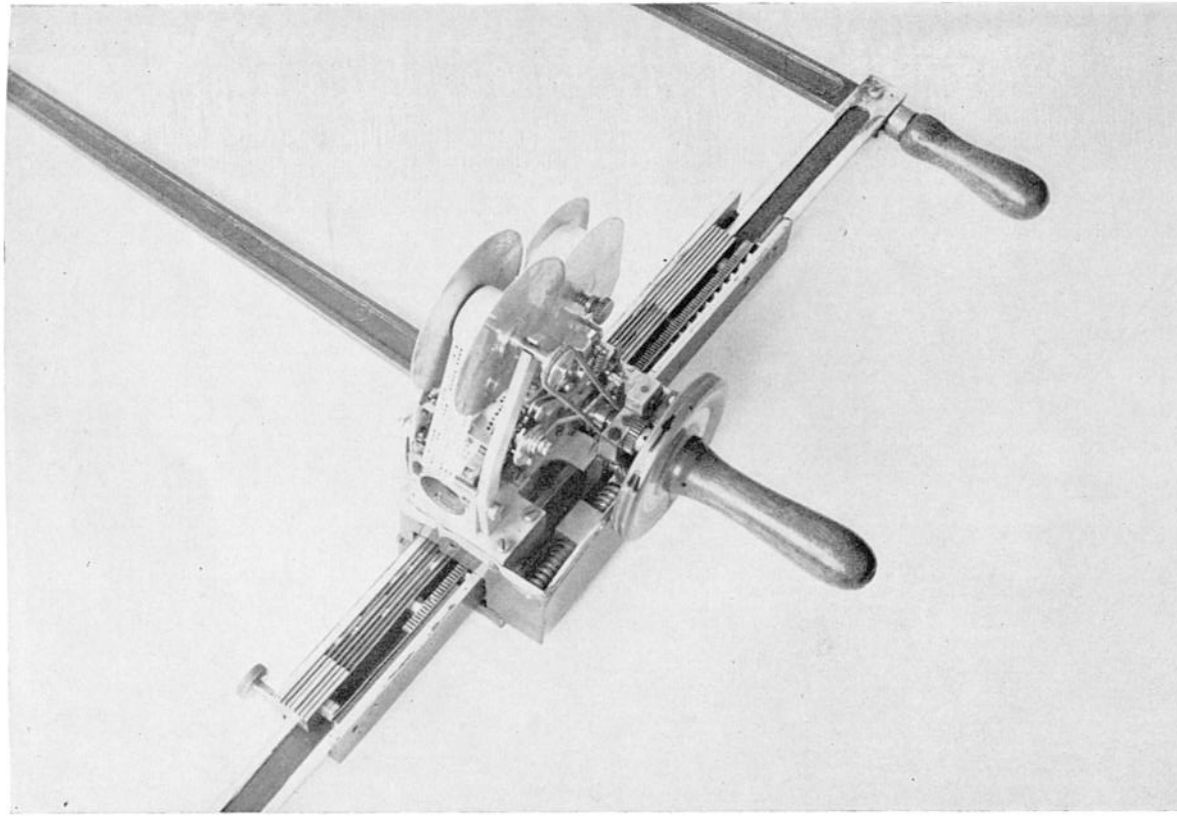

PLATE 5. Bradley, Christie and Mackenzie: Mensuration: Prototype caliper showing details of rack, carriage and punching apparatus.

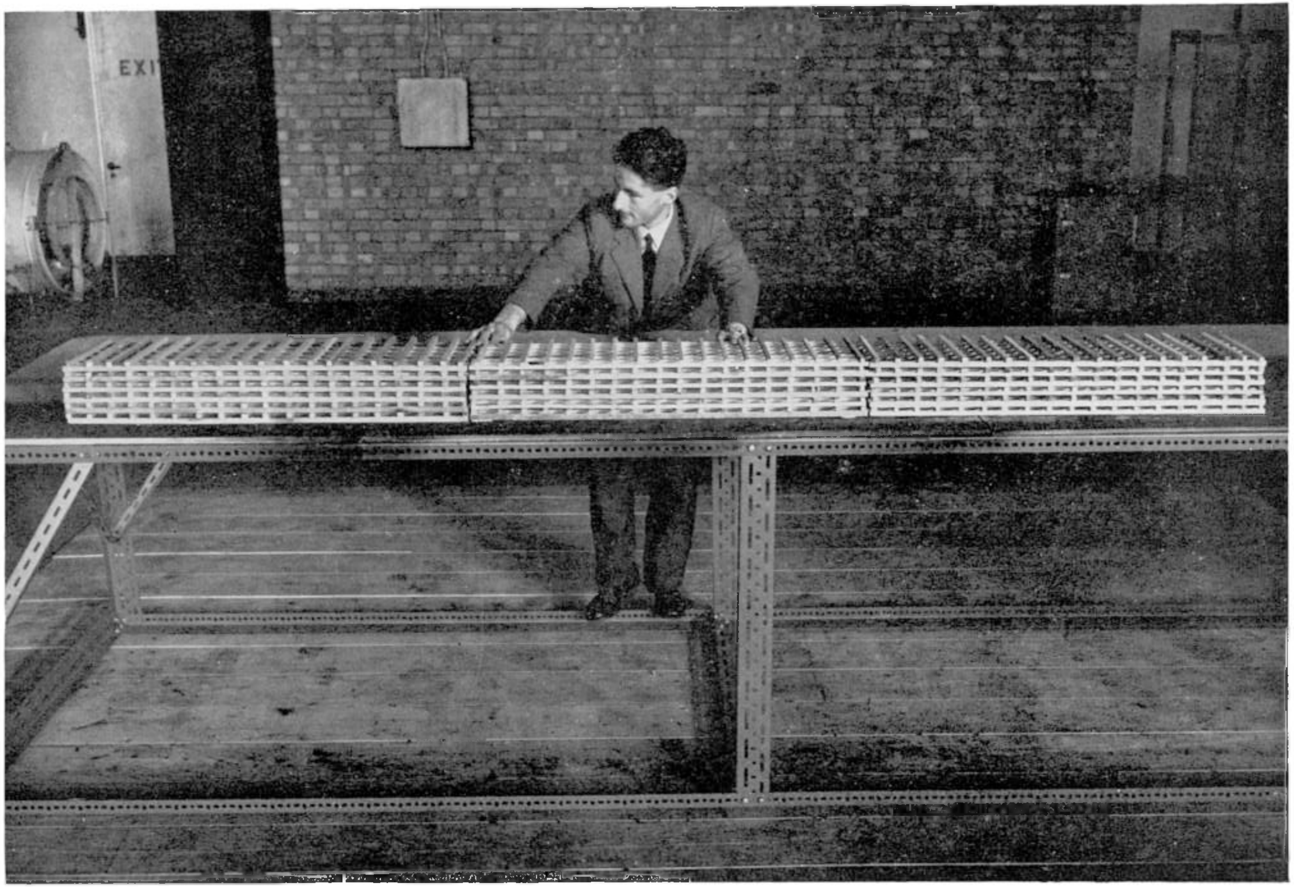

PLATE 6. Thomas and Pickard: Fire Spread: Ten-foot long wooden crib for studying spread of fire.

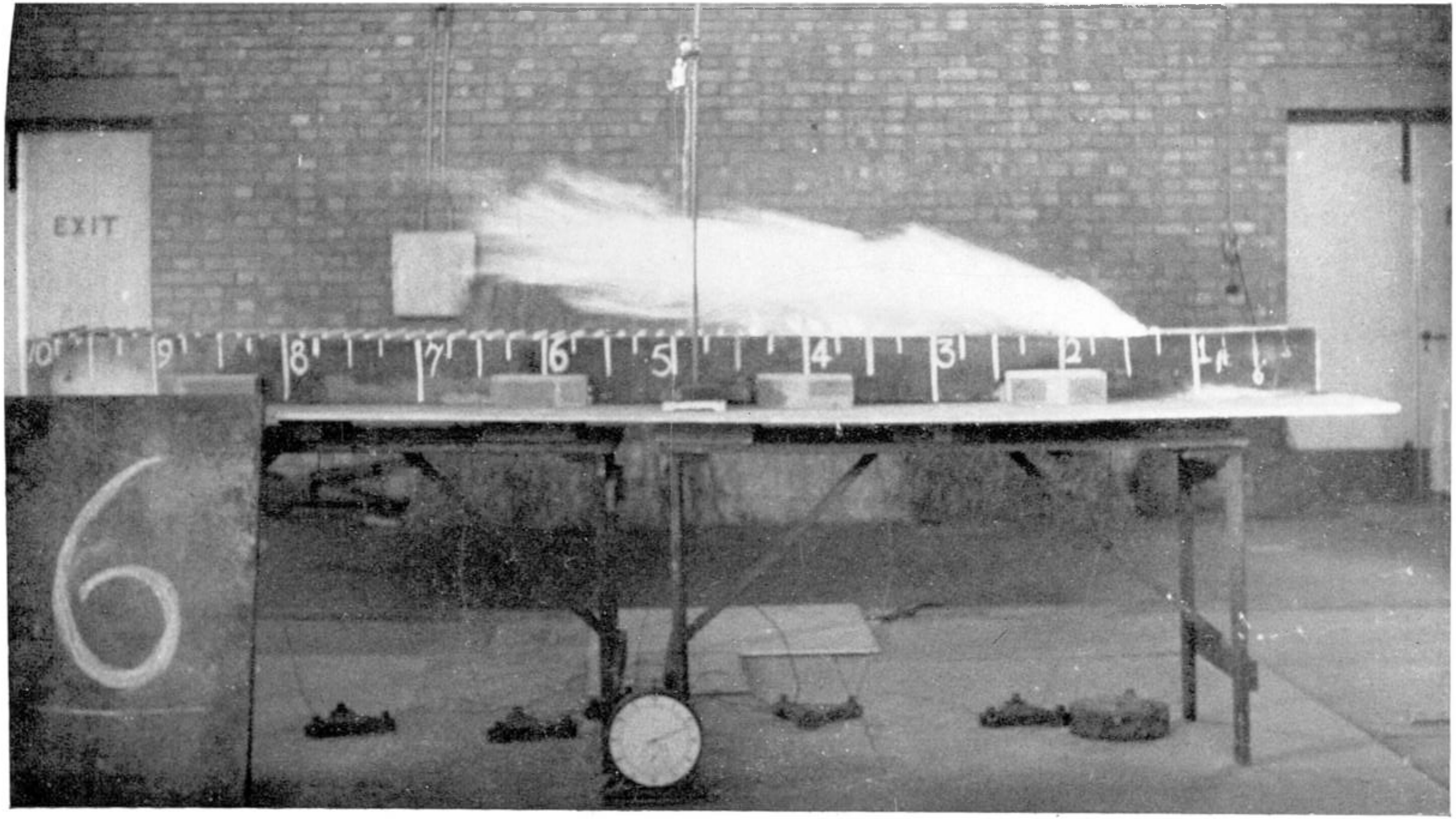

PLATE 7. Thomas and Pickard: Fire Spread: Spread of Fire in a wooden crib, with a six-miles-per-hour wind.

PLATE 8. Nimmo and Weatherell: Leguminous Nurses: *Wareham Forest. Experiment* 73, 1945. Douglas fir and broom with phosphate. Total of 5 cwt. of bonemeal per acre. Average height at 6 years, 6.2 feet. Very little return of heather in the broom plots.

PLATE 9. Nimmo and Weatherell: Leguminous Nurses: *Wareham Forest*. Experiment 73, 1945. Douglas fir with phosphate (bonemeal $2\frac{1}{2}$ cwts. per acre) but no broom. Average height at 6 years 4.1 feet. Note return of dense heather.

PLATE 10. Nimmo and Weatherell: Leguminous Nurses. *Allerston Forest: (Broxa Area). Experiment* 9, 1943. Sitka spruce grown with phosphate and broom plus Scots pine as a long term nurse. An example of lay-out pattern No. 4. Age 10 years. Basic slag 2.8 cwt. per acre.

PLATE 11. Nimmo and Weatherell: Leguminous Nurses: *Allerston Forest:* (*Broxa Area*). *Experiment* 9, 1943. Sitka spruce with phosphate but no nurse crop. Very much slower growth. Age 10 years. Basic slag 1.25 cwt. per acre.

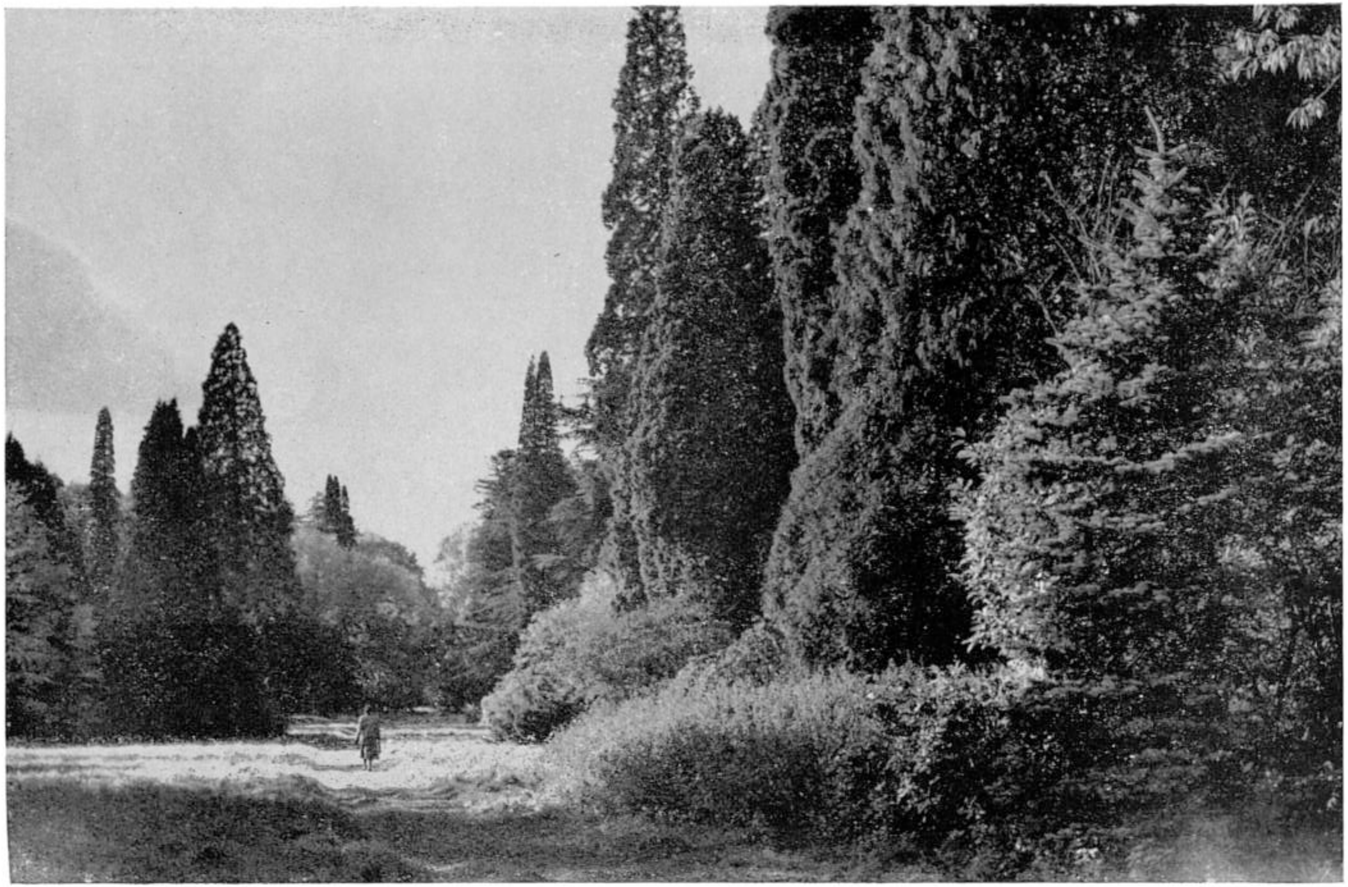

PLATE 12. Wood: Westonbirt Arboretum. A view down one of the rides at Westonbirt.

It was possible to confirm this by making velocity measurements with a pitot-static tube in flow whose direction was observed with the vane. In a vortex, for example, where the mean horizontal velocity is zero, the measured velocity was zero. When there was a strong negative horizontal velocity component in addition to other high-frequency fluctuations, a negative velocity was measured.

When shelter effect is being considered, such measurement of the mean horizontal velocity alone is largely irrelevant and may be seriously misleading. The transport and diffusion effected by the wind when it is highly turbulent will not be negative or zero. It will, on the contrary, be proportional to the sum of the mean fluctuations (or eddy velocities) of the different velocity components, and may considerably exceed the rate at which diffusion occurs in the absence of shelter. This was observed by Blenk (1953), for example, for the rate of evaporation in the lee of a dense windbreak model. Structures analogous to windbreaks, a mesh or perforated screen, are widely used in wind-tunnels to regulate the level of turbulence. Since the natural wind is always more or less turbulent, a shelterbelt can be regarded as a device for damping turbulence. It follows that an important feature of air flow which requires investigation in relation to shelter is its fluctuation, as well as the mean value of the horizontal velocity component. In most investigations attention has been focussed almost exclusively on the latter, mainly because of the inherent difficulty of measuring atmospheric turbulence, particularly with the instruments usually available for research into shelter.

Instrumentation

The only satisfactory method of measuring fluctuating flow is to use a hot wire anemometer designed for the purpose. This is an expensive and long-term undertaking which was impractical under the conditions of field work described below. However, in a series of experiments about to be carried out, an attempt to examine the relative magnitude of the fluctuations will be made.

For this purpose a bi-directional vane, responding to and recording the horizontal and vertical fluctuations of the wind, is being constructed. A non-directional evaporimeter is also being designed, to measure relative rates of evaporation. A comparison of the relative fluctuations and rate of evaporation, with the mean wind speed recorded by the usual cup-anemometers, will indicate the significance of the latter for potential shelter effect, in the same way as has been done for pitot-static tubes in the wind-tunnel.

A vane which gives a continuous record of wind direction has been constructed. Its purpose is to record variations in the direction of the incident wind over the course of a day, for which a movement of 180 degrees is quite sufficient. This limitation greatly simplified the design, in which only one pen is used. The vertical axis of the wind vane passes through the centre of a disc, which revolves with the axis. The disc is inclined to the horizontal, and is in contact with the end of a spring-loaded lever. At the other end of the lever is a pen, in contact with the recording paper, which revolves on a clockwork drum. Contact between the lever and the disc is maintained mainly by the weight of the pen and through a rotating bearing. As the wind vane moves, the rotation of the inclined disc forces the lever up or down and this movement is recorded by the pen. For the latter a ball-point refill has been found very satisfactory, and particularly suitable for a robust instrument which is moved about a great deal.

Field Work

The measurements on field shelterbelts are incomplete and it is too early to discuss them. Instead it is proposed to record briefly the practical difficulties encountered in making an intensive collection of data on farm shelterbelts scattered about the countryside, and a method which has been devised to overcome them.

The intensive collection of data was in fact never achieved, because conditions were rarely suitable for making measurements at all, let alone replicating them or extending them to each phase of seasonal variation in the belts. Wind studies could only be made when the weather and wind direction was suitable and, a more frequently limiting factor, when there was no interference with, or from, farming activities. When these conditions were met, the actual time available for measurement was limited by the necessity to erect and remove the equipment newly every day, as the sites were freely accessible to anyone. The time and facilities for the transport and erection of the equipment were further strained by the actual height of the shelterbelts, say 30 to 60 feet, which made the windfields to be investigated very large. It also virtually precluded measurements at any level greater than could conveniently be reached from the ground.

Although for two years equipment and techniques to cope with these conditions were evolved, so that progress with the collection of data was eventually being made, the method was finally abandoned. Its vulnerability to trivial accidents, such as an outbreak of foot and mouth disease, which stopped access to all farms; or damage to instruments by livestock, indicated that it might take years to collect adequate data. A more intensive method, better suited to the limited facilities available, has therefore been devised and is currently being implemented.

Investigations of air flow on shelterbelts in the field are a necessary complement to wind-tunnel experiments, because from the latter alone it is not possible to make adequate predictions about the effects of such factors as the varying level of atmospheric stability; the absence of a closed system of flow and variation in the free wind speed in relation to the form drag of flexible shelterbelts. These features may be preserved, while eliminating or controlling most of the variables and disadvantages described above, by using a single small-scale shelterbelt constructed of natural tree material and capable of being moved to suit any wind direction. Work is thus concentrated on one site, while rain or the absence of wind remain the only factors to hinder it.

Finding a suitable site not put to other use posed a problem for some time, until the Commandant, Edinburgh Airport, whose co-operation is here gratefully acknowledged, made a part of Turnhouse Aerodrome available. As well as being a protected site where equipment may be left erected, it provides hourly meteorological records.

After preliminary trials, the artificial shelterbelt is now under construction. Its dimensions are: height, 10 to 12 feet; length, 120 feet; aspect ratio, 10 to 12. Nägeli (1953) found that an aspect ratio of 11 gave a full development of the potential shelter zone of a free-standing screen.

The belt is made by fixing horizontal strands of rope, at various levels above the ground, along the two sides of a line of posts supported by guy-ropes. This provides a 'hollow' fence into which tree material (tops, branches, or small trees) can be placed in any required pattern. The central post is fixed in the ground and provides an axis around which the belt can be moved when the tree material has been taken out.

Shelter Planting Practice

In August 1960, Denmark and North West Germany were visited to study the policies and techniques of shelter planting, in the context of the large-scale land reclamation and agricultural improvement projects which are in progress there. An account of these, under the above title, has been published in *Scottish Forestry*, 1961, 15 (1), 17–32.

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FIRE SPREAD IN FOREST AND HEATHLAND MATERIALS

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A study of the spread of fire in forest and heathland materials has been started. It is hoped eventually to find the effects of different moisture contents and different surface-to-volume ratios of fuel on the rate of spread, but so far experiments have largely been confined to two effects of wind speed:

(1) On the spread of fire in long wooden cribs.
(2) On the burning of localised fires.

The work will provide data from which it is hoped to be possible to predict the rate of spread and the extent of a heathland or forest fire, thus improving the fire-fighting strategy for any particular fire.

The initial investigation into the effect of wind speed on the rate of spread has been made using 10 feet long and one foot wide wooden cribs (Plate 6) made of Parana pine of $\frac{1}{2}$-inch square section, chosen in the first instance because it provides a regular and reproduceable form of fuel.

All the cribs used were conditioned at 65°F and 65 per cent relative humidity prior to being burnt in the working section of a large wind-producing apparatus. The sides of the crib were protected by sheets of asbestos wood of the same height as the crib (Plate 7) so that the burning would be representative of the propagation on a wide flame front where the entry of air to the centre of the burning zone from the sides is excluded.

The rates of spread of the front and rear faces of the burning zone were measured over a range of wind speeds from 0 to 30 feet per second, from photographic and temperature records at points along the crib. These results are shown in Fig. 4, where it can be seen that although increasing the wind speed increases the rate of fire spread, the effect becomes progressively less as the wind speed rises. It has been found that at any given wind speed the rates of spread of the front and rear faces of the burning zone become the same within the length of 10 feet used experimentally. Theoretical studies suggest the rate of spread increases as the thickness of the fuel element decreases, but it is not yet known whether there is always a maximum rate independent of wind speed.

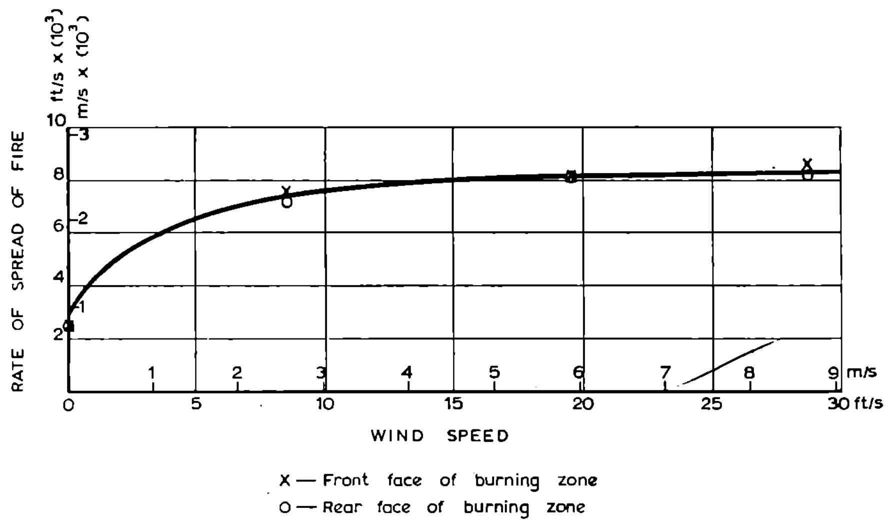

FIG. 4. —The Effect of Wind on the Rate of Spread of Fire.

A limited number of laboratory experiments on grass and heather gave rates of spread about 10 times greater than those obtained with the wooden cribs. This increase is probably mainly due to the high surface-to-volume ratio of the natural vegetation. A more extensive study of natural fuels will commence after the factor of specific surface has been studied on a regular fuel-bed of the kind already used (Plate 6).

On the assumption that the spread of fire is controlled by the heating of the unburnt fuel ahead of the burning zone, any effect of wind speed on the size and deflection of the flames, and on the heat transfer to the material ahead of the burning zone, or the rate of burning of unit area of the fuel, will affect the rate of spread of the fire. A series of experiments is therefore being made in which these effects can be studied separately as far as possible, by using localised fires in the form of wooden cribs, the whole crib burning at the same time. This type of fire approximately represents the burning zone of a spreading fire at any given instant.

In these experiments, four sizes of crib have been used, 3 feet wide and 6 inches high, with lengths of 6, 12, 18 and 24 inches, made of white pine. Wood of $\frac{1}{4}$, $\frac{1}{2}$ and one inch square section has been used. The rate of burning (measured as rate of loss of weight), the flame length and deflection of the flames are being measured. These are the principal quantities affecting the heating of the unburnt fuel ahead of the flames and, in addition, provide information on which the design of fire-breaks can be based.

The crib, which rested on an incombustible base extending downwind, had its sides parallel to the wind direction protected by incombustible boards, as in the case of the long 10-foot cribs (*see* Plate 7). This had the effect of increasing the effective width of the burning zone and restricting the air flow to the underside of the flames; the latter condition would occur in practice due to the ground.

Effect of Wind on Flame Length

The measurements of flame length from these localised fires have been correlated by means of a formula based on theoretical considerations. Assuming the fire is wide enough for the flame length L to be independent of width, we expect the ratio L/D to depend for a given fuel type on the dimensionless ratios:

$$\frac{m^2}{g\rho^2 D} \quad \textit{and} \quad \frac{U^2}{gD}$$

where g is acceleration due to gravity
U is the wind speed
D is the length of the burning zone in the direction of the wind
m is the rate of weight loss per unit ground area
ρ is the density of the gases liberated by the fuel

A statistical analysis of the experimental results, excluding the data for still air, shows that L/D is correlated with m, U and D according to the groups of terms above for the range $0{\cdot}5 < \frac{U^2}{gD} < 20$ and, assuming $\rho = 62 \times 10^{-3}$ lb/ft³,

$$1 \times 10^{-4} < \frac{m^2}{g\rho^2 D} < 400 \times 10^{-4}.$$

The analysis shows

$$\frac{L}{D} = 55 \left\{\frac{m^2}{g^2 D}\right\}^{0{\cdot}43} \left\{\frac{U^2}{gD}\right\}^{-0{\cdot}11}$$

Fig. 5 shows $\frac{L}{D}\left\{\frac{U^2}{gD}\right\}^{0{\cdot}11}$ plotted against $\frac{m}{\rho\sqrt{gD}}$

For a given rate of burning the flame length decreases as the wind speed rises, because the rate of mixing of air with fuel rises and this leads to a reduced flame surface necessary for the combustion.

One would expect that, to a first approximation, a change of fuel would raise or lower the line along the L/D axis but not change the slope significantly.

The importance of this relation is that, coupled with a similar correlation of flame orientation and data on convective heating, it should be possible to estimate the heat transfer ahead of the burning zone. This heat transfer to a large extent controls the rate of spread, which will be affected by the thickness of the fuel elements, moisture content, etc. The value of m and D are also related to the rate spread by a relation of the form

$$m = \frac{WV}{D}$$

where W is the amount of fuel burnt per unit ground area
and V is the rate of fire spread.

Combining the various relations has enabled a theoretical model of fire spread to be constructed and experimental studies are now being made in the context of this theory.

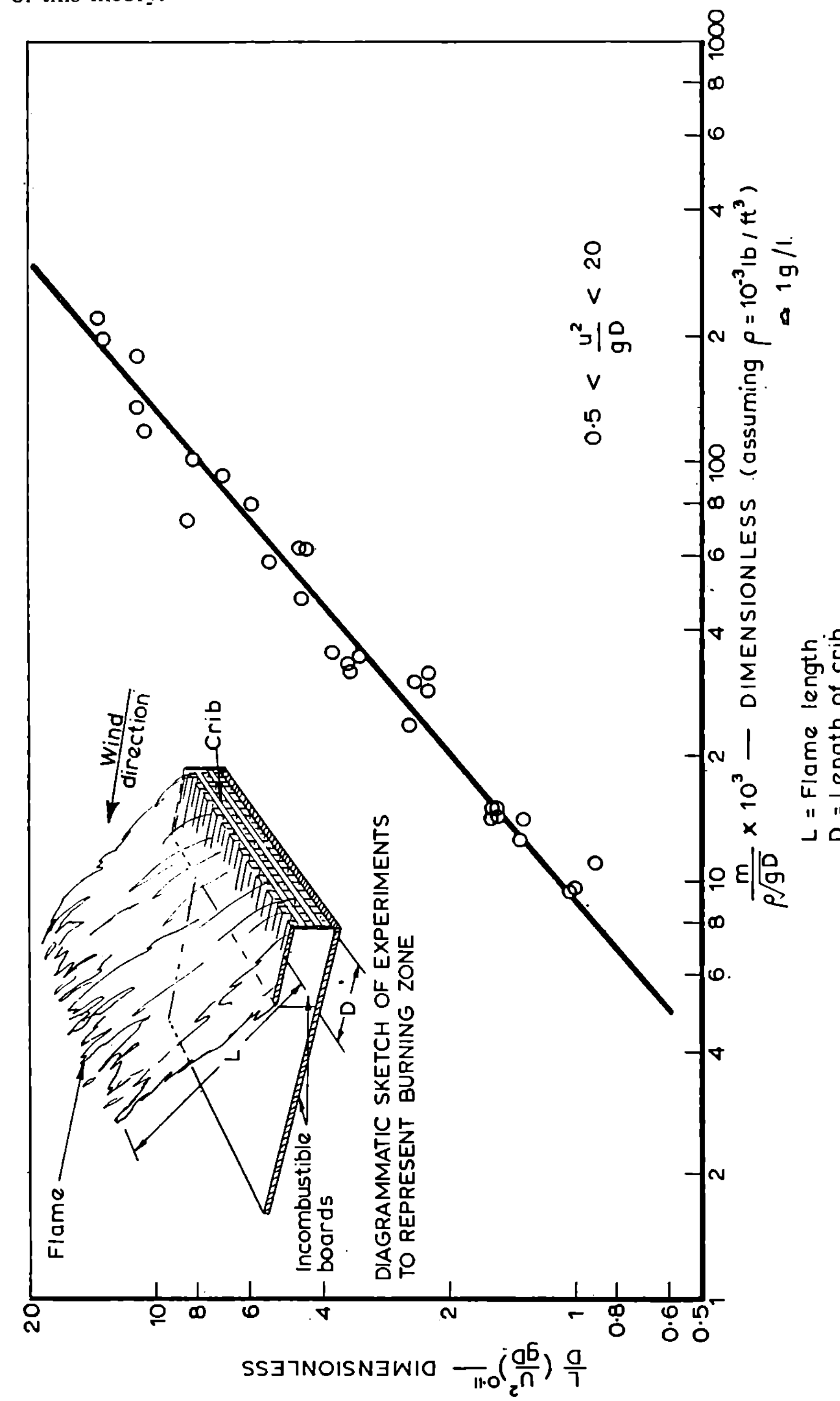

FIG. 5.—Effect of Wind Speed and Burning Rate on Flame Length.

OAK POPULATION STUDIES IN SCOTLAND: I. VARIATION OF SOME IMPORTANT DIAGNOSTIC CHARACTERS OF QUERCUS PETRAEA (MATT.) LIEBL. AND Q. ROBUR L.

By J. E. COUSENS

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This study originated from an earlier investigation by Mr. W. Finlayson aiming to locate stands of indigenous oak. He ran into immediate difficulties in the identification of the Pedunculate oak, *Q. robur* L., and the Sessile oak, *Q. petraea* (Matt.) Liebl. 'Dr. E. W. Jones' 'monograph' (1959) on British oaks appeared at the critical moment, but did not prove completely satisfactory for practical field identification of any but the obvious 'good' types of either species.

There are thus two objectives in this investigation. The immediate objective is to determine the normal range of variation of the diagnostic characters of the two oaks so that limits, arbitrary if needs be, can be set defining them for the purpose of population surveys. The more distant objective is to devise a technique for sampling oak populations and recording characters which, although perhaps not useful in diagnosis of individuals, may yield valuable indications as to the nature of the population.

Collections made to date are listed by Ordnance Survey National Grid letter squares in the Addendum.

Study of Variation on the Tree

Five terminal shoots were collected at accessible crown level from the North, East, South, and West aspects of two isolated trees, one a good *Q. petraea* type, and the other apparently good *Q. robur*. Each leaf on these shoots was detached, measured for total length, maximum width, length of petiole and position of maximum width, and then pressed and dried. Re-measurement when dry showed greater shrinkage in width than in length, and a slight apparent increase in petiole length. The pattern of variation on individual shoots was remarkably constant on both trees, even though there were small but distinctive differences between them. Both had smaller, relatively broader leaves at the base of the shoot, and smaller but relatively narrower leaves at the apex, as compared with those in mid-shoot. Auricles were less well-developed on apical and basal leaves. General observation suggests that the distinct patterns of variation shown by these two trees may well apply to *Q. petraea* and *Q. robur* generally. However, it was sufficient for this investigation to establish that mid-shoot leaves were likely to be most typical, if slightly larger than average. This was confirmed by selecting two leaves from mid-shoot, and demonstrating a very close agreement between relative dimensions (petiole length, and width of leaf relative to length) of these, as compared with the average for all leaves per shoot.

There was also significant variation on both trees, again with slightly different patterns, according to aspect; and there would appear to be direct correlation between the type and number of leaves per shoot, and the amount of insolation that the shoot is likely to receive. Leaves on the north side of the trees approached true 'shade leaves' in appearance. It was also apparent that flowers were borne more abundantly on those parts of the crown receiving greater insolation. Because of the importance of peduncle characters in diagnosis of the two species, and in order to reduce the number of specimens to be examined, it was decided that specimens should consist, wherever possible, of fertile shoots taken from that part of the accessible crown apparently receiving the greatest insolation (the south or south-east). While this was a satisfactory solution for the elucidation of the identification problem, it is not so satisfactory when it comes to sampling woodland populations; for in sampling dense stands of even moderate age only 'shade leaves' may be available.

A third tree of more definite *Q. robur* affinity than the second of the above, was also sampled in the same way, but on the north and south sides only. The results confirmed those outlined above.

Epicormic shoots were present on the *Q. robur* types, and the distinctive characters of their leaves enumerated by Jones were confirmed.

A further minor study was made on a *Q.* aff. *robur* in Dalkeith Old Wood, Midlothian, to compare lower (accessible) crown leaves, upper crown leaves and inner crown (shade) leaves. As was expected, the leaves became smaller and more coriaceous towards the top of the tree, while the shade leaves were larger and thinner in texture. Possibly the most important observation here was the remarkable consistency of the depth of the lobes (as a percentage of the width of the leaf) on all leaves, except those on epicormic shoots. The shade leaves of *Q. robur* types do not apparently have relatively shorter petioles, as is the case with *Q. petraea* (from a comparison of sun-shoot and shade-shoot leaves subsequently made in several *Q. petraea* woodland areas).

Study of Variation Through the Growing Season

In early April, 12 trees were selected to give a range of types based solely on peduncle length and stoutness, and ranging from the short, stout type of *Q. petraea* to the long, thin type of *Q. robur*. Specimens were taken from each at increasing intervals through the season, starting on April 27th, 1960. The five early collections, made before the end of May, were fully described and then preserved in formalin. Subsequent collections were dried, pressed and mounted as herbarium specimens after description.

The more important observations are given below:

(i) Leaves approached their full dimensions by early June, though mature texture is not attained till later.

(ii) Abaxial stellate pubescence was strikingly constant throughout the growing season: adaxial pubescence and glandular hairs (abundant in the buds of both species) are rapidly lost (before the end of May).

(iii) Buds developed slowly through the season and were seldom of use in diagnosis till the winter – those of both species being small and obtuse early in the season.

(iv) Peduncles of both *Q. petraea* and *Q. robur* types were densely pubescent at first, *Q. robur* types losing it rather irregularly till they were mainly glabrous by June.

(v) Peduncles reached their maximum length about mid-June. Subsequent development of the peduncle depended on the development of fruit. Generally from mid-June till the end of July the peduncle became stouter and more woody as far as the most distal developing acron. Any part of the flowering peduncle beyond this point withered, but usually remained attached. The maximum girth attained by the green peduncle at the end of July was significantly greater than that of the brown fruiting peduncle in October.

(vi) Study of the ripening acorn was unfortunately not possible. Jones' other qualitative character difference, the stripes on the fully developed, but still green, acorns of *Q. robur*, was not observed.

Method of Collection and Recording of Data

Much of Scotland's oak woodland is rather open and consists of trees of small stature presenting no problems either in sampling or collection. A pole-cutter was carried which could reach to 20 feet if necessary. In dense stands, specimens were taken on the north side of rides and gaps where present, or from the south or south-east margin of the wood. The sampling was thus sometimes neither random nor systematic. The preferred method, where it could be applied, was to make a number of traverses, collecting from the nearest accessible tree at spaced intervals. Where collections of shade-shoots had to be made, they were almost invariably infertile.

A register of all collections has been kept showing date, locality, National Grid reference and number of specimens. Each specimen, consisting of one to several shoots, was numbered: two representative leaves from mid-shoot were detached and marked to show the number of the specimen and the position on the shoot. The original specimen and the two leaves were then dried, pressed and mounted separately. The following characters were recorded for each specimen.

(1) Total length of each of the two leaves, in mm.
(2) Length of petiole of each leaf, to the nearest half-mm.
(3) Petiole percentage: combined petiole length over total length of the two leaves.
(4) Presence of abaxial stellate pubescence on the lamina.
(5) Presence of larger stellate hairs alongside the mid-rib abaxially.
(6) The type of auricle on each leaf classified as 'strong', 'medium', 'weak' or 'nil'.
(7) The total number of lobes on each leaf, counting as a lobe only those possessing a nerve running direct from mid-rib right to the leaf margin.
(8) The combined width of the two largest lobes on either side of the mid-rib.
(9) The width of lamina between the sinuses on either side of these largest lobes as an average for each leaf. The method used was to draw a line across the lobes between the bases of its flanking sinuses and then measure from the point at which this line crossed the lateral vein to the mid-rib and at right angles to it.
(10) The lobe depth percentage, being $\frac{8-9}{8} \times 100$.
(11) Total length in mm. of each peduncle present on the specimen.
(12) Length of peduncles to the first flower locus (bract) or acorn.
(13) Stoutness of peduncles.
(14) Pubescence on peduncles.

This work has been completed for 380 of the Scottish collections and some 260 more are in various stages of the process.

Preliminary Results from Collections

These collections show a preponderance of *Q. petraea* types and are rather poorly representative of the north-east, where collections were made early in the year (May–June). Collections in 1961 will aim to redress the balance between *Q. petraea* and *Q. robur* types, and provide reasonably complete geographical coverage in Scotland. Some samples larger than those taken to date are required, in order to determine the optimum sample size.

Some tentative observations and conclusions based on analyses made to date are:

(i) *Q. petraea* is a much happier botanical entity than *Q. robur*. The natural limits of variation in the important diagnostic characters of *Q. petraea* in Scotland could already be described.

(ii) Semi-natural oakwood composed predominantly of *Q. petraea* types is far more common than woodland dominated by *Q. robur* types.

(iii) In *Q. robur*-dominated woodland, 'good' *Q. robur* has so far always been found with apparent *Q. robur* forms which have abaxial stellate pubescence (considered by Høeg (1929) to be the most definite hybrid form).

(iv) The variation between individuals in every sample is so great that if ecotypes and provenances are to be recognised it will only be possible with the use of biometric indices from standardised samples.

Plans for 1961–62

(1) Fairly extensive collections in *Q. robur* woodland to bring the numbers of these species up to those already made of *Q. petraea*.

(2) Some collections in North East Scotland to give a reasonably complete geographical coverage.

(3) Some larger samples than have so far been taken – for purpose of estimating the optimum size of sample necessary to assess population characteristics.

(4) Complete compilation and analysis of data.

ADDENDUM

LIST OF LOCALITIES WHERE COLLECTIONS WERE MADE, BY ORDNANCE SURVEY NATIONAL GRID SQUARES

				Specimens
Square	NG (N.W.)	1959 Aug.	Gruinard Bay, Gairloch, and Loch Maree	43
,,	NM (W.)	1959 Aug.	Ardgour to Loch Sunart	38
		1960 Oct.	Appin, Taynuilt	31
,,	NR (S.W.)	1959 Aug.	Kintyre	37
,,	NH (N.)	1959 Aug.	Speyside, Lochan a Chuillin, Falls of Rogie	8
,,	NH (E.)	1960 June	Cawdor	8*
,,	NH (N. Central)	1960 Oct.	Falls of Leny, Loch Voil, Glen Dochart, Loch Arkaig, Spean Bridge, Glen Falloch	152
,,	NS (S. Central)	1959 June	Menstrie (Ochills)	7
		1960 Oct.	Loch Long	7
,,	NX (S.)	1960 July	Glentrool, Cree Valley, Cairnryan, Currarie Glen, Burnfoot, Bladnock, Castramount	104
,,	NJ (N.E.)	1960 June	Donside (Nr. Invermosset)	13*
,,	NO (N.E. Central)	1959 June	Earnside, Dunkeld, N.E. as far as Glen Prosen	65

		1960 June	Glen Tanar	8*
„	NT (S.E. Central)	1959	Lothians and Borders	6
		1960 June/July	Dalkeith, Elibank, Aikieside	112
„	NY (S.E.)	1959 June	S.E. of Moffat	3
			Total	642

* Specimens taken too early in June, not fully developed.

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TRACHEID LENGTH IN CORSICAN PINE

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The ultimate object of this work is to examine the feasibility of predicting tracheid length in the mature stem from that in the first-year shoot. It seems that the pattern of variation outward from the pith may change abruptly after the first year's growth and/or after the time of needle fall in any one internode. Elucidation of these points, which are being investigated at the time of writing, will bring the investigation to a close. The results should show how near the pith, and with what degree of confidence, prediction of mature tracheid length can be made.

The pattern of tracheid length variation within the leading shoots of Corsican pine has been extensively studied. This pattern has been shown to be complex, and this emphasises the need to standardise the location of samples in studies involving the comparison of shoots. Both the length and diameter of cells decrease upwards in the shoot. At the same time the ratio of cell wall to lumen increases, resulting in increased density towards the tips of shoots. The number of rays also increases up the shoot. These changes parallel increases in needle density, and in the relative size of the pith up the shoot; these in turn appear to be associated with differing rates of elongation of the shoot. Some measurements have shown that the lengths of the primary cells near the pith are very much longer than those of the tracheids to which they give rise. It is probable that it is through these primary cells that a direct connection between shoot elongation and cell length might be established, and this might well be the subject of some future work.

The complexity of the pattern of variation in single shoots is increased by the strands of shorter cells beneath each leaf trace, already reported, and by minor variations in the vicinity of an apparently undescribed structure underneath leaf traces and a short distance from them. This structure resembles a miniature leaf trace. It appears to be a duct running parallel to the trace, and is composed of both parenchyma cells and tracheal elements with spiral thickening. Further investigation of this structure might show it to be useful for taxonomic purposes.

There is some evidence that density of needles tends to be a constant feature on all the internodes in any one tree, independent of the length of the internodes. As wide needle spacing towards the base of leading shoots is associated with long tracheids, it is hoped that the same relationship might hold for a number of shoots, sampled at the same point, and that needle density may prove to be a useful external index of inherent tracheid length. Analysis of the tracheid data is now in progress.

THE JUVENILITY PROBLEM IN WOODY PLANTS

By P. F. WAREING and L. W. ROBINSON

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The main scope of this investigation was outlined in the *Report on Forest Research*, 1960 (p. 95). Observations have been carried out on the effect of grafting juvenile scions on to flowering trees of birch and larch, and on to adult vines of ivy, in the field. So far the juvenile scions have shown very little flowering response, although the branches of the stock trees are flowering profusely. The same results have been obtained in similar graftings with blackcurrant. Observations will continue to be made in future years on these, and also further graftings which have been carried out. Clones of precocious-flowering birch have been successfully established by cuttings, and seedling scions will be grafted on to these to determine whether the precocity of the rootstock is transmitted to the non-precocious juvenile scions.

Experiments with grafted plants of larch grown in pots have been used to study the effects of day-length and temperature on flower-initiation, using controlled environments in growth-rooms, but no clear-cut effects were observed.

A series of experiments has been carried out on the effect of the 'size-factor' in the flowering of seedling blackcurrants, and the results obtained were similar to those previously reported for birch (*Report on Forest Research*, 1958, p. 108) viz., flowering of seedling blackcurrants can be rapidly obtained by growing the seedlings continuously in a greenhouse under favourable conditions of day-length and temperature; flowering appears to depend upon the attainment of a certain minimum *size* and does not require periodic growth with alternating periods of activity and rest, as occurs under natural conditions. On the basis of these results it would seem important, in breeding forest-trees, to grow the seedlings as rapidly as possible until they attain the minimum size for flowering, and then to apply the various other treatments known to promote flowering.

Attempts are being made to determine what is the operative factor in the 'size-effect', i.e. (1) whether the distance of the apical meristem from the roots is important, or (2) whether the attainment of the adult condition depends upon the apical meristem undergoing a certain number of cell-divisions.

The transition from the juvenile to the adult condition in ivy has been studied by taking series of stem cuttings from vines at different heights, and studying the behaviour of the transition zone between the juvenile and adult regions of the vine. This experiment has indicated that the transition to the adult condition takes place in lateral buds on the main axis, before the axis itself becomes adult. This is an interesting result and may have important implications for forest trees.

It has been reported that the roots of juvenile ivy produce a substance capable of causing reversion from the adult to the juvenile condition. Attempts are being made to verify this report and, if possible, to extract the substance involved.

THE EFFECTS OF STUMP TREATMENTS ON FUNGAL COLONISATION OF CONIFER STUMPS

By D. PUNTER

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The effects of a range of chemicals on colonisation of Scots and Corsican pine stumps have been investigated by means of laboratory and field experiments. Special attention has been paid to *Fomes annosus* and other 'primary stump invaders', such as *Peniophora gigantea, Stereum sanguinolentum,* and 'blue-stain' fungi (*Ceratocystis* spp.).

The method of laboratory screening by growing the fungi on treated sections of fresh pine stem is essentially similar to that described by Rishbeth (*Ann. Appl. Biol.*, 1959, 47, 529). Replicates of each treatment are inoculated with basidiospores of *F. annosus* and with a variety of microfungi. Air-dried litter can be stored successfully for up to a year at ca. 5°C and 5 g. samples shaken with 25 ml. water provide a consistent source of stump-colonising microfungi. Results of these tests have shown that the great majority of treatments cause some reduction in colonisation by *F. annosus*. Among inorganic radicals, metals are more extensively fungitoxic than non-metals, while there is a tendency towards non-selective toxicity by heavy metals and reducing agents. Two boron compounds, ammonium biborate and ammonium pentaborate, inhibit growth of basidiomycetes while allowing increased colonisation by fungi imperfecti, such as *Botrytis cinerea*, *Penicillium* spp., and *Trichoderma viride*. This is in agreement with results of earlier tests with disodium octaborate and ammonium compounds (Rishbeth, 1959). Treatment with basic compounds appears to favour growth of certain fungi imperfecti at the expense of basidiomycetes. Only a few members of some major groups of organic compounds have been tested; of these, the dihydrio phenols, catechol, resorcinol, and quinol are all strongly fungitoxic, while N-methyl aniline favours growth of basidiomycetes.

Small-scale field experiments have been carried out to test the applicability of laboratory screening to field conditions. Results have shown good agreement within certain limits. Stump inoculation is necessary for adequate testing of basidiomycetes in the field, whereas heavy inoculation with microfungi has been found to have little effect on colonisation. Field conditions, as might be expected, are most favourable for the 'primary stump invaders', but all are subject to seasonal variation, especially the 'blue-stain' species.

Large-scale field experiments have been laid down to test selected treatments more fully. Killing of stump tissues, rate of initial penetration, and subsequent movement through the stump body by a number of treatments, are also being investigated.

STUDIES ON THE FUNGUS FOMES ANNOSUS

By J. RISHBETH
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Inoculation of pine stumps with spores of the fungus *Peniophora gigantea*, as a means of protection against *Fomes annosus*, continues to give encouraging results. In 10 experiments, involving some 400 stumps of *Pinus sylvestris* or *P. nigra* var. *calabrica*, samples taken after six to 12 months showed that inoculation had consistently prevented colonisation of the cut surface by *F. annosus*, whether derived from natural sources or from adding up to 3,000 spores per stump. About 90 per cent of inoculated stumps produced sporophores of *P. gigantea* within a year. The treatment also prevented growth of *F. annosus* into stumps root-inoculated with the parasite soon after felling: in five stumps excavated a year later, no roots were found to contain *F. annosus*. By contrast, in root-inoculated stumps treated with creosote or urea at the time of felling, two-thirds and one-third of the roots respectively were occupied by the parasite. With naturally infected pine stumps, however, *P. gigantea* was rather less effective because it seldom replaced *F. annosus* in resinous roots already dead at the time of felling. Stump inoculation is effective at any time of year; in cold weather *P. gigantea* spores may be suspended in 10 per cent ammonium sulphate, which considerably depresses the freezing point without greatly affecting spore viability.

Studies have been continued on spore dispersal of certain wood-rotting fungi. The deposition rate of spores of such fungi may be measured by exposing discs of pine wood previously treated with sodium o-phenyl phenate and then sterilised. Such discs, which may be stored in tins or sterile polythene bags, are often superior to untreated discs with respect to selectivity and retain this property for many months. They also provide a more uniform substrate than untreated discs and support growth of a wider range of species.

D. S. Meredith has published a second paper on *Fomes annosus* and other stump-colonising fungi in *Ann. Bot.*, 24, 1960. A survey of losses in East Anglian pine plantations through killing by *F. annosus* has been published by G. W. Wallis in *Forestry*, 33, 1960.

PART III

Results of Individual Investigations

THE LONGEVITY OF BEECHNUTS IN RELATION TO STORAGE CONDITIONS

By G. M. BUSZEWICZ

The nuts of the beech tree, *Fagus sylvatica*, are by nature short-lived seeds, and in practice they are not normally stored for longer than about six months after collection, i.e. storage overwinter in preparation for spring sowing. Relatively little is known about methods of prolonging the life-span of the seeds beyond this period. These facts, coupled with the long intervals of six to eight years between good mast-years (years of heavy seed-fall), make it difficult for foresters to plan and organise regular plant supplies for annual planting programmes.

These problems can be overcome to some extent by costly collection of seeds during poor mast-years, and there is a possibility that low-temperature storage may enable plants to be held over from one year to the next. However, these are incomplete and costly answers to the problem and may result in an undesirable type of planting stock. The only satisfactory answer would seem to be storage of seed over two or more seasons to permit stocks of good quality seed to be maintained between mast-years.

Beechnuts, when collected in the autumn, are normally dormant and a period under cool or cold conditions is necessary to hasten the ripening and maturation of the embryos. They are not easy to test in the laboratory, as germination tests are prolonged, requiring three to four months for completion (International Seed Testing Association, 1959). Rapid biochemical methods of testing seed viability may be of value, but their accuracy has not been adequately proven (Rohmeder 1951, Schönborn 1958).

Methods for storing beechnuts over a single winter have been the subject of many experiments, and the published literature is extensive (Holmes and Buszewicz 1958). In Britain, the normal practice is to store the seeds by spreading them on an earth or concrete floor in a cool shed until mid-February, when they are stratified in moist sand in an open pit for three weeks before sowing (Forestry Commission 1957). Alternatively, the seeds may be sown shortly after collection in autumn. In this event, the beds require careful netting, or covering with soil, to protect the seeds against birds and rodents. The choice of method for short-term storage depends very much on local conditions and requirements, but the essential principles common to all are: good ventilation, an even and moderately low temperature, and an equable and fairly high moisture content, i.e. about 20 to 25 per cent (fresh weight). The normal germinative capacity to be anticipated from seeds properly stored overwinter is about 80 per cent.

Methods of storage for periods longer than a single winter have been investigated by several workers (Holmes and Buszewicz 1958; Johannsen 1921; Messer 1960; Nyholm 1960; Schönborn 1958), and their reports indicate the complexity of the problem. Nyholm's investigations are among the most extensive, and he succeeded in storing germinable seeds over four winters. His tests included storage in open and sealed containers at temperatures of —15°C, —5°C and +2°C, with a range of seed moisture content from 11 to 30 per cent. He concluded that sub-freezing temperatures are best for long-term storage, and in general the lower the temperature and the lower the seed moisture content, the longer the seeds remain viable. Careful pre-drying of the seeds, and storage at 11 per cent moisture content at —15°C gave the best results in these trials. Careful preparation of the seed for storage is important, and Nyholm found that best results followed preliminary storage in a cool shed for three months, with care to ensure uniform and slow drying of the seed, before storage at low temperatures.

Schönborn (1958), carried out similar studies, but his trials extended only over two winters. He found that sealed storage was better than open storage, and a temperature of —4°C was superior to —15°C at all levels of moisture content. (At —15°C, the only seeds surviving over two winters were those below 15 per cent moisture content.) His results at above-freezing temperatures were poor. Messer (1960) reports successful storage of beech over two winters in polythene sacks at a temperature of —4°C, and moisture content levels of 25 to 27 per cent.

The Results of Storage Trials at Alice Holt, 1956–60

In preparation for these trials, beechnuts were collected in late October 1956, and thoroughly cleaned, removing inert matter and empty and damaged seeds. The seed bulk was then well mixed and samples allocated to a range of storage conditions in series, as follows:

Series 1 – Storage of *pre-dried* seed in sealed containers at a range of moisture and temperature levels.

(Seed was pre-dried at 20°C to moisture levels of about 15, 20, 25 and 30 per cent, and stored in sealed containers at —10°C, +2°C, and +8°C.)

Series 2 – Storage of *pre-dried* seed stratified in peat in closed containers.

(Seed was pre-dried at 20°C to moisture levels of about 15, 20, 25 and 30 per cent, mixed with peat adjusted to equilibrium moisture levels (i.e., 25, 30, 35 and 40 per cent respectively), and stored in closed containers at 2°C only).

Series 3 – *Undried seed* stored at a range of controlled atmospheric moisture levels at 2°C.

(Open and sealed storage was tested, viz.:

(*a*) *Open* – seeds stored in containers through which a continuous flow of air of controlled relative humidity (R.H.) was passed. Air relative humidity levels were maintained at 95, 85, 75 and 45 per cent in separate containers.

(*b*) *Sealed* – seeds placed in sealed containers within which the atmosphere was controlled at relative humidity levels of 90 per cent, 80 per cent and 60 per cent, by sulphuric acid solutions within the containers.)

Series 4 – Seed stored in open (a), and closed (b) containers at 2°C. Seed moisture content was maintained at approximately 20 per cent by periodic re-moistening.

Seed samples were removed from each of these conditions at intervals of several months for moisture content and germination analyses. Seed moisture content was measured using an air-drying oven at 105°C, testing two replicates of 20 grm. seed. Drying was discontinued when the samples attained constant weight, and moisture content calculated on the fresh seed weight.

Germination tests were carried out as prescribed in International Seed Testing Association Rules (I.S.T.A. 1959), except that replicates of 4 x 25 seeds were used instead of the prescribed 4 x 100, on account of shortage of germinator space. A filter paper substrate was used throughout.

Table 10

The Germinative Capacity and Moisture Content of Beechnuts in Sealed Containers at a Range of Temperatures and Initial Seed Moisture Levels

Initial Seed Moisture Level (%)	Storage Temper-ature (°C)	Test	Germination and Moisture Content: *Percentages* after Months of Storage						
			0	5	8	17	21	31	39 months
30·9	8	Germination	92·0	67·0	9·0	0·0			
		Moisture	30·9	30·3	33·4	32·3			
	2	Germination	92·0	95·0	73·0	17·0	1·0		
		Moisture	30·9	31·1	32·3	36·2	38·4		
	—10	Germination	92·0	76·0	64·0	59·0	15·0	9·0	3·0
		Moisture	30·9	29·6	29·9	30·6	30·8	29·3	29·7
25·5	8	Germination	93·0	77·0	79·0	0·0			
		Moisture	25·5	24·0	25·4	28·8			
	2	Germination	93·0	77·0	80·0	4·0	8·0	0·0	
		Moisture	25·5	23·8	26·1	22·1	28·6	24·4	
	—10	Germination	93·0	76·0	73·0	75·0	91·0	61·0	5·0
		Moisture	25·5	25·3	24·9	26·6	25·1	23·7	24·4
20·6	8	Germination	95·0	76·0	51·0	0·0			
		Moisture	20·6	17·6	19·7	16·5			
	2	Germination	95·0	73·0	81·0	25·0	5·0	0·0	
		Moisture	20·6	20·6	20·7	19·7	19·8	22·5	
	—10	Germination	95·0	73·0	72·0	97·0	77·0	3·0	0·0
		Moisture	20·6	20·8	20·6	21·2	20·3	20·8	20·0
15·6	8	Germination	95·0	49·0	1·1	1·1			
		Moisture	15·6	15·2	15·1	13·8			
	2	Germination	95·0	77·0	64·0	0·0			
		Moisture	15·6	15·6	15·6	15·4			
	—10	Germination	95·0	59·0	87·0	63·0	17·0	4·0	0·0
		Moisture	15·6	15·6	15·5	15·6	15·0	15·4	14·4

It will be noted that, with the exception of Series 3 trials, which included seed down to 10 per cent moisture content, the trials were restricted to a seed moisture range of 15 to 30 per cent. This is now considered to have been a mistake, as a range of lower moisture levels should have been included. However, it must be remembered that at the time the trials were established, it was a general opinion that beech seed would not withstand drying below 15 to 17 per cent.

Series 1

This was the most extensive trial, including sealed storage at a range of temperatures and moisture levels. Results are summarised in Table 10.

Several unexplained fluctuations in seed germinative capacity were found during the period, but the general pattern of germination behaviour suggests that the *lower* the storage temperatures the *longer* the life-span of the seed. Results at 2°C and 8°C show that seed may be stored over one winter, i.e. five months, without serious loss; but only at —10°C was it possible to maintain seeds at a reasonable germination level over a second winter, i.e. over 17 months. Seed moisture content clearly had an effect, and the best results were achieved and 20 per cent and 25 per cent, around the middle of the range tested. The most successful method was —10°C at 20 per cent and 25 per cent moisture content, which preserved seeds in good condition for 21 months.

Series 2

These trials included a similar range of seed moisture levels maintained by stratification in dried peat at 2°C in sealed containers. Results are presented in Table 11.

Results were generally similar to those achieved with unstratified seed in sealed containers at 2°C (Table 10). The seed was successfully stored only over one winter, the seed being of good germination quality up to nine months at 29, 23, and 18 per cent moisture content, and only up to five months at 15 per cent moisture content.

Series 3

These trials were concerned with seed longevity under conditions in which the seeds received no pre-drying treatment, seed moisture content being con-

Table 11

The Germinative Capacity and Moisture Content of Beechnuts Stratified in Peat in Sealed Containers at a Range of Moisture Levels at 2°C

Period of Storage (months)	Germination and Moisture Content Percentages after Storage											
	Germ %	Moisture Content %		Germ %	Moisture Content %		Germ %	Moisture Content %		Germ %	Moisture Content %	
		Seed	Peat		Seed	Peat		Seed	Peat		Seed	Peat
0	*99*	28·7	38·4	*99*	23·1	34·2	*99*	18·3	30·3	*99*	14·7	25·9
5	*90*	31·7	32·2	*85*	22·7	28·5	*77*	18·1	26·3	*85*	15·5	23·0
9	*79*	29·8	30·9	*83*	22·6	27·4	*77*	18·1	23·8	*57*	14·6	22·1
12	*18*	28·2	30·9	*60*	21·4	26·6	*71*	17·5	24·1	*48*	14·6	22·1
17	*0*	23·8	29·0	*8*	19·7	25·4	*13*	16·3	23·3	*1*	14·4	21·9
22				*1*	20·7	25·4	*4*	16·1	21·8	*0*	14·3	21·1
35				*0*	19·8	24·4	*0*	14·6	21·5			

trolled by means of the storage atmosphere, which was fixed at a range of constant relative humidity levels. These seeds were stored in open and sealed containers at a constant temperature of 2°C.

The 'open' containers were in fact glass cylinders through which air of controlled humidity was passed at a slow rate throughout the period of storage. The relative humidity of the air was controlled at 95, 85, 75 and 45 per cent, in separate containers, by bubbling the air supply through sulphuric acid solutions of appropriate specific gravity. In this way, it was possible to control seed moisture content precisely without hermetic sealing, and its possible effects on the seed respiratory processes. In the case of sealed containers, the seeds were stored over sulphuric acid solutions inside the containers to provide a relative humidity range from 60 to 95 per cent.

During the first year of storage, seed moisture content was checked frequently to assess the rate at which equilibrium with the storage atmosphere was achieved. The results of these tests, together with germination tests, are summarised in Table 12.

Table 12

The Germinative Capacity and Moisture Content of Beechnuts Stored in 'Open' and Sealed Containers at 2°C in Atmospheres of Controlled Relative Humidity

Storage (months)	Germination and Moisture Content Percentages															
	'Open'– Relative Humidity (%)								Open Control		Sealed – Relative Humidity (%)					
	95%		85%		75%		45%				95%		80%		60%	
	G	M.C	G	M.C	G	M.C	G	M.C	G	M.C	G	M.C	G	M.C	G	M.C
0	*99*	26·9	*99*	26·9	*99*	27·2	*99*	29·5	*99*	34·0	*99*	34·0	*99*	34·0	*99*	34·0
1	—	25·8	—	25·9	—	25·3	—	22·4	—	32·4	—	33·9	—	29·5	—	27·3
2	—	25·7	—	24·6	—	22·9	—	15·2	—	27·3	—	33·8	—	22·9	—	19·4
3	—	25·5	—	23·3	—	20·3	—	8·7	—	17·9	—	33·4	—	18·8	—	14·2
6	—	25·0	—	21·8	—	16·4			*95*	15·5	*84*	32·6	*66*	14·6	*72*	11·7
7	*88*	24·7	*74*	19·6	*67*	14·8	*66*	8·6		13·8	—	31·8		13·6	—	11·2
8									*66*	13·8	*64*	31·8	*68*	13·8	*77*	11·4
12	*57*	23·9	*79*	17·2	*35*	14·2	*62*	8·9								
18	*12*	24·0	*35*	17·6	*1*	14·7			*1*	14·3	*0*	28·0	*0*	12·5	*69*	11·1
22	*0*	22·6	*4*	17·5			*76*	—								
33					*5*	14·5	*48*	8·3								
35															*35*	10·9
38					*0*	14·4	*23*	8·8								

Notes: 'G' = Germination percentage; M.C. = Moisture Content percentage. Moisture Content determinations were made at more frequent intervals than Germination determinations. A dash, '—', indicates that no determination was made.

The initial moisture content of the seed in 'open' containers was lower than for those in sealed containers, as these test conditions were set up some three weeks after the others, and the seeds dried to some extent during this period.

Seed moisture levels were slow in reaching equilibrium with their storage atmospheres, especially for those seeds kept at high relative humidity levels. However, seed stored at the lower relative humidity levels dried quite quickly, and equilibrium was reached after three to six months.

All seed lots stored well over one winter, including control samples stored in an open-topped jar. As the trial proceeded, seeds at the higher moisture levels began to deteriorate, until after the second winter, 18 months after storage began, only those seeds at 45 per cent and 60 per cent relative humidity levels were of acceptable germination quality. These seeds had moisture contents between eight and 10 per cent, much lower than were reached in any other tests.

Series 4

These tests were carried out as additions to the main trials to compare open and sealed storage at 2°C, the seed being maintained at 20 per cent moisture content. The seeds in open containers were moistened at intervals to maintain seed moisture at a level comparable with that in the sealed containers. In this

Table 13

The Germinative Capacity and Moisture Content of Beechnuts Stored in Open and Closed Tins at a Temperature of 2°C

Storage (months)	Germination and Moisture Content			
	Open		Closed	
	G%	M.C%	G%	M.C%
	95	23·7	*95*	23·7
1		22·1		23·4
2		21·7		23·5
3		20·5		23·4
5	*73*	18·0	*75*	22·3
6		22·8*		21·9
8		16·6		21·7
9		26·9*		21·5
10		22·1		21·0
11		19·8		21·0
12	*80*	14·9	*49*	20·7
13		24·8*		20·4
14		17·2		20·3
15		25·7*		
16		19·7		20·2
17		23·1*	*9*	20·8
18	*73*	14·6		26·6*
19		21·0*		
20		20·3		22·8
21				
22	*13*	22·3*		

*After soaking in the previous month.

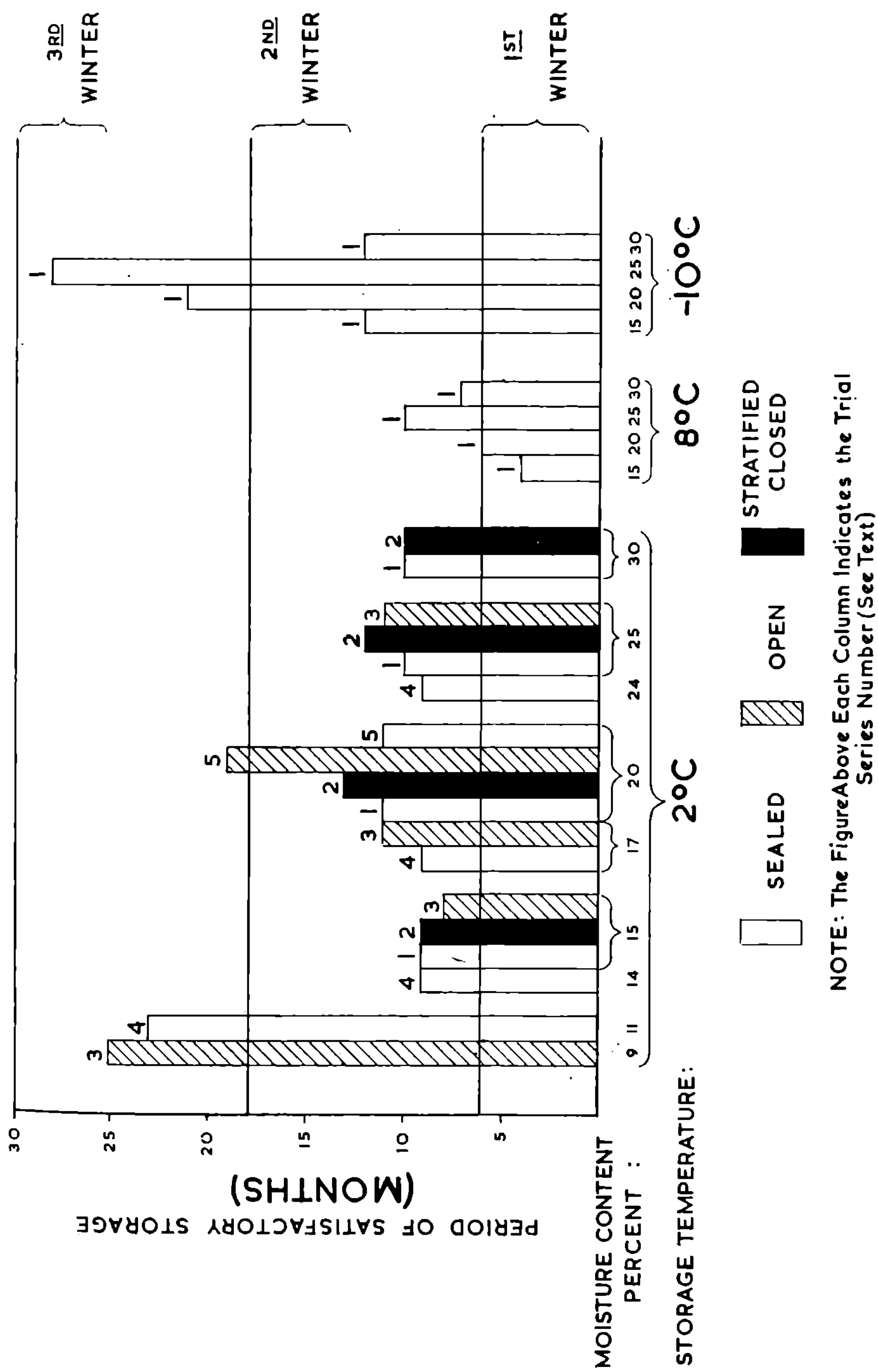

FIG. 6.—Maximum Storage Periods (Months) for which Seeds Maintained a Minimum Germinative Capacity of Sixty per cent.

way, it was hoped to obtain a direct comparison of open and closed storage at similar seed moisture levels. As can be seen in Table 13, seeds dried rapidly in open containers, and adjustment of moisture content was necessary every two months throughout storage.

Seeds in closed containers maintained a near-constant moisture level, but deteriorated in germination quality much more rapidly than those in open storage. In fact, the open-stored seed, with periodic adjustment of moisture to the 20 per cent level, was one of the most successful treatments in the whole enquiry, the seed showing 73 per cent germination after storage for 18 months under these conditions.

Discussions and Conclusions

It will be seen from Tables 10 and 12 that seeds remained alive and germinable for over three years under certain conditions, notably a subfreezing temperature of —10°C, or low seed moisture content eight to 10 per cent. Three years was the maximum period that *any* seeds remained alive, and in no case was the germinative capacity high enough to be of practical importance after this period.

A more practical appraisal of results can be obtained if a minimum acceptable germinative capacity can be fixed. For this purpose, it is suggested that the minimum germinative capacity of practical value to the nurseryman is about 60 per cent. This arbitrary minimum standard of germination quality has been used in preparation of Fig. 6, which shows the period of time for which seed germination levels were maintained above the 60 per cent minimum standard with the storage methods tested.

With the exception of sealed storage at certain moisture levels at 8°C, all storage methods tested were successful in maintaining an acceptable standard of seed germination quality over the first winter.

Seed germination quality fell below the suggested 60 per cent minimum standard at about the same time, i.e. after nine to 12 months' storage, under the majority of storage conditions examined.

Table 14

Storage Conditions Tested

Storage Temperature	Seed Moisture Content During Storage	Method of Moisture Content Control
—10°C	25%	Hermetic sealing
—10°C	20%	,, ,,
2°C	20%	Open, seeds, moistened periodically.
2°C	11%	Hermetic sealing, humidity controlled with H_2SO_4 solution.
2°C	9%	Open, aeration with air-flow of controlled humidity.

These treatments are of three classes, i.e.:

(*a*) Sub-freezing temperature + high controlled seed, moisture-content %
(*b*) Near-freezing ,, + ,, ,, ,, ,,
(*c*) ,, ,, + low ,, ,, ,,

Seeds were satisfactorily stored over the second winter, i.e. a storage period of 18 months, under five sets of conditions, as shown in Table 14.

At 2°C, seeds stored well at about 10 or 20 per cent moisture content. However, it is interesting to observe that seed with moisture levels between 12 and 20 per cent did not store well under any temperature conditions. This seems to be a critical range, and may explain the opinion of some workers that beechnuts cannot be stored at a seed moisture content below 17 per cent.

The favourable results obtained with the lowest temperature (—10°C), *or* the lowest moisture content (10 per cent), suggest that seed respiration and destructive metabolism are retarded under these conditions. Unfortunately, the trials did not include a combination of these extremes, i.e. low temperature + low moisture content, but there is good reason to suggest that such a combination would provide favourable storage conditions.

A low seed moisture level of the order of 10 per cent is clearly an advantage, *providing* it can be achieved without damage to the seed during the process of drying. In these trials, the lowest seed moisture levels were reached by storage of the seed in dry air at low temperatures, thus avoiding possible damage to seed through the effects of heat and rapid moisture loss associated with normal seed-drying methods. Nyholm's views (Nyholm 1958), seem important in this connection, and he suggested that the seed should be dried slowly over a period of several weeks at temperatures not exceeding 20°C, to reduce seed moisture content to around 10 per cent prior to low-temperature storage.

Several of the storage methods tried would be difficult or impractical to apply on a large scale, notably those involving air-humidity control or frequent adjustment of seed moisture content. The use of sealed containers is undoubtedly the most convenient practical method of controlling seed moisture content once the seed has been correctly pre-dried.

The practical long-storage methods indicated would seem to be as follows:

(i) Slow pre-drying at temperatures not exceeding 20°C, reducing seed moisture content to eight to 12 per cent for storage at —10°C to + 2°C, or 20 to 25 per cent for storage at —10°C.

(ii) Seed moisture levels are most easily maintained using *sealed* containers, and heavy-gauge polythene bags are the most convenient in large-scale work.

Summary

Investigations of the longevity of the nuts of beech, *Fagus sylvatica,* under contrasting storage conditions were carried out in the period 1956–60. The storage conditions examined included temperatures of —10°C, 2°C, and 8°C, with seed moisture content controlled at levels ranging from 10 to 30 per cent (fresh weight). Altogether, 26 different storage conditions were examined, including storage in open and sealed containers, and storage at a range of controlled air relative humidity levels.

The experiments showed that beech seed can withstand drying to 10 per cent moisture content, and can be satisfactorily stored over two winters at 2°C. Similar results were achieved by storage at —10°C with a moisture content of 20 to 25 per cent. On the basis of these results, it was suggested that a favourable storage method for beech would be a combination of low temperature, —10°C, and low moisture content, eight to 12 per cent, with a suitably slow method of seed pre-drying.

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EXPERIENCES WITH LEGUMINOUS NURSES IN FORESTRY

By M. NIMMO and J. WEATHERELL

Introduction

As long ago as 1928, following the publication of the results of Prof. Süchting's work in Germany (Süchting 1928), Mr. W. H. Guillebaud, then the Forestry Commission's Chief Research Officer, became interested in the possible use of leguminous nurse crops in forestry, and between that date and 1956 no less than 54 experiments were carried out on this subject. Süchting's work, with broom and lupin, on sites where Norway spruce struggled for 20 to 30 years against dense heather competition, specially emphasised several points – firstly, the greatly increased height growth of the spruce in the treated plots, and secondly, the remarkable differences in the root systems. In the control plots the spruce roots were very sparse, hardly penetrating the mineral soil below the surface humus and with very few fine rootlets and little mycorrhiza; whereas in the nurse crop units not only were there ample fine roots with well-developed mycorrhiza, but also good penetration for as much as six inches into the mineral soil.

Notes on Experimental Sites

Work has been carried out mainly at Wareham Forest in Dorset (Nimmo 1952), Allerston (Wykeham) and Allerston (Broxa) Forests in Yorkshire, the Forest of Dean and Dymock Forest in Gloucestershire, Wilsey Down and Croft Pascoe, Land's End Forest, in Cornwall, with subsidiary trials at Teindland Forest in Morayshire, Rockingham Forest in Northamptonshire, Queen Elizabeth Forest in Hampshire, and Friston Forest in Sussex. At all these sites planting in the early years resulted in very slow initial growth, often followed by severe check of the more exacting tree species, and it was therefore considered worth while to experiment with leguminous nurse crops. In later years the use of mechanical cultivation, and phosphate at the time of planting, lessened this liability to check, but did not always prevent it occurring before canopy was reached.

At Wareham, Wykeham, Broxa and Teindland, the problem was concerned with dense heather on acid podzols; at the Forest of Dean, Dymock and Rockingham, the difficulty was to raise oak on heavy soils with dense grass-herb vegetation, with consequent prolonged and expensive weeding, unless early growth could be accelerated; while at Queen Elizabeth and Friston Forests, the experiments were concerned with getting beech crops, hampered by dense grass mats on thin soils overlying chalk, to grow away.

The Leguminous Species Used

Over the years the following legumes have been used:

Species	Number of Trials
Common broom (*Sarothamnus* (*Cytisus*) *scoparius*)	39
Dwarf broom (from Holland) a variety of *S. scoparius*	1
Spanish broom (*Spartium junceum*)	6
White broom (*Sarothamnus alba*).	1
Perennial lupin (*Lupinus polyphyllus*)	11
Yellow tree lupin (*Lupinus arboreus*)	3
Bladder senna (*Colutea arborescens*)	1
Pea tree (*Caragana arborescens*)	1
Locust (*Robinia pseudoacacia*)	2
Gorse (*Ulex europaeus*)	4
Scotch laburnum (*Laburnum alpinum*)	2

Thus the Forestry Commission's work has followed that of Süchting (1928) and concentrated mainly on common broom. The other species will be dealt with later.

Common Broom (Sarothamnus scoparius)

The 39 experiments dealing with common broom were widely distributed – there were 16 at Wareham, 11 at Allerston (Broxa, Wykeham and Harwood Dale), four at Wilsey Down, three at Croft Pascoe, two each at Queen Elizabeth Forest and Friston, and one at Teindland. Details appear in Table 17, page 139.

Some early attempts were made to raise broom in the nursery and transplant into the forest, but far better results were obtained by direct sowings.

(1) Sowing Technique

(a) Pre-treatment of Seed. The testa of a broom seed is highly impermeable to cold water, and unless the seed is scalded before sowing it may lie in the soil for several years before germinating. The accepted practice is therefore to pour water, just off the boil, over the seed and then leave to soak overnight, before sowing; the volume of water used should not exceed about five times the volme of the seed to be treated, or the temperature may keep too high for too long and the seed may be damaged. Allowance should be made for the fact that the seeds swell considerably.

(b) Date of Sowing. Early sowing, such as late March or early April, is strongly recommended because it lengthens the first growing season, thus giving bigger seedlings better able to stand frost lift and other adverse weather conditions. Frost lift is usually particularly troublesome on heavy soils, but at Broxa in Yorkshire it was quite serious, even on a soil classified as a sandy loam.

(c) Density of Sowing. It is interesting to find that the density of sowing has steadily diminished as experience has increased, coming down from as much as 22 lb. per acre in the earliest Yorkshire work to 2 lb. per acre in the most recent experiments at Croft Pascoe in Cornwall.

Assuming good quality clean seed and broom patches spaced at five feet along every furrow, 2 lb. of seed per acre gives over 50 seeds per patch and has resulted in excellent crops in the South of England. Even in the rather more unfavourable conditions in Yorkshire, 3 to 4 lb. per acre should be ample, provided the seed is good. Unless the soil conditions are very bad, experience has shown that continuous drill dowing does not need any more seed than is used for patch sowings.

(d) Soil Conditions. Early work at Allerston (Broxa), Friston and Wareham showed that on poor soils, whether heather, (*Calluna vulgaris*), podzols or thin soils over chalk, a reasonable degree of cultivation is essential if broom is to succeed. Nowadays this is usually achieved by some form of ploughing, but in many of the older experiments hand cultivation of strips or patches proved quite satisfactory where the ground was not subject to waterlogging; on wet sites, however, ploughing is the best way of ensuring sufficient aeration to get the broom roots well started. Elaborate seedbed conditions are not necessary and, on ploughed ground, it is sufficient to prepare levelled and firm patches, sow the seeds and cover lightly by raking.

(e) Manuring. Experiments both at Allerston (Wykeham) and Wareham showed that phosphate is essential for the survival and successful development of broom. In the early years there was unfortunately some doubts about using the more soluble forms of phosphate, and consequently almost all the work with broom involved the use of slow-acting types such as basic slag, bonemeal or ground mineral phosphate; but in recent Experiments in South West England, superphosphate gave a much better result with broom than did bonemeal; both applied at similar rates of P_2O_5 per patch. Triple superphosphate would, of course, have the considerable advantage of far less bulk for the same dosage of phosphate. At the same time it should be remembered that ground mineral phosphate has given very good results, and it is not likely that any other fertiliser will prove cheaper per unit of P_2O_5. As regards dosage, experience has shown that it is worthwhile to put 3 oz. of basic slag or 2 oz. of bonemeal, ground mineral phosphate or superphosphate per sowing patch, but with triple superphosphate 1 oz. would be sufficient. For continuous strip sowings approximately the same amounts per yard run as per patch will be found adequate.

The fertilisers should be worked into the top soil at the time of preparation of the patches or strips for broom sowing.

If, as sometimes happens on poor, uneven ground, some broom patches check severely, an ounce of nitro-chalk once or twice, as a surface dressing during the growing season, can be very beneficial. Recent work in the South West suggests that if potash is given to broom it greatly encourages flowering. This is a disadvantage, firstly because it makes the shoots top-heavy and more cutting back is needed, and secondly because it shortens the life of the broom.

(2) Tending

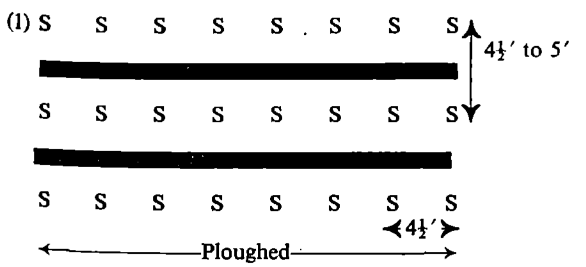
It is usual for broom to make heavy growth in the second and third years, and experience has shown that, using planting patterns described below (excepting No. 4), it is necessary to make from three to five annual cuttings to avoid side shoots of the broom whipping or suppressing the nursed trees. Topping of the broom will shorten the period required for the trees to get their leaders free, and also helps to minimise snow damage.

(3) Lay-out Patterns

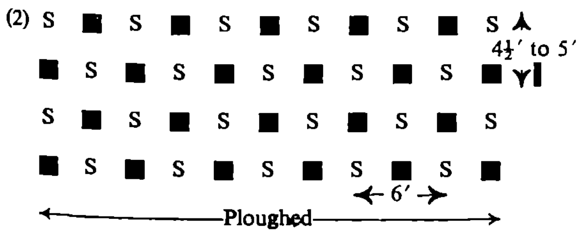
Very many different lay-out patterns with broom have been tried and the ones illustrated in Table 15 are only a selection of those widely used. Experience has shown, however, that certain principles govern all successful lay-outs; the broom must be close enough to the nursed species to have rapid effect, yet not so close that early smothering takes place; many early experiments gave good results with the broom patches alternating with, and 2½ feet away from, the tree species in the lines and 4½ feet between the lines, but, where the broom was vigorous, this resulted in too much cutting back being required, and more recent work has favoured a spacing of six feet for the trees along each furrow with broom patches at three feet from each planting point.

Table 15

Lay-out Patterns for Broom Experiments

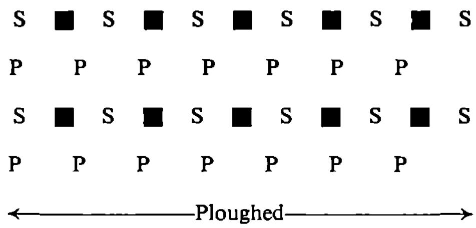
(1)


Bands of broom alternating rows of spruce.
In old experiments on this pattern the broom was sown along the top of the ridges and the spruce planted in the furrow, but the same design has been used more recently on complete ploughing.

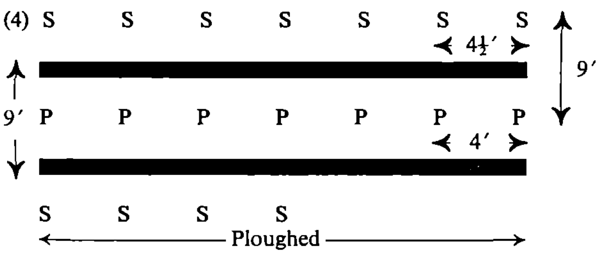
(2)


Alternate patches of broom and spruce.
In early work the spacing between the spruces in the lines was the same as between the lines, i.e. 4½ to 5 feet.

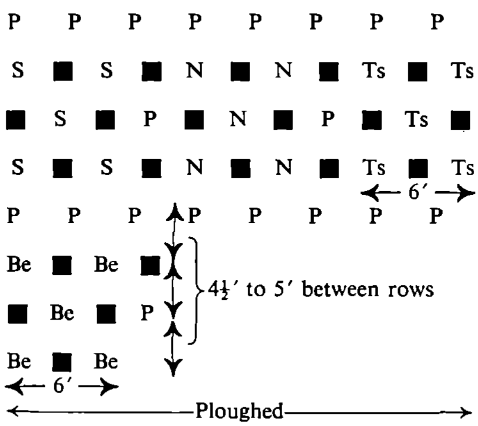
Table 15—*continued*

(3)


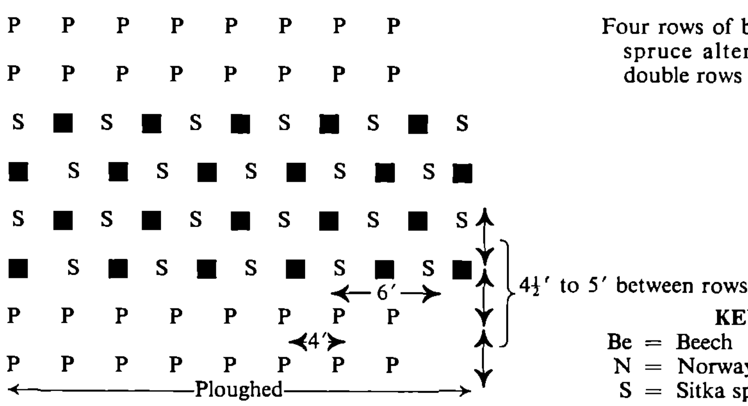
As (2), plus alternate rows of Scots pine (dilutant and possible long-term nurse).

(4)


Wide spacing of conifers, as used in certain Broxa experiments.
In some experiments in Southern England two rows of nursed trees have been planted between 9 foot spaced broom banks.

(5)


A mixture design, using groups of five plants of final species, with occasional Scots pine nurses.

(6)


Four rows of broom-nursed spruce alternating with double rows of pine.

KEY

Be = Beech
N = Norway spruce
S = Sitka spruce
Ts = Western hemlock
P = Pine nurse
▬ = Broom band
■ = Broom patch

Where the ground has been ploughed in single furrows, at the usual intervals of about five feet, if the broom and the tree species are on alternate furrows, as in pattern No. 4, the full benefits are likely to be somewhat delayed because, on most soils, the roots of either species may take quite a few years to grow across the furrows. For quick results it is therefore safer to sow the broom along the same furrows as the species to be nursed, especially on poor, light soils in Southern England where the life of the broom may only be about seven years. The success of pattern No. 4 at Allerston (Broxa), however, suggests that alternate furrows of broom and tree species encourage the tree roots to develop roots in the broom-sown furrow, resulting in good growth and increased stability.

If the aim is to produce a full crop of an exacting species, then some variation of pattern No. 2 will give the maximum broom effect. Changes from this to such patterns as Nos. 3, 4, 5 and 6 have two main aims – economy in establishment and the introduction of a pioneer tree species, such as pines or Japanese larch, that would prolong the nursing effect after the broom died back and might also give some intermediate yield – a most desirable feature not catered for by broom alone (Plate 10). Patterns such as 5 and 6, evolved from northern experiments, seem likely to give some of the best results, combining as they do the benefits of maximum broom effects with a reduction in the number of sowing points per acre and the inclusion of long-term nurses.

Work at both Allerston (Wykeham) and Wareham has shown that if the number of broom patches is drastically reduced – for example to 350 or 400, evenly spaced per acre – the response on tree growth is so poor as to be ineffective; it is far better to keep areas of fairly close-spaced broom and economise by planting intervening strips or groups of pioneer trees.

It is interesting to note that pines raised with broom tend to grow rather too vigorously, becoming coarse and top-heavy with a consequent liability to wind-throw.

(4) Costing

A detailed costing carried out in Yorkshire and based on work between 1943 and 1953, but adjusted to 1960 wage rates, can be summarised as shown in Table 15.

Table 16

Costing of an Experiment in Yorkshire

Operation	Man-hours (@ 3/7 per hr.)	Cost per acre £	*s.*	*d.*
Collection of sufficient pods for 3 lb. of clean broom seed	29	5	3	11
Extraction of broom seed	3		10	9
Carriage to and from stores	—		5	0
Sowing patch preparation (say 1,500 patches) .	10	1	15	10
Sowing seed and fertiliser	10	1	15	10
2 cwt ground mineral phosphate . . .	—	1	5	0
Weeding and cleaning (three times) . . .	18	3	4	6
Total per acre	70	14	0	10

At Wareham the cost of broom seed collection was rather less, because women were employed, while the cost of preparation of patches was a little heavier, but it is interesting to note the total came to £15 per acre, very close to the Allerston cost.

Providing the spacing of the trees is normal, this cost represents the actual increase per acre entailed by using a broom nurse crop, but if the trees are planted wider apart than usual, to allow for the broom sowings, then the excess figure would be proportionally less.

By far the largest single item is the cost of seed collection and there is no doubt that this could be considerably reduced if large-scale work was envisaged.

(5) Magnitude of Nursing Effect

It is fair to say that on many infertile sites successful broom nurse crops, together with phosphate given to both the broom and the trees, gave one of the most dramatic effects seen in any of our early experiments. Taking two examples from widely different areas, the results were as follows:

a. *Wareham Forest, Dorset* *Experiment* 36, 1938 *Sitka spruce*

Complete ploughing. Broom sown in 3-foot strips at 9 feet apart, centre to centre. Bonemeal at 3 cwt per acre to broom and basic slag 2 oz. per plant to trees. Assessment after 10 years:

Treatments	*Mean height in ft.*	*Total bonemeal and basic slag per acre in cwts*
Control	1·1	0
Tree-plus-phosphate . . .	2·4	1½
Trees-plus-phosphate in broom-plus-phosphate	6·2	3½

A similar experiment at Wareham (No. 73, 1945, details in Table 17, p. 141) is illustrated in Plates 8 and 9.

b. *Allerston Forest* (*Broxa*). *Experiment* 9, 1943. (Plates 10 and 11)

Sitka spruce planted on five different ploughing methods with basic slag, with and without broom sowing. Assessed at 13 years (ploughing treatments pooled for this comparison):

Treatments	*Basic slag per acre in cwt*	*Mean height in ft.*
Pure Sitka spruce . .	1¼	6·3
Sitka spruce-plus-broom.	2⅞	12·8

In this experiment Japanese larch also gave excellent nursing effect but Scots pine much less (Weatherell 1957; Leyton and Weatherell 1959). The mean figures for all the broom experiments that contain the three treatments noted above cover results of 18 experiments on five different sites and including seven tree species.

Overall means at average age of 10 years:

Treatments	*Phosphatic fertiliser (total cwt per acre)*	*Mean height in ft.*
Control	0	3·48
Trees-plus-phosphate	2·6	4·74
Trees-plus-phosphate in broom-plus-phosphate	4·1	8·23

The few cases of poor results in our older work were usually concerned with failure to get the broom properly established – due to such factors as poor seed, seed killed by leaving in water that was actually boiling, ravages of slugs and snails, insufficient soil cultivation, effects of drought or of waterlogging. It should also be mentioned that, where exposure is severe, excessive stimulation of growth by either broom or phosphate, especially with pines or Japanese larch, may lead to relatively coarse and top-heavy growth, resulting in an increased liability to wind-throw, particularly on single-furrow ploughing and with widely-spaced trees.

One of the most interesting aspects of the effect of broom has been its *sustained* benefit as compared with the relatively short-term results usually obtained by the equivalent doses of phosphate alone. In recent work on south western heaths in Cornwall, however, the results with broom have not been quite as expected in that the early effect was good but has not given the usual progressively improved growth. So far we cannot say why this should be so.

(6) Time of Establishing the Broom Crop

In the early days it was thought advisable to sow broom in advance of the tree crop, but later experiments, both at Allerston (Broxa) and Wareham, gave no evidence of any gain from advance sowing. Work concerned with other projects clearly indicated that delayed planting following ploughing was disadvantageous (Weatherell 1953). Far better early growth of the nursed trees is obtained if planted before any re-invasion of heather or of grass-mat has started, and also the cost of cutting back the broom is less with simultaneous sowing and planting.

(7) Alleviation of Check by Broom

The usual role of the leguminous nurse has been to obviate tree check, but work at both Wareham and Wilsey Down has shown that severely checked spruces may be brought back to good growth by inter-plant or inter-row sowings of broom, though these results were confounded with the effect of the phosphate given to the broom (*see* paragraph 9 below). On any site completely re-invaded by dense heather, the cost of establishing and maintaining the broom would be too high to justify any large-scale work. On difficult unploughed ground at Harwood Dale the broom did not grow well enough to affect the checked spruce at all.

(8) Tree Species Raised with Broom

Much of our early work, especially in Yorkshire, was done with Sitka spruce but, over the years, the range has been much extended and the following species have all responded to broom nursing.

Scots pine
Corsican pine
Lodgepole pine
Japanese larch
Douglas fir

Norway spruce
Sitka spruce
Abies grandis
Abies procera (*nobilis*)
Western hemlock

Western red cedar
Thuja occidentalis
Lawson cypress
Pedunculate oak
Red oak

Beech

(9) The Addition of Phosphate

A frequent and very legitimate criticism of most of the broom experiments has been that they were so designed that it was never possible to separate the effect of the broom from the effect of the phosphate given to it. To resolve this point an experiment was laid down at Wareham in 1949 in which in one treatment phosphate was applied to prepared patches, exactly as for broom, but no broom was sown. Despite the fact that this experiment was on such poor ground that the broom started to die-back after six years, the results showed that while the phosphate effect was only temporary, the broom effect continued even several years after the broom plants themselves had died out.

Experiment 93, 1949

Ploughing: Single furrows five feet apart.
Species: Norway spruce.
Manuring: 2 oz. of bonemeal per plant plus 2 oz. of bonemeal per patch.
Lay-out: Six replicas of each treatment.
Assessment after 10 *years:*

	Bonemeal (cwt per acre)	*Height in feet after* 10 *years*	
(a) Pure Norway spruce, 2 oz. bonemeal per plant . . .	2	2·48	S.E.
(b) As (a) plus 2 oz. bonemeal to blank patches between each pair of Norway spruce	4	2·97	±
(c) As (b) but broom sown on the prepared patches . .	4	3·92	0·349

Apart from increased growth, the colour of the spruce in the broom plots was far better than in the plots with the double dose of phosphate, but no broom.

At Wareham, where so much of the broom work was done, there were two other experiments which added to the evidence that there, at any rate, phosphate alone did not give the same results as broom plus phosphate. In Experiment 8, 1932, a total of 5 cwt per acre of basic slag was given in two doses – one at the time of planting and the other five years later – but the responses only lasted from three to four years and all the plants went into check; the species were Douglas fir, Japanese larch, Western hemlock and Sitka spruce.

Then in Experiment 43, 1939, a total of 15 cwt of basic slag per acre was given to both Norway spruce and Sitka spruce, again in two doses – 5 cwt at the time of planting and a further 10 cwt five years later; here again the effect was disappointing – the first application gave a very good start lasting up to five years, but the second slagging gave a very poor response and did not get the spruces away.

It is perhaps significant that there was little Dwarf gorse (*Ulex gallii*) on either of these two sites, and experience now suggests that phosphate alone is never so effective on pure heather areas as on those where either gorse or broom is present.

(10) Comparison of Common Broom and Tree Species as Nurses

So far there have been very few examples of tree species giving results as good as those obtained by the combination of phosphate and broom. One such example was with Japanese larch at Allerston (Broxa area). In the South of England Japanese larch has not given nearly such good results.

In practically all the experiments a successful broom crop has given a quicker and greater nursing effect than was obtained by pioneer tree species. Very often from five to 10 years have elapsed before pine nurses begin to exert a marked influence on the more exacting tree species. Against this, however, must be set the expense of its establishment and maintenance and the fact that the broom crop itself yields no returns other than the possible harvesting of its seed.

Work with pines at both Broxa and Wareham has shown that in using pioneer trees the method of mixing is highly important and that intimate mixtures such as alternate plants, and to a lesser extent two-row two-row arrangements, nearly always result in a high proportion of the nursed species being suppressed. Better results are obtained with at least three rows of the nursed species, or group arrangements on the same principles. Experience has also shown that mixtures *across* the furrows give earlier nursing effects, but work in Yorkshire has suggested that if the mixture is made so that each furrow contains only one species increased stability may be expected.

Probably, therefore, the best results may be expected with staggered groups arranged so that the pioneer trees adjoin the nursed species both *along* the furrows and *across* the furrows. By this means one may hope to get the best of both worlds – i.e. the early benefits of mixing the species along each furrow and the later advantage of rooting across the furrows into the sheltering pioneer crop.

Lastly, when comparing the effects of broom with the benefits of a pioneer tree crop, it should be made clear that the greatly improved colour of trees within broom, together with the remarkable change in surface vegetation, suggests that it is giving slow but continuous nitrogen supply and that until a cheap, slow-acting nitrogenous fertiliser can be found it is difficult to produce this effect in any other way.

(11) Discussion

The beneficial effect of broom is undoubtedly complicated and due to the collective influence of quite a number of separate factors. By affording shelter it reduces transpiration and evaporation and helps to avoid extremes of temperature, providing a most favourable micro-climate for the nursed trees.

It is a deep-rooted species and does not rob the top-soil of moisture nearly so quickly as does dense heather, and during short dry spells it has been observed that in broom shelter the soil round the shallow roots of spruces remains quite moist, while on open ground it has already become dry.

The nitrogen factor has several aspects; the fixation of nitrogen by the root nodules, thus making it available to adjacent tree roots; followed by the suppression of the surface vegetation by the broom foliage. Heather, *Calluna vulgaris*, often dominant or frequent, makes a high nitrogen demand and its suppression has a two-fold action – first eliminating its competition and then making available extra nutrients from its decomposition.

A further point of interest is that on poor soils, especially those having a pan development, the deep roots of broom may bring back into circulation chemicals that have been leached out of the upper layers, as well as helping to aerate the lower soil.

Before going on to the major consideration of cost, one or two other difficulties associated with broom crops should be mentioned.

On chalk downland slugs and snails can ruin a crop of newly-germinated broom seedlings and it may be necessary to use slug bait, but this trouble has not been met with on heathland sites. In exposed positions, especially in the north, wet snow can severely flatten a broom crop, as well as increasing the depth of snow between the broom rows, thereby doing damage to young nursed trees. In severe weather both hares and deer may browse on broom, but they seldom do permanent harm unless the damage is constantly repeated. Lastly, it should be mentioned that if broom dies out before the nursed crop is getting into canopy, the dead material increases fire danger.

It has been shown, earlier in this paper, that a successful broom crop can be established on newly-ploughed ground for about £14 per acre and that, with the possible exception of Japanese larch on certain sites, no pioneer tree species has ever given comparable early nursing results. The question is whether similar results could be produced at less cost by any other methods.

Since the main work on broom nurses was done, two further lines of experimentation have opened up new possibilities; firstly, the application of far heavier doses of fertilisers than have usually been used in the past, and, secondly, the use of herbicides as a means of controlling dense ground vegetation such as *Calluna* or heavy grass swards.

Recent work in South West England has shown that on heathland carrying dwarf gorse (*Ulex gallii*) heavy doses of phosphate will get Sitka spruce away without a check but, elsewhere, on pure *Calluna* ground without any gorse, phosphate alone does not wholly succeed and extra nitrogen seems essential. At the moment, however, no cheap, slow-acting form is available, but results with urea and di-ammonium phosphate are hopeful.

Broom may therefore still have a place on certain difficult sites, particularly where exposure is a major factor, or where pioneer tree species can only be induced to grow very slowly. It is now felt, however, that there are probably few areas where more exacting species cannot be successfully and more economically raised in a suitable matrix of pioneer trees combined with heavy manuring and, if necessary, heather suppression by the use of herbicides.

Probably on some areas the ideal may be to combine groups of the nursed species with broom sowings in a general matrix of manured pioneer trees, thus greatly reducing the cost per acre of the broom while at the same time providing longer term nursing and the possibility of intermediate yields.

On sites where manuring may be successful, but exposure effects are very severe, continuous rows of broom at perhaps half a chain apart, both along and across the furrows, may greatly accelerate closure of canopy.

Other Species of Broom

Dwarf Broom (Sarothamnus scoparius var.)

At Wareham, Experiment 102, 1952, compared the effect of common broom and dwarf broom on the growth of Western hemlock.

There were no losses in either treatment, and after seven years the hemlock in the common broom had a mean height of 7·5 feet as against 5·0 feet in the dwarf broom. The dwarf broom gives far less shelter than does the common broom, so it is not known whether the same growth ratio would have applied if a more wind-resistant species such as Sitka spruce had been used in place of hemlock.

Since dwarf broom is less vigorous than common broom, it costs less to prevent it overgrowing the tree species; but this advantage is outweighed by the fact that it does not compete so well with the heather, so that it is not so easy to attain adequate suppression of the surface vegetation. In exposed situations common broom gains by giving far more shelter. In severe winters, however, when there is drifting on exposed ground, tall broom can encourage the deposition of snow resulting in severe damage to the tree crop, and dwarf broom may be preferable.

Spanish Broom (Spartium junceum)

Tried out in six experiments, four at Friston, and two at Teindland, Spanish broom lives much longer than common broom, having a life up to 30 years compared with 15 years for the latter species, but it gives much less shelter, does not suppress vegetation nearly so well, and often results in a crop of rather uneven density and height. It also has the disadvantage that the seed is far more expensive. For these reasons Spanish broom cannot really compete with common broom, except perhaps on highly calcareous soils, to which it seems specially suited.

White Broom (Sarothamnus alba)

Only tested on a very small scale, this species seeds itself very freely but does not seem to stand periods of very cold winter wind as well as does common broom. It grows taller than common broom and is inclined to be 'leggy' and top-heavy.

Other Leguminous Nurses

Gorse (Ulex europaeus)

For several reasons gorse cannot be recommended for large-scale use despite the fact that in some circumstances it can be a very successful nurse species. Unfortunately, it is a very prickly shrub and creates an expensive and highly unpopular weeding problem! It is most inflammable and causes an extremely severe fire danger and, once established, its rapid and successful self-seeding makes it difficult to control.

At Queen Elizabeth Forest there are some fine examples of how remarkably successful it can be as a nurse species. On War Down there are two areas of gorse sown for game cover about 1925, on a rendzina soil with chalk at about eight inches below the surface. They formed a dense canopy completely suppressing the *Festuca Agrostis* grass-mat. Beech was introduced into lanes cut through the gorse at five-foot intervals in 1933 and grew well right from the start. The cut lanes were invaded by a vegetation of better grasses and herbs with some bramble, but the beech never looked back and made a most extraordinary contrast with those planted on the adjoining open downland in the same year. It is important to note that neither the gorse, nor the beech plants received any phosphate.

Planted		*Mean height in 1937*	*Mean height in 1953*
1933.	Beech on open Down (grassland)	17·3 inches	17·4 feet
1933.	Beech amid gorse	45·5 inches	28·1 feet

Similar examples of the beneficial effect of gorse were noted in the early days of planting beech at Friston Forest, also on chalk.

On the Yorkshire moors, however, gorse has at times been associated with check to conifers – particularly Japanese larch; while at Thetford, possibly owing to the light soil and low rainfall (approximately 23 inches annually), it has not usually assisted tree establishment.

Bladder senna (Colutea arborescens)

This species did very badly at Wareham and is not thought to be worthy of further trial. It is very subject to drought damage, and, in its early years, does not compete well with ground vegetation. Later it assumes a very 'leggy' habit of growth and would not afford much low shelter.

Pea Tree (Caragana arborescens)

Only tried on a very small scale, this shrub was not very successful at Wareham, germination was poor and the plants were badly cut back by spring frosts, but a further trial is to be made before completely condemning the species.

Locust (Robinia pseudoacacia)

Robinia was tested at Wareham and in Experiment 89, 1948, it gave a very good result with Sitka spruce (Nimmo 1950).

Treatments	*Mean height, in inches, of spruce after five years*
Control	24·9
Control + phosphate	27·3
Robinia + phosphate	39·1
Broom + phosphate	42·5

Despite its successful nursing effect, however, it is not a species that can be recommended for general use because not only is it very thorny, and therefore difficult and expensive to trim away from the nursed trees, but it produces a mass of suckers and itself becomes a weeding problem.

Scotch Laburnum (Laburnum alpinum)

Tried out at Teindland and Queen Elizabeth Forest, laburnum has not proved to be a successful nurse species, being very slow at suppressing the ground vegetation and making poor growth on exposed sites.

Perennial Lupin (Lupinus polyphyllus)

More work has been done with this species than with any other except common broom, but the results have not been good and further use of perennial lupin in the forest cannot be recommended. There were four experiments at Dymock, three of which involved ash and sycamore and two oak; two in the Forest of Dean – one with oak and one with ash; three at Rockingham – two with ash and one with oak and, in the north, two at Wykeham, one being with Sitka spruce and the other with European larch and beech. Details appear in Table 18, page 144.

After dressing with "Nitragin", a proprietary preparation to provide inoculation with the necessary nitrogen nodule-forming bacteria when sowing on non-arable soils, the lupin seed was sown in bands along prepared strips about

Table 17

Broom Nurse Crop Experiments

List of Experiments with Comments and Abridged Summary of Assessments

Key to Fertilisers Used: B=Bonemeal. BS=Basic Slag. PS=Potassic Superphosphate

Experiment No., Location and Year of Planting	Tree Species	Age when Assessed (Years)	No Broom: Heights (feet): Control Trees	No Broom: Heights (feet): Trees+Phosphate	No Broom: Fertilizer (cwt per acre)	With Broom: Heights (ft.): Trees+Phosphate with Broom +Phosphate	With Broom: Total Fertilizer (cwt per acre)	With Broom: Type of Fertilizer Used	Comments
BROXA 6, 1942	Sitka spruce	14	5·2	7·6	5·0	14·5	7·25	BS	First broom sowing upset by sheep and frost lift. Partial re-sow in second year.
9, 1943	Sitka spruce (ploughed ground)	13	—	6·3	1·25	12·8	2·8	BS	Two other interesting mean heights: Sitka spruce with Japanese larch nurse 12·5 feet. Sitka spruce with Broom and Scots pine nurse 14·2 feet (Plates 10 and 11).
	(No ploughing)	13	—	1·8	1·25	2·0	2·8	BS	The broom failed without ploughing.
11, 1943	Norway spruce	15	—	—	—	16	3·75	BS	This experiment had both broom and Scots pine nurses throughout, but there were unmanured control plots of each nursed species. The Scots pine with broom but without phosphate had a mean height of 18 feet at 15 years.
	Sitka spruce	15	—	—	—	16			
	Western hemlock	15	—	—	—	17			
	Beech	15	—	—	—	16			
	Douglas fir	14	—	—	—	15			
	Abies grandis	14	—	—	—	18			
	Lawson cypress	14	—	—	—	12			
18, 1946	Sitka spruce	—	—	—	—	—	—	—	Intended as a demonstration of broom as a short-term nurse with Scots pine for later nursing, but broom failed too badly to serve its purpose.
CROFT PASCOE 2, 1954	Sitka spruce	5	—	2·7	2·0	3·2	4·0	PS	Complete ploughing gave better results than partial ploughing (3·4 feet as against 2·5 feet).
2, 1954	Lawson cypress	5	—	2·0	2·0	3·0	4·0	PS	Complete ploughing again best (3·03 feet against 2·03 feet).
11, 1956	*Pinus radiata*	1	—	0·6	2·0	0·4	2·0	PS	Broom sown one year in advance on separate furrows and was 4 feet high when pine was introduced. Poorer growth in broom plots no doubt due to shading. No nitrogen effect from broom could be expected in one year as it was not on the same furrows as the pine. In this experiment potassic superphosphate gave faster growth of broom than was obtained by using bonemeal.

Table 17—*continued: Broom Nurse Crop Experiments*

Experiment No., Location and Year of Planting	Tree Species	Age when Assessed (Years)	No Broom: Heights (feet): Control Trees	No Broom: Heights (feet): Trees + Phosphate	No Broom: Fertilizer (cwt per acre)	With Broom: Heights (ft.): Trees + Phosphate with Broom + Phosphate	With Broom: Total Fertilizer (cwt per acre)	With Broom: Type of Fertilizer Used	Comments
FRISTON									
7, 1928	—	—	—	—	—	—	—	—	Trials of Spanish broom partly failed due to slugs, snails and drought, but where successful, lived for 30 years and grew to 10 feet high. No controls or comparative figures.
8, 1928	—	—	—	—	—	—	—	—	
9, 1928	—	—	—	—	—	—	—	—	
25, 1938	—	—	—	—	—	—	—	—	Common broom failed due to slugs, snails and drought. No useful data.
26, 1938	—	—	—	—	—	—	—	—	
HARWOOD DALE 27, 1941	Sitka spruce	14	—	—	—	5·3	6·0	BS	Broom heavily pruned in 1944, after which it lost vigour and began to die. Sitka spruce reverted to check. Difficult site. Sitka spruce nursed by Scots pine 6·2 feet in 14 years.
32, 1941	Sitka spruce	13	9·8	10·4	3·5	9·3	3·5	BS	An experiment on the stimulation of 9-year-old checked Sitka spruce on a difficult unploughed area. Broom never grew well. Results not significant.
ALLERSTON (LANGDALE) 3, 1939	Sitka spruce	15	—	—	—	13·4	4·0 1·25	B BS	Sitka spruce nursed by Scots pine only 6·8 feet at 15 years and being suppressed by pine.
QUEEN ELIZABETH 31, 1939 (Plantings 1945)	Western red cedar Beech	14 14	— —	— —	— —	17·0 16·8	3·0	B	In these two experiments a broom crop was first established and then beech and red cedar introduced a few years later. There are no controls, but both species have done far better than would be expected on open downland.
38, 1940 (Plantings 1945)	Western red cedar Beech	14 14	— —	— —	— —	15·5 14·7	3·0	B	
Observation area. Planted 1943.	Beech	20	—	—	—	—	—	—	Beech introduced 1933 in gorse sown 1925. Mean height after 20 years: 28·1 feet. Control beech outside = 17·4 feet. No phosphate on this area to gorse or trees.

Table 17—*continued: Broom Nurse Crop Experiments*

Experiment No., Location and Year of Planting	Tree Species	Age when Assessed (Years)	No Broom: Heights (feet): Control Trees	No Broom: Heights (feet): Trees + Phosphate	No Broom: Fertilizer (cwt per acre)	With Broom: Heights (ft.): Trees + Phosphate with Broom + Phosphate	With Broom: Total Fertilizer (cwt per acre)	With Broom: Type of Fertilizer Used	Comments
TEINDLAND 37, 1929	Sitka spruce	—	—	—	—	—	—	—	No Sitka spruce were planted until 5 years later the broom sowings, so no proper comparisons were possible.
WAREHAM 20, 1933 } 21, 1933 }	Various pine	—	—	—	—	—	—	—	Experiments badly damaged by rabbits and hares, and later destroyed by fire during war.
27, 1934	Scots pine	10	2·3	5·3 }		6·3			A direct sowing experiment. Most of Corsican pine failed.
	Corsican pine	10	—	5·5 }		—			
	P. radiata	10	5·6	8·1 }	3·0	11·9	5·0	B	
	Lodgepole pine	10	3·8	4·7 }		7·5			
36, 1938	Sitka spruce	10	1·1	2·4	2·0	6·2 }			Only the Sitka spruce had phosphate alone. After 20 years the controls were all dead and the trees in the broom plots still growing well despite the death of broom at about 10 years.
	Abies procera (*nobilis*)	10	1·3	—		2·9 }	4·0	B	
	Western hemlock	10	1·8	—		4·8 }			
	Thuja occidentalis	10	0·8	—		6·0 }			
64, 1942	Corsican pine	6	—	11·0	2·0	12·8	4·0	B	Mean diameter increased from 3·3 inches to 4·0 inches. In this experiment broom was sown between the plants in an existing Corsican pine plantation 4 years old from direct sowing.
70, 1945	Sitka spruce	11	1·7	3·1	2·5	5·9	5·0	B	Data on pine nurses will also come from this experiment.
71, 1945	Norway spruce	11	1·6	3·4	2·5	6·6	5·0	B	Data on pine nurses will also come from this experiment.
72, 1945	Western hemlock	11	2·6	2·9	2·5	6·4	5·0	B	Data on pine nurses will also come from this experiment.
73, 1945	Douglas fir	11	3·0	4·9	2·5	8·1	5·0	B	Data on pine nurses will also come from this experiment. In one plot in this experiment the Douglas fir has a mean height of 12·2 feet with broom (Plates 8 and 9).
76, 1946	Norway spruce Sitka spruce	—	—	—	—	—	—	—	No comparative data from this experiment, which was really a trial on a 'look-see' basis of many different treatments of checked spruces. It was in this experiment that nitro-chalk was applied with very good effect to checked broom sowings.

Table 17—*continued: Broom Nurse Crop Experiments*

Experiment No., Location and Year of Planting	Tree Species	Age when Assessed (Years)	No Broom			With Broom			Comments
			Heights (feet)		Fertilizer (cwt per acre)	Heights (ft.)	Total Fertilizer (cwt per acre)	Type of Fertilizer Used	
			Control Trees	Trees + Phos- phate		Trees + Phosphate with Broom + Phosphate			
WAREHAM—*cont.*									
79, 1945	Norway spruce	7	—	2·6	2·0	5·2	4·0	B	No plants without phosphate.
81, 1946	Douglas fir	6	2·4	3·4	2·5	10·3	3·25	B	Data on pine nurses will also come from this experiment.
82, 1946	Sitka spruce	6	3·4	4·5	2·5	8·3	3·25	B	Data on pine nurses will also come from this experiment.
89, 1948	Sitka spruce	5	2·1	2·3	2·0	3·5	4·0	B	With *Robinia* instead of broom, mean was 3·3 feet.
93, 1949	Norway spruce	10	2·4	2·5	4·25	3·9	4·25	B	With extra phosphate applied to some patches where broom would have been sown, the mean height of the Norway spruce was 3·0 feet.
102, 1952	Western hemlock	—	—	—	—	—	4·0	BS	A comparison of hemlock with common broom and dwarf broom. After 7 years hemlock with common broom 7·5 feet, hemlock with dwarf broom 5·0 feet.
WILSEY DOWN									
1, 1953	Sitka spruce	5	3·04	3·1	2·0	4·2	5·0	B	This experiment was carried out on checked Sitka, and the assessment was made 5 years after the treatments were applied.
2, 1954	Sitka spruce	4	2·9	3·8	2·0	5·3	4·0	PS	Another experiment on checked Sitka, with the assessment 4 years after the treatments were applied. With Lodgepole pine in place of broom, the Sitka spruce height was 4·6 feet with phosphate and 3·6 feet without. The manure used was potassic superphosphate.
3, 1954	Sitka spruce	4	—	3·3	1·25	5·5	2·75	PS	In this experiment the manure used was potassic superphosphate and Lodgepole pine was used as a nurse crop throughout, in addition to the broom.
	Lodgepole pine	4	—	4·9		5·9			
	Japanese larch	4	—	3·9		5·2			
	Lawson cypress	4	—	3·6		3·9			
	Pinus radiata	4	—	3·5		4·0			
	Red oak	4	—	1·6		2·0			

Table 17—*continued: Broom Nurse Crop Experiments*

Experiment No., Location and Year of Planting	Tree Species	Age when Assessed (Years)	No Broom: Heights (feet): Control Trees	No Broom: Heights (feet): Trees + Phosphate	No Broom: Fertilizer (cwt per acre)	With Broom: Heights (ft.): Trees + Phosphate with Broom + Phosphate	With Broom: Total Fertilizer (cwt per acre)	With Broom: Type of Fertilizer Used	Comments
WYKEHAM 15, 1931	Sitka spruce	—	—	—	—	—	—	—	Alternate bands of lupin and broom with Sitka spruce planted between them: lupins died out after 5 years. Broom failed without phosphate but vigorous with phosphate. No control plots, and no comparison between the effect of broom and lupin, because of alternate band lay-out.
32, 1933	Sitka spruce	19	6·7	9·4	2·5	23·6	7·5	BS	Broom died at 12 to 15 years, after which Sitka spruce lost colour and some vigour. Owing to the Sitka spruce being introduced 4 years after the broom sowings and with no further ground preparation, the control trees were quickly affected by *Calluna* and comparisons are not really fair.
40, 1934	Sitka spruce	12	3·1	3·5	2·5	6·4	3·0	BS	Complete ploughing. One broom patch to every 5 spruce.
70, 1944	Norway spruce	15	—	—	—	17			A similar experiment to Broxa No. 11, 1943, but the Wykeham site is more fertile. The Scots pine with broom but without phosphate, had a mean height of 21 feet at 15 years.
	Sitka spruce	15	—	—	—	24			
	Western hemlock	15	—	—	—	22			
	Western red cedar	15	—	—	—	17			
	Beech	15	—	—	—	22	3·0	BS	
1945	Douglas fir	14	—	—	—	20			
	Abies grandis	14	—	—	—	20			
	Lawson cypress	14				14			

Table 18

Lupin Nurse Crop Experiments

List of Experiments with Comments and Abridged Summary of Assessments

Experiment No., Location and Year of Planting	Tree Species	Age when Assessed	Heights in Feet		Comments
			Control	With Lupin	
FOREST OF DEAN					
34, 1931	Oak	7	3·2	3·4	Stocking poorer in the lupin plots.
35, 1931	Ash	7	2·4	2·7	Losses slight and similar in both treatments.
DYMOCK					
10, 1929	Oak	18	9·1	8·9	Severe frost damage spoilt early assessments, and heavy weed growth resulted in very slow early growth of all species. Losses were considerably higher with all species in the lupin plots. In the first few years sycamore did show a patchy response to lupin, but this was not maintained.
	Ash	18	10·1	6·7	
	Sycamore	18	6·4	6·0	
19, 1930	Ash	2	0·19	0·29	Severe frosting ruined the crop.
	Sycamore	3	1·08	1·33	Severe frosting made growth very slow.
	,,	8	1·75	2·1	
20, 1930	Ash	—	—	—	No useful data from this experiment owing to frost lift and frost damage. The lupin was mainly poor, but in a few dense patches it smothered small ash and sycamore seedlings.
21, 1930	Oak	8	2·7	2·2	Lupin smothered many oak seedlings and did not improve growth of the remainder.

Table 18—*continued: Lupin Nurse Crop Experiments*

Experiment No., Location and Year of Planting	Tree Species	Age when Assessed	Heights in Feet		Comments
			Control	With Lupin	
OUNDLE					
1, 1930	Ash	3	0·72	0·72	Lupin gave no significant result.
	,,	15	9·2	9·8	
2, 1931	Ash	3	1·6	2·03	Dense lupin caused some damage to small plants in first two years; after about six years the lupin began to die out.
	,,	15	17·8	17·7	
ROCKINGHAM					
1, 1931	Oak	3	0·61	0·67	Very slight early benefit by lupin, but against this must be taken the fact that it smothered many small plants.
	,,	14	6·4	6·1	
WYKEHAM					
8, 1929	Beech and European larch	—	—	—	Lupins failed completely by end of 1931.
15, 1931	Sitka spruce	—	—	—	Alternate bands of lupin and broom with Sitka spruce planted in between them. Lupins died out after five years and there were no control plots. No comparison between the effect of broom and lupin possible because of the alternate band layout.

six inches wide and dressed with lime and basic slag. Germination was usually very good and in most cases the lupin flourished, although growth was sometimes very uneven, but its life was rather short – often only five years.

The hardwood seedlings, or in some cases direct sowings, were made either in the strips prepared for the lupins or parallel with them at a distance of approximately nine inches on either side. Under these circumstances the lush growth of the lupins proved to be more of an embarrassment than a blessing and smothered many small plants, in some cases reducing the stocking by as much as half. The use of larger plants, or wider spacing away from the lupin, might have avoided this but, in most cases, only a very small height increase could be attributed to the effect of the lupins and this would presumably have been even smaller had the lupin been further away.

One small point of interest was that where the lupin was very vigorous it did afford a little protection against spring frost damage.

To sum up, one can only say that the small benefits in height growth and frost protection gained from the use of the lupin nurse crop did not balance its bad smothering effect, coupled with its high cost of establishment.

Yellow Tree Lupin (Lupinus arboreus)

Of the three experiments with Yellow tree lupin, two were at Teindland and one at Wareham, but all were unlucky in that almost all the seedlings either died out during drought soon after germination or failed during the next two years while still very small. However, judging from its general behaviour on waste ground in the South of England and at Aldeburgh on the Suffolk coast, it is the most promising of all the lupins and might well give results comparable with those obtained by the use of broom, if it could be successfully established.

Summary

Of the various species of broom tried in the forest, common broom and dwarf broom are the only ones likely to merit any further consideration.

Techniques have been evolved by which a successful broom crop can be raised on the majority of poor sites and its beneficial early nursing effect usually exceeds that produced by any pioneer tree species, but recent work suggests that on most areas it will be more economic to use pine or Japanese larch nurses combined with heavy manuring and, if necessary, control of surface vegetation by chemical sprays.

On some sites, however, where exposure is extremely severe or where pioneer trees, even with fertilisers, grow very slowly, broom may still have a place, not as a full crop but in groups or strips combined with tree nurses to give long-term shelter and the possibility of intermediate yields. Recent work suggests that if *Ulex gallii* is abundant, the use of broom may be unnecessary.

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PROVENANCE OF SITKA SPRUCE

An Account of the Nursery Stage of Experiments Sown in 1958

By J. R. ALDHOUS

Summary

An account is given of the first three years' growth of 12 provenances collected between latitudes 61°N and 43°N from the coast of N.W. America

Height growth increased with decreasing latitude, especially in the range 61°N to 49°N, the taller provenances having the longer growing period; root-collar diameter and seedling weight did not vary with latitude of origin so clearly. The time of cessation of growth in late summer varied by up to three months, the last provenances to stop growing being damaged by frost.

Introduction

During the past 30 years, the species most extensively planted by the Forestry Commission has been Sitka spruce. The 1947–49 Census of Woodlands (Forestry Commission 1952) showed that the species occupied 27 per cent of the high forest area managed by the Forestry Commission. Since then, successive annual reports show that while the percentage of this species planted each year has dropped slightly (to 20–22 per cent), it still remains the most important species used.

From the first years of the Commission's acitivites, over 90 per cent of the seed from which the plants have been raised has come from the Queen Charlotte Islands. The sustained use of this provenance, and the absence, until the present collection was made, of a comprehensive representation of the provenances of Sitka spruce in Britain, reflect the suitability of the Queen Charlotte Islands provenance to the many sites where it has been planted and the ease with which seed has been obtained from the same source in most years. Seed from Washington and Oregon has been obtained from time to time, but as early as 1926, there were reports from the nurseries of young plants of these provenances being damaged by autumn frosts while plants of Queen Charlotte Islands provenance were not affected (Edwards 1953).

There are three older provenance collections. The first was planted in 1929 at Radnor Forest, comprising single plots of four provenances (Queen Charlotte Islands; Olympic peninsula, Washington; Siuslaw Mts., Oregon; Siskiyou Mts., California). The second was planted in 1934–38 at Kielder and Newcastleton Forests in the Borders, and Leanachan Forest in Inverness-shire; it included provenances from Queen Charlotte Islands, North British Columbia, Washington and Oregon. The third collection, comprising six provenances from Washington and one from Queen Charlotte Islands, was established in 1950 at Gwydyr Forest, Caernarvonshire; Kielder, Northumberland; and Glendaruel, Argyll. All these experiments show the rate of growth of the Queen Charlotte Island provenances to be appreciably less than those from further south, notwithstanding early frost damage (Wood and Lines 1959). These observations, and an interest in Alaskan provenances for planting in the northern counties of Scotland, led to the decision in 1956 to obtain seed from sites ranging from Alaska to Oregon. Most of the seed was obtained in 1957 through a firm of seed merchants and represents seed available commercially, rather than seed from specially selected seed sources. The sources of the seed are listed in Table 19 below.

Table 19

Origin of Provenances

F.C. Indent No.	Centre of Collection	Province or State	Latitude (°N)	Rainfall (inches)	Mean Annual Temp. (°F)
				From nearest	Met. Station
57(7985)1	Cordova	Alaska	60½	25	36
56(798)500	Lawing	Alaska	60*	25	36
56(7987)1	Juneau	Alaska	58¼	60	40
57(7986)1	Sitka	Alaska	57	80	44
57(7114)1	Terrace	British Columbia	54½	50	44
57(7111)2	Skidegate, Q.C. Isles	British Columbia	53	55	48
57(7116)500	San Juan River, Vancouver Is.	British Columbia	48½	60	49
57(7116)3	Sooke, Vancouver Is.	British Columbia	48¼	60	50
57(7971)1	Forks, Olympic Peninsula	Washington	48	115	49
57(7972)2	Hoquiam	Washington	47	62	50
57(7951)4	Jewell	Oregon	46	69	50
57(7952)1	North Bend	Oregon	43	52	51
55/121	Jutland	'Denmark' (this seed collected from a stand raised from seed from Washington)			

*Though slightly to the south of Cordova, Lawing is four degrees to the west, and near the limit of the species, which followed the retreating ice along the coast from British Columbia.

The elevation of all the seed sources, except Jewell, is between 0 and 500 feet above sea level; the sources at Jewell are between 500 and 1,000 feet above sea level. All are within a few miles of the coast, with the exception again of those around Jewell, which is about 30 miles inland. In addition, seed was obtained from a stand growing on the west coast of Jutland, Denmark, which is known to have been raised from seed from Washington.

Treatment of Seed and Production of Plants

Most of the seed was received in January 1958 and was immediately tested for quality. (The seed, with identification numbers commencing '56' or '55', had been in storage for one or two years and was tested in late 1957.) Germination percentage was determined on Copenhagen tanks, seed remaining on the tanks for 35 days following pre-chilling for a similar period; the weight of 1,000 pure seeds of each provenance, and the number of viable seeds per lb., were also determined.

Seed was sown in mid-April on replicated plots in three nurseries, at Wareham, Dorset, at Fleet, Kirkcudbrightshire, and at Benmore, Argyll. The methods of preparing seedbeds, preparing and sowing the seed, covering, manuring, etc., were those in general practice in each locality. Towards the end of the growing season, assessments were made of bud formation and cessation of growth, and at the end of season, yield and height of seedlings.

At all three nurseries, seedlings were big enough to be transplanted during the first winter after sowing. Seedlings were taken from each plot with the minimum of grading, rejecting those which were forked or physically damaged (of which there were very few), those which were too small to handle, and those damaged by frost.

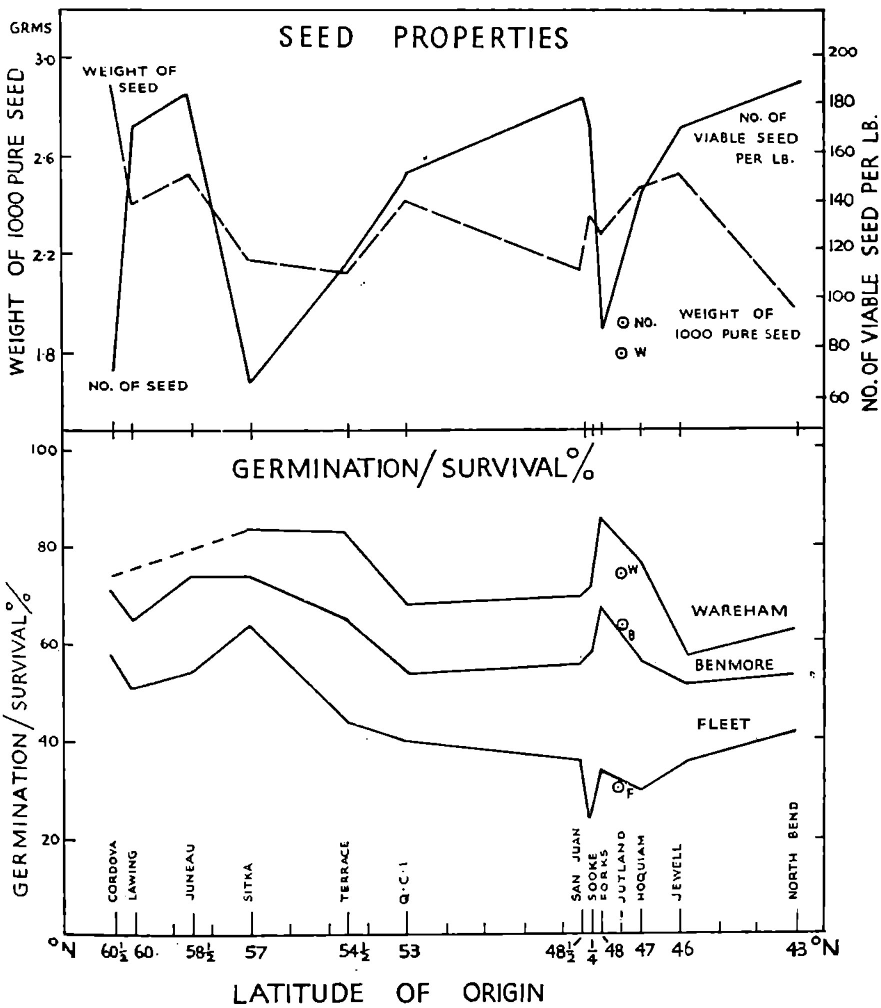

FIG. 7. *Above:* Properties of Seed,
Below: Germination/Survival Percentage, for Several Provenances of Sitka Spruce.

Treatment of transplants again followed the normal practice of the locality. Assessments were made of the time of commencement and cessation of growth, and of height and survival at the end of the growing season. The majority of plants were then sent out for planting in the forest, but at Wareham and Benmore nurseries those plants required for planting in the following year were transplanted again. Assessments of height and survival were again made on these plants at the end of the third growing season.

Results

Seed Quality

The two top lines in Figure 7 show the number of viable seeds per lb. and the weight in grams of 1,000 pure seeds for each provenance, both plotted against latitude of origin. It will be seen that there is no very clear relationship between latitude and either of these seed attributes, though there is a suggestion that seed size *decreases* the farther south the origin of the seed. This is unusual, and at present unexplained.

The percentage germination, determined by test, was closely correlated to the number of viable seeds per lb.; so also was the number of seedlings produced per lb. of seed sown. The seed from Jutland was poorer in most respects than seed of other provenances.

Seedling Production

The lower three lines in Figure 7 show the percentage of the viable seed which germinated and produced seedlings surviving to the end of the first year. There was a slight overall reduction in germination/survival percentage, the farther south the origin of the seed. (This trend does not coincide in detail with the similar trend in seed size.) The reduction is a little less than the range of variation between certain neighbouring provenances and markedly less than the differences in germination/survival percentage between the three nurseries where the provenances were grown. In spite of the big differences between nurseries, the relationship between germination/survival and latitude of origin follows the same pattern at each nursery.

Growth of Seedlings and Transplants

(a) **Height.** Figure 8 shows the height growth of the various provenances after one, two and three years' growth, plotted against the latitude of origin of the parent stands.

The expected increases in height of seedling with decreasing latitude of origin of the parent stand are clearly marked at all stages of growth and in each nursery.

The linear regressions of height on latitude are highly significant for each age of plant and nursery, though there is a suggestion in Figure 8 of a diminished height response in provenances from south of latitude 49°N. At Wareham, plants from the southern latitudes (49° to 43°N) have grown faster, relative to those from further north, than have similar plants in the two northern nurseries. (This difference in response is reflected in the greater angle of slope for the regression line for Wareham than for the two northern nurseries). This difference is thought to be due to a response by the southern provenances to the higher temperatures at Wareham, rather than a response by the northern provenances to the longer summer day-length at Benmore and Fleet.

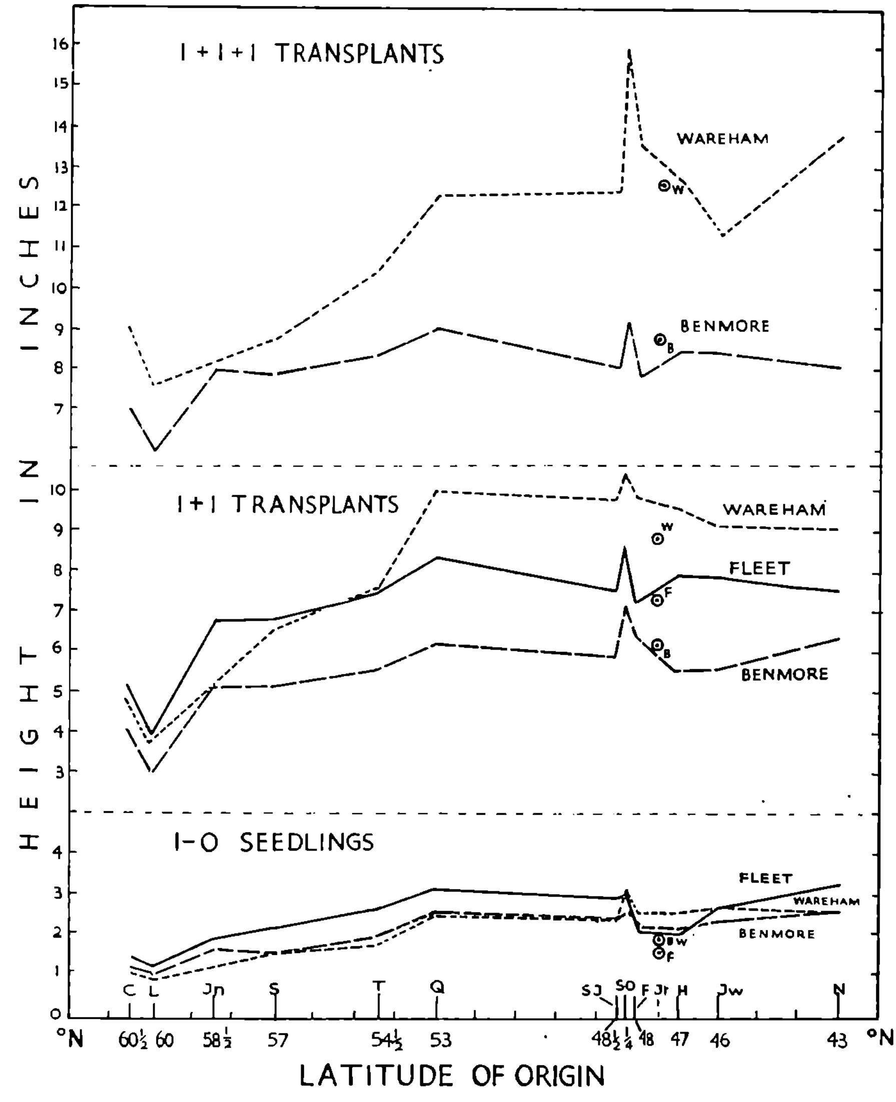

FIG. 8.—Height of Seedlings and Transplants in the Sitka Spruce Provenance Experiments.

A consistent feature of these experiments is the good performance of plants from Sooke, Vancouver Island, both in relation to the other provenances as a whole and in relation to the growth of the neighbouring provenances of San Juan River, 40 miles to the north, and Forks, 40 miles to the south. At present this can only be attributed to a local variation in the general pattern of behaviour. The plants from Jutland, were similar in height to plants from Washington.

It has already been noted that there is a tendency for seed size to *decrease* with decreasing latitude, but that seedling size *increases* with decreasing latitude. This would appear to lead to the conclusion that there is no relationship between seed size and seedling size, a conclusion contrary to that found for many other species. However, a closer examination of the data shows that within any group of three or four neighbouring provenances, the differences in weight of a thousand seeds is reflected in the height of the one-year old seedlings, thus supporting the generally accepted view that the bigger the seed, the bigger the seedling. However, this relationship appears less important for Sitka spruce (the seed of which is relatively small) than the relationship that southern provenances grow faster than northern ones.

(b) **Root Collar Diameter.** The root-collar diameter of a sample of 30 seedlings and 30 transplants of each provenance from Wareham was assessed at the end of the first and second seasons. Table 20 shows these diameters and also the ratio of root-collar to height of the same plants.

Table 20

Root-collar Diameter and Height Diameter Ratio for 1+0 *Seedlings and* 1+1 *Transplants, Sitka Spruce at Wareham Nursery*

	Root-collar Diameter (mm.)		Ratio Height/Collar Diameter	
	1+0	1+1	1+0	1+1
Cordova	1·48	3·95	3·9	3·3
Lawing	Not assessed	3·89	—	2·7
Sitka	1·53	4·47	4·3	4·5
Terrace	1·74	4·25	5·5	4·5
Skidegate	1·79	4·52	6·3	5·2
San Juan River	1·70	4·33	5·9	5·7
Sooke	1·62	3·86	7·1	6·3
Forks	1·48	4·04	7·9	6·7
Hoquiam	1·49	3·88	6·6	6·2
Jewell	1·58	3·84	6·6	6·2
North Bend	1·43	4·00	6·7	6·2
Jutland	1·49	4·02	7·1	5·9

It is clear from Table 20 that there is far less variation in root-collar diameter between various provenances than there is variation in height; the variation in the ratio root-collar/height principally reflects the differences in height. Comparison of the root-collar and height measurements for the seedlings showed that for any given provenance there was a very highly significant correlation between diameter and height of seedling; this has been previously shown for Sitka spruce by Rutter (1955). Comparisons of the mean root-collar diameters of the different provenances have given far less indication of relative subsequent growth than have comparisons of mean height.

Survival of all provenances was so good following transplanting that there was no evidence on which to test the relationship between diameter and survival reported by Holmes (Edwards and Holmes 1951).

(c) **Seedling Weight.** The seedlings measured for root-collar diameter were also weighed. The variation in weight with provenance followed a pattern intermediate between those for height and root-collar diameter.

Commencement and Cessation of Growth

(a) **Commencement of Growth.** All the plants in these experiments were disturbed by transplanting in late winter or early spring, before the commencement of growth. Not too much importance should, therefore be given to the observations that there was only a short interval between the dates when provenances started to grow, and that the Alaskan provenances broke bud about a week earlier than the more southerly ones. There were no severe late spring frosts during the period of these experiments.

(b) **Cessation of Growth.** In contrast to the beginning of the season, the time of cessation of growth and formation of resting buds has varied by more than three months between extreme provenances, the pattern of behaviour being similar in each of the three nurseries. All Alaskan provenances commenced to form terminal buds in July; a certain amount of lammas growth was made, especially by plants from Sitka, but growth had virtually stopped by the end of August. Plants from further south continued growing longer and hardened off later, the farther south their origin; the British Columbian provenances (except Sooke) had formed most of their terminal buds by early October, provenances from Washington (together with Sooke) by mid to late October, and most of the plants of the two Oregon provenances by the end of October.

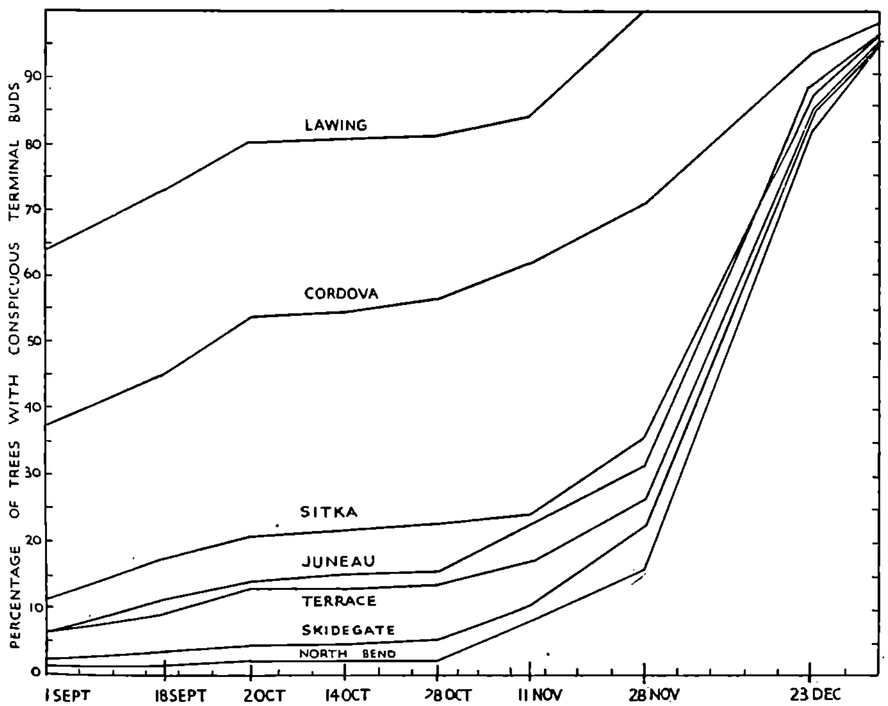

FIG. 9.—Progress of Development of Conspicuous Terminal Buds by Plants in the Sitka Spruce Provenance Experiments.

Figure 9 shows the differences in the date of terminal bud formation at Fleet nursery in 1959. In this figure, values indicate the percentage of *conspicuous* terminal buds formed. Observations suggest that plants are relatively frost-hardy as soon as terminal and side buds can be found, even though the terminal bud is not conspicuous.

There is an obvious *prima facie* connection between date of cessation of growth and height growth made during the season; the longer the plants grow, the greater their height at the end of the season. This is considered to be real and to be a more important cause of the differences in height found between provenances, than differing rates of growth during the earlier part of the growing season.

(c) **Susceptibility to Frost.** There were autumn frosts in late October each year in all three nurseries, but the frosts were not severe, and serious damage was sustained only in the seedbed stage and by the two Oregon provenances; losses in the seedbed due to frost varied from 10 to 25 per cent for the most southerly provenance of all (North Bend, latitude 43°N) while the next most southerly provenance – Jewell, latitude 46°N – suffered 1 to 5 per cent losses. Losses in the lines also occured, but these involved less than one per cent of all the plants in the experiments, the provenances affected again being those from Oregon. In view of the relatively mild and late autumn in 1958, '59 and '60, none of the provenances which continued growing late in the season can be considered to have been severely tested. The reports by Edwards (1953) of past instances of severe autumn frost damage to Washington and Oregon provenances in the nursery, stressed the association of damage and growth late in the season.

The evidence from the nursery stage of the present collection does, however, suggest that the southerly provenances may suffer more severely from autumn frost in colder years, and that susceptibility to frost may yet limit their performance in the field.

Postscript

The raising and observation of provenances in the nursery is merely the first stage in establishing a provenance experiment in the forest. Almost all the plants raised in these experiments have been planted on sites ranging over most of the western part of the British Isles. It remains to be seen whether the patterns of behaviour observed in the nursery continue or are replaced by others.

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SIMAZINE – A WEEDKILLER FOR FOREST NURSERIES

By J. R. ALDHOUS

Summary

The results of about 50 experiments carried out in 1958 to 1960 show that simazine can be applied with safety at rates up to 4 lb. (50 per cent wettable

powder) per acre to most conifer and hardwood transplants raised in forest nurseries. Some second-year seedbeds can also be treated safely with simazine at this rate. These results agree closely with those of workers in other countries. Species which are not clearly resistant to simazine at 4 lb. (50 per cent W.P.) per acre are European larch, *Picea omorika*, poplars, and common ash.

The residues from one year's treatment do not affect the crops in the following year.

Growth of germinating annual weeds following treatment with simazine is very substantially reduced, but established annual weeds or perennials may be unaffected.

Properties of Simazine

Simazine (2-chloro-4, 6-bisethyl-amino-1,3,5-triazine) is one of several derivatives of triazine, the weed-killing properties of which group were discovered in Switzerland and were announced in England in 1956 (Gysin and Knüsli 1956). It is a stable colourless solid which is almost insoluble in water. It is not poisonous to human beings or animals (Weed Control Handbook, 1960). It is usually formulated and sold as a wettable powder containing 50 per cent simazine.

Herbicidal Properties

Simazine (also other triazines) appears to be taken up through the roots, of these species being able to germinate in the presence of quantities of simazine which kill most other seedlings, including germinating conifers. Established deep-rooted plants and, in particular, many species of woody plant, are also able to tolerate amounts of simazine which kill germinating seedlings (Gysin and Knüsli 1958). Simazine is extremely toxic to newly-germinated seedlings of all weed species commonly found in forest nurseries, but it has no effect on weed seeds.

Mode of Action

Simazine (also other triazines) appears to be taken up through the roots, and to be translocated to the leaves where it interferes with photosynthesis, inhibiting sugar formation. It is usual for seedlings of susceptible species treated with simazine to survive for two to four weeks after germination before dying; towards the end of this period, the seedlings turn yellow and eventually wither. The triazines do not have any growth-regulating effect. Reports agree that it is essential for rain to carry simazine into the rooting zone of young weeds (i.e. 0–$\frac{1}{2}$ inch of the top-soil) if the chemical is to have any effect.

Simazine is not taken up through the foliage; the risk of damage to established plants (whether weed or crop) by this weed-killer coming into contact with the foliage is very small indeed.

Factors Influencing the Persistence of Simazine in the Soil

(a) **Uptake by Plants.** Appreciable amounts of simazine can be taken up by plants and so removed from the soil; in particular, plants resistant to simazine can take it up and so lead to more rapid re-colonisation of treated ground than on ground where the resistant species is absent (Dewey 1960).

(b) **Absorption on Soil Particles.** Absorption on the soil colloids (and hence, inactivation) is given as the reason why up to five times more simazine may be required to control weeds on heavy soils or soils with a high content of organic matter than on light sandy soils (Gysin and Knüsli 1959, Dewey 1960).

(c) **Leaching.** Leaching does not appear to be a serious cause of loss of simazine. Most workers who have investigated the penetration of simazine into the soil report that after a period of not less than four months, the bulk of the residues in the soil were found in the surface 0 to 2 inches, and that only a very little penetrated 6 inches or more.

(d) **Microbiological Breakdown.** Simazine can be broken down by fungi and by bacteria in the soil, the rate of breakdown being faster in soils with a high organic matter content than in soils where the organic matter is low. The results of Audus (1960) for the microbiological breakdown of growth auxin weedkillers, can be expected to apply to simazine, so that the rate of microbiological breakdown of simazine may well *increase* with successive applications as the population of micro-organisms capable of breaking down and utilising simazine builds up (i.e. successive applications of simazine may gradually become less persistent and less effective in controlling weeds).

(e) **Photochemical Breakdown and Evaporation.** Little is known about either of these factors, though there is some evidence that they might be important in hot weather (Dewey 1960).

It is quite impossible at present to say which of the above factors will determine how simazine disappears. However, it is quite clear that simazine does slowly disappear from the soil, and that its 'half life' (i.e. the time taken for the quantity existing in the soil to be reduced to a half of that originally applied) is in the region of 10 to 16 weeks.

Table 21

Details of Location and Soil of Nurseries Where Simazine Experiments Have Been Carried Out

Nursery	County	pH of Soil (in water)	Mechanical Analysis of Soil (U.S.D.A. System)			
			Fine and Coarse Sand	Silt	Clay	Soil Type
Alice Holt	Hampshire					
Bramshill	Hampshire	4·6; 5·9*	85	8	7	Loamy sand
Fairoak	Monmouth	5·1; 7·5	56	21	23	Sandy clay loam
Ferndown	Dorset	4·5; 5·5	74	15	11	Sandy loam
Honeywood	Essex	7·1	44	36	20	Loam
Kennington	Berkshire	5·1	83	3	14	Sandy loam
Llyn	Caernarvon	4·9; 5·1; 5·9	62	23	15	Loam
Savernake	Wiltshire	4·3	18	59	23	Silt loam
Tair Onen	Glamorgan	5·2; 5·8; 6·2	28	48	24	Loam/Silt loam
Wareham	Dorset	5·3; 5·9	65	20	15	Sandy loam
Waveney	Norfolk	5·2	89	4	7	Sand
Ystwyth	Cardigan	4·6; 5·1	8	46	46	Silty clay

Note: *Where two or more pH values are given, they represent values in different sections of the nursery. Each value is the average of two samples.

Experimental Work

Experiments on the use of simazine were carried out in the period 1958–60, as detailed in Tables 21 and 22. The objects of these experiments were:

(1) To confirm reports that woody species were resistant to simazine;
(2) To obtain quantitative evidence on the effect of simazine as a weed-killer;
(3) To assess the importance of simazine residues persisting from one year to the next. (At the time this programme was planned very little work on persistence of simazine had been published.)

(1) The Resistance of Woody Species to Simazine

These can be most conveniently discussed in three groups:
(a) Transplants and undercut rising two-year-old seedlings;
(b) Poplars;
(c) Rising one-year-old seedlings.

(a) Transplants and Undercut Seedlings. Table 22 gives details of the species and of the age of stock used at the *end* of the year in which they were treated, and a note of species damaged by simazine.

In 1958, there was one experiment, at Alice Holt Research Nursery. In 1959, experiments were carried out at Kennington Research Nursery and in part of the Conservancy nursery at Bramshill. In 1960, there were experiments at Kennington and Alice Holt Research Nurseries and at 14 Conservancy nurseries. A list of these nurseries, together with the results of a mechanical analysis and pH test of the soil in each experimental area, are given in Table 21.

Simazine was applied, using an 'Oxford' precision sprayer, as a suspension in water at rates of 2, 4, 8 or 16 lb. (50 per cent wettable powder) in 60 gallons of water per acre. (The 16 lb. rate was omitted in trials in Conservancy nurseries.) The spray was applied between the rows of plants, spraying right up to the base of the stems. No attempt was made in the majority of nurseries to remove weeds which were already established at the time of spraying.

The spray was applied between the end of March and mid-May, according to circumstances. In experiments in research nurseries, it was applied one week after transplanting or five weeks after transplanting. In the experiments in Conservancy nurseries, the interval between transplanting and application of simazine varied, though it was applied in late April/early May in all cases.

Plots were usually six feet by four feet, though they varied by $\pm$ one foot to suit local circumstances. Each plot contained six or more rows of plants. Transplants were usually spaced at eight by two inches. Undercut seedlings were in rows six to seven inches apart, the distance between seedlings varying from a half to two inches. In research nurseries, each plot included six species of transplants (one per row); in Conservancy nurseries, there was one species only per plot. Plots were replicated three, four or six times according to the experiment.

The number and height of live plants in each plot was assessed at the beginning and end of the growing season. Where there was only one row of a given species in a plot, *all* plants were assessed for survival and height growth; where there were several rows of one species in a plot, all the live trees were counted and a sample from the centre two rows in each plot was assessed for height.

Table 22 summarises these and earlier results, and shows that applications of 4 lb. per acre of simazine (50 per cent w.p.) have generally done no damage at all to transplants and second-year seedbeds; the scorch that has occurred has

Table 22

Age, Type and Species Used in Experiments on the Effect of Simazine on Transplants

Year:	1958		1959		1960	
Species	No. of Expts./ Age of Plant	Damage	No. of Expts./ Age of Plant	Damage	No. of Expts./ Age of Plant	*Damage; Nursery Concerned; Rate of Simazine; and Age of Plant
Scots pine	1/1+1	None	1/1+1	None	1/1 u 1, 4/1+1	Ferndown, 8 lb. reduced No.1+1
Corsican pine	—	—	1/1+1	None	1 each/1 u 1, 1+1, 1+2, 2+1	None
Lodgepole pine	—	—	—	—	4/1+1	Kennington; 4 and 8 lb. slightly scorched 1+1
European larch	—	—	—	—	1/1+1	Wareham; No. of 1+1 reduced by 8 lb.
Hybrid Larch	—	—	—	—	1/1+1	None
Japanese larch	1/1+1	None	1/1+1	None	1/1 u 1, 4/1+1	Kennington; 8 and 16 lb. scorched and reduced No. and height of 1+1
Norway spruce	—	—	—	—	1 each/1 u 1, 1+2, 2+1	None
Sitka spruce	1/1+1	None	1/1+1	None	4/1+1, 1/1+2	None
Serbian spruce	—	—	—	—	2+1	Fleet, 3 lb. scorched 2+1
Douglas fir	1/1+1	None	1/1+1	None	1/1 u, 3/1+1, 1/1+2	Kennington, 8 and 16 lb. scorched 1+1
Western hemlock	—	—	1/1+1	None	1/1 u 1, 2/1+1, 1/1+2, 1/2+2	None
Tsuga mertensiana	1/2+1	None	—	—	—	—
Western red cedar	—	—	1/1+1	None	1 each/ 1 u 1, 1+2, 2+2	None
Lawson cypress	—	—	—	—	1 each/1 u 1, 1+1+1, 1+2	None
Abies grandis	—	—	—	—	1 each/2+1, 1+2	None
Abies procera	—	—	1/1+1	None	1/1+2	None
Beech	—	—	—	—	1 each/1+1, 2+1, 1+2	None
Sweet chestnut	—	—	—	—	1/1 u 1	None
Oak	—	—	—	—	1/1 u 1, 1/2+1	None
Ash	1/1+1	None	—	—	—	—
Birch	1+1	None	—	—	—	—

†1u1 = One-undercut-one, i.e. two-year-old seedlings undercut at three to four inches in March of the second year.

‡Included only in an unreplicated trial at Fleet Nursery, South Scotland.

*'Damaged' means either that a statistically significant reduction in the numbers or height of plants was found as a result of assessments, or that there was some visible scorch of foliage. The two forms of damage did not always go together, e.g. the remaining Scots pine transplants at Ferndown appeared quite healthy and normal in spite of the significant reduction in plant numbers.

been slight. Applications of 8 lb. simazine have caused damage in about one experiment in six. These results form the basis for the recommendations for the use of simazine given at the end of the paper.

No species appears especially susceptible to simazine from the results in Table 22, though Euorpean larch plants were damaged by the higher rates of simazine; Gast (1960) also reports that European larch is more susceptible to simazine than other conifers. Japanese larch appeared to be more resistant. The other species which appeared to suffer quite extensive scorch was *Picea omorika*. However, this species was included only in an unreplicated field trial, and it was not quite clear whether the scorch was due to simazine or to some other factor.

At one nursery, application of simazine to Sitka spruce, and at another application to Japanese larch, was followed by an increase of height at the end of the season. This increase in height can be attributed to the benefits of a reduction of weed competition, which on untreated ground at both nurseries was intense. In unreplicated trials in 1960 in two Scottish nurseries, similar increases were observed in the height of Norway and Sitka spruce and Lodgepole pine transplants sprayed with 3 lb. per acre simazine (50 per cent), compared with unsprayed transplants.

(b) Experiments on Poplar. Experiments were carried out in 1959 and 1960 at Alice Holt and Kennington Nurseries. Table 23 gives details of the age and clones used, the plot size and number of plants per plot. The rates and method of application of simazine were similar to those in the transplant experiments already described.

Table 23

Poplar Stocks Used

Year	Nursery	Clone	Age at Beginning of Experiment	Plot Size (feet)	No. of Plants Per Plot
1959	Alice Holt	Various. . . .	3 to 6-year-old Poplar stools	4 × 8	8
1960	Kennington	P. tacamahaca x trichocarpa 37	9-inch cuttings	4 × 8	8
1960	Alice Holt	P. nigra x tacamahaca . .	9-inch cuttings	4 × 8	8

Table 24

Survival and Height of Poplar One-year Shoots from Cuttings End of 1960

Rate of Application lb. Simazine (50% w.p.) Per Acre	Percentage Survival		Height in Feet	
	Kennington	Alice Holt	Kennington	Alice Holt
0	82	100	3·6	5·7
2	84	99	3·2	5·6
4	80	100	2·8	5·5
8	76	100	2·5	5·4
16	59	97	2·1	5·1

In 1959, simazine was applied in early June to poplar stools which had been cut back at the beginning of the year and had formed new, actively growing shoots. The stools were examined carefully at the end of the season but no damage was observed on any plot.

In 1960, simazine was applied within seven days of cutting insertion or 28 days later, cuttings being inserted in mid-April so that the top of the cutting was flush with the soil surface. The mean height of the shoots growing from each cutting was assessed at the end of the season; results are given in Table 24 (page 159). (The mean of the results for the two dates of treatment are given as they did not differ significantly from each other.)

The number of plants surviving at Kennington was seriously reduced by sprays of simazine at 16 lb. per acre, and slightly reduced by 8 lb. At Alice Holt there was no significant effect on survival. The effect of simazine on height growth was also more marked at Kennington than at Alice Holt, where it was very slight. At both nurseries, however, the more simazine was applied, the less height growth the poplars made. These results agree with those obtained in Switzerland (Anon. 1959).

(c) **Experiments on Newly-sown Seedbeds.** Simazine was applied as pre- or post-emergence sprays to seedbeds in Kennington and Bramshill Research

Table 25

Number and Height of Seedlings in Experiments with Simazine Applied as Pre- or Post-emergence Spray

(Heights in inches)

Rate of Application lbs. Simazine Per Acre (50% wettable powder)	Scots Pine				Japanese Larch				Douglas Fir				Sitka Spruce			
	Ken.		Bram.		Ken.		Bram.		Ken.		Bram.		Ken.		Bram.	
	No.*	Ht.*	No.	Ht.	No.	Ht.	No.	Ht.	No.	Ht.	No.	Ht.	No.	Ht.	No.	Ht.
Pre-emergence (late April)																
2	80	2·7	70	2·4	36	4·3	20	3·2	11	2·9	37	1·9	63	1·1	38	1·2
4	48	2·5	113	2·7	24	3·9	15	3·4	14	2·5	42	2·3	36	1·3	29	1·1
8	19	2·4	85	2·5	9	6·1	10	4·3	3	2·1	45	2·4	2	0·6	21	1·3
Post-emergence 4 weeks after pre-emergence (late May)																
2	97	3·3	95	2·4	68	5·7	12	2·1	23	2·6	45	2·0	89	1·3	29	1·0
4	102	3·2	98	2·6	62	5·6	10	4·6	17	2·6	39	2·4	76	1·4	18	1·6
8	103	3·1	92	2·4	56	4·7	18	4·8	16	2·3	41	2·2	52	1·2	27	1·2
8 weeks after pre-emergence (early June)																
2	100	3·4	89	2·6	54	6·0	14	4·3	18	2·7	41	2·5	84	1·5	33	1·6
4	103	3·0	76	2·4	67	5·7	13	4·1	11	2·3	37	2·0	90	1·3	38	1·0
8	98	3·1	93	2·6	54	5·5	17	3·5	12	2·7	37	2·2	87	1·3	21	1·3
12 weeks after pre-emergence (late July)																
2	96	3·1	99	2·5	63	5·7	16	3·6	14	2·0	45	2·5	104	1·2	32	1·5
	104	3·2	92	2·6	63	5·5	14	2·9	23	2·2	43	1·9	91	1·5	29	1·3
	104	3·1	98	2·5	60	5·2	18	4·3	18	2·2	36	2·1	104	1·2	28	1·3
Control (a)**	108	3·1	98	2·4	66	5·5	12	3·6	17	2·6	42	2·0	98	1·4	22	1·5
(b)	102	3·1	92	2·3	57	5·4	14	3·5	23	2·3	39	2·1	104	1·4	26	1·0
Standard +	4·7	0·36	11·0	0·18	2·6	0·32	3·2	0·64	2·9	0·20	5·1	0·21	8·0	0·10	7·6	0·22

*Number of seedlings per band, 4 by 36 inches. Height in inches.

**Control (a) was given a pre-emergence spray of vaporising oil at 60 gallons per acre at the same time as the pre-emergence spray of simazine was applied. Control (b) was given the same pre-emergence spray as control (a), but in addition sprays of white spirit at 15 gallons per acre were applied monthly, commencing one month after the pre-emergence spray.

Nurseries in 1959. Beds were sown in early April with five conifer species; the pre-emergence spray was applied 21 days after sowing, and the post-emergence sprays four, eight or 12 weeks after the pre-emergence spray. The rates and method of application were as in the experiments previously described. Table 25 summarises the results of these two experiments.

Table 25 shows that at Kennington pre-emergence sprays of simazine seriously reduced the number of all four species and reduced the height of two species, but that the post-emergence sprays had little effect except for application of 8 lb. per acre four weeks after the pre-emergence spray. At Bramshill, the simazine had no apparent effect on any species. These results suggest that simazine may possibly be of use as a post-emergence spray.

(2) The Effect of Simazine on Weeds

(a) Weeding Time. In all the experiments previously described, the time taken to hand-weed individual plots was recorded. With one exception, the weeding time was less where simazine had been applied than where it had not, though the amount of the reduction varied according to the nursery and the amount applied. Table 26 shows the average weeding times, taking together the results of 34 experiments in Conservancy nurseries in 1960.

Table 26

Average Annual Weeding Time – 1960 Conservancy Experiments

Rate of Simazine (lb. per acre, 50 per cent wettable powder)	Total Weeding Time (Minutes per square yard)	Weeding Time as a Percentage of Control
0	2·42	100
2	1·67	69
4	1·40	56
8	1·07	44

These results show that there was a substantial saving where simazine had been applied even at the lowest rate, but that the higher the rate of application, the less the time spent weeding. Although the reduction in weeding time in these experiments is clear and substantial, it is not as great as it might have been owing to the failure in some nurseries to remove established weeds before spraying.

The reduction in weeding time following an application of 4 lb. simazine (50 per cent w.p.) per acre ranged from as little as 7 per cent at Waveney, where there were very few weeds, to 68 per cent at Fairoak, where there were numerous annual weeds.

In terms of cash, the saving in direct cost of hand-weeding following an application of 4 lb. simazine per acre, has ranged from 15*s*. per acre to £30 per acre, with an average of £19 per acre; against this, £9 to £10 per acre has to be set as the cost of simazine plus cost of application.

(b) Weed Species. All species of newly-germinating weeds have been killed by simazine in these trials, death occuring *after* the seedlings emerged above ground. Annual weeds which root deeply (e.g. spurrey), or perennial weeds (e.g. couch, creeping buttercup) which were well-established at the time of spraying, have not been killed by simazine, though established shallow-rooting weeds (e.g. annual meadow grass) have been checked severely or killed. There was a suggestion in two nurseries that perennial weeds, sorrel in particular, had benefited from the removal of competing annual weeds and were more vigorous where simazine had been applied than where it had not.

(c) **Effect of Soil Type on Weed Growth.** There was no clear evidence in any of the results that lighter soil nurseries needed less simazine for a given control of weeds than nurseries with heavy soils. Table 27 gives the effect of 4 lb. simazine (50 per cent w.p.) with the two lightest soils (Waveney and Bramshill), two of the heaviest soils (Savernake and Tair Onen), and two soils intermediate in texture.

Table 27

Reduction in Weeding Time (per annum) in Nurseries of Contrasting Soil Type

Nursery	Soil Type (percentage coarse + fine sand)	Weed Category (see footnote)	Percentage reduction in weeding time following application of 4 lb. simazine (50% w.p.) per acre	Actual reduction in weeding time (minutes per plot) following application of 4 lb. simazine (50% w.p.) per acre
Waveney	Sand (89)	1	7	0·1
Bramshill	Loamy sand (85)	3	47	1·3
Llyn	Loam (62)	5	22	0·4
Fairoak	Sandy clay loam (56)	3	32	1·5
Tair Onen	Silt loam (28)	4	6	0·1
Savernake	Silt loam (18)	3	46	1·2

Weed categories: (1) Few weeds – those present almost entirely *Poa annua.*
(2) Moderate weed population – mostly annuals, very few perennials.
(3) Numerous annual weeds, few perennials.
(4) Numerous perennial weeds, some annuals.
(5) Numerous annual and perennial weeds.

The table shows clearly that in these experiments, the most important factor was the weed flora, and that soil type was relatively unimportant.

(3) Simazine Residues

Experiments were carried out in 1960, at Kennington and at Bramshill, to test the effect of simazine residues on crops in the year following application.

In the main experiments, plots which had been sprayed with simazine in spring 1959 at rates up to 16 lb. (50 per cent w.p.) per acre had seed of four species, namely Scots pine, Sitka spruce, Japanese larch and Western hemlock, sown in spring 1960 on half of each plot, and one-year-old seedlings of the same species transplanted on to the other half.

Germination of the seed and growth of young seedlings and transplants was quite normal on all plots. On this evidence, there is no reason to fear the effect of any residues on ground treated in the spring of one year with simazine at rates of up to 16 lb. per acre, when crops are established in the following spring.

In subsidiary experiments, known quantities of simazine were cultivated into top-soil shortly before sowing or transplanting. These experiments had been intended to provide a yardstick against which any damage occurring in the main experiments could be measured. Table 28 shows the least quantity of simazine causing a reduction in numbers or height of seedlings and transplants.

Table 28

Least Quantities of Simazine Found Effective

(Least quantity of simazine (lb. 50 per cent w.p. per acre) applied and dug into the top five inches of soil, immediately before sowing or transplanting, which reduced numbers and heights of conifer seedlings and transplants. Kennington and Bramshill, 1960)

Species	Number				Height			
	Seedlings		Transplants		Seedlings		Transplants	
	Ken.	Bram.	Ken.	Bram.	Ken.	Bram.	Ken.	Bram.
Scots pine	8	8	16	>16	(2·4)8	(8)16	>16	(8)16
Japanese larch	4	(8)16	4	>16	(4) 8	8	4	>16
Sitka spruce	8	16	(16)>16	>16	(4) 8	16	(8)>16	(16)>16
Western hemlock	8	>16	4	>16	(4) 8	>16	>16	>16
Lodgepole pine	–	—	8	>16	—	—	>16	>16

Note: (i) Figures in brackets indicate quantities of simazine which reduced numbers or heights appreciably, but not significantly.

These results show that there was often no damage to plants where 4 lb. of simazine (50 per cent w.p.) is cultivated into the top five inches of soil, transplants being markedly less susceptible than seedlings. Where transplants were damaged, the maximum reduction in survival was 25 per cent, and the maximum reduction in height was of the same order. On this evidence, if simazine newly applied to transplants at the recommended rate (*see* the Addendum) did, by accident, get incorporated in the surface layers of the soil, the crop would certainly not be completely lost and might well escape serious damage.

Conclusions

The results of the experiments described above agree closely with the results of other work going on at the same time (Geigy 1959, Gysin and Knüsli 1959, Gast 1960). They lead to the conclusion that simazine is eminently suitable for use as a weedkiller among transplants and some second-year seedbeds in forest nurseries. The majority of the tree species commonly raised in forest nurseries are relatively resistant to simazine, while newly-germinated seedlings of the weed species commonly found in forest nurseries are highly susceptible. There is no clear evidence that the rate of application of simazine should vary according to the soil texture; this is the only point where the results obtained in Britain differ from those obtained elsewhere. There is complete agreement that residues which persist from one year to the next are not likely to damage seedlings or transplants raised in the year following treatment.

Full recommendations for the use of simazine as a weedkiller in forest nurseries are given below.

Recommendations for the Use of Simazine in Forest Nurseries

(1) Rate of Application

4 lb. simazine (50 per cent wettable powder) in 60 to 100 gallons water per acre.

(2) Time of Application

(a) March – May (– August, but see 7(c) below). It can be used immediately after transplanting.

(b) Simazine must be applied when the ground is free of weeds. Established deep-rooting weeds will not be affected by simazine.

(3) Method of Application

(a) Apply as an inter-row spray where possible. (While there is no risk of simazine causing scorch of foliage, every effort should be made to apply it to the soil, rather than waste it on foliage. There is no objection to the spray striking the bottom of the stems of transplants.)

(b) When spraying, take care to avoid overlap (i.e. double dosage), especially if this is likely to occur near the stems of plants.

(c) It is most important to keep the contents of the spray tank continuously moving. Simazine does not dissolve in water and is sprayed as a suspension. It will settle to the bottom of the tank if not kept moving. For this reason:

(i) Make up the simazine/water spray mixture as near as possible to the time it is to be used.

(ii) Ensure that the spray mixture is kept constantly agitated. Many makes of tractor-mounted sprayer have a recirculating device which keeps the contents of the spray tank agitated.

(iii) Clean out the sprayer thoroughly immediately after use. On no account leave a sprayer containing any simazine/water mixture standing for any length of time.

(4) Species

(a) The following species may be sprayed: Norway and Sitka spruce, Scots, Corsican and Lodgepole pine, Douglas fir, Lawson cypress, Western red cedar, Western hemlock, Hybrid and Japanese larch, *Abies procera* (*nobilis*) and *Abies grandis*, oak, beech and Sweet chestnut.

(b) The following species should not be sprayed: poplars, ash, European larch, *Picea omorika*, conifer and hardwood species not mentioned above. Poplars and ash are definitely susceptible to damage. Recommendations with regard to the others may be changed after further experiment.

(5) **Age of Plants**

(a) For species in 4(a) above, transplants of all ages may be sprayed (subject to the preceding paragraph).
(b) Second-year seedbeds, whether under-cut or not, may also be sprayed, as long as plants are more than 2 inches high.
(c) Newly-sown seedbeds must not be sprayed.

(6) **Precautions**

Care should be taken not to get simazine on to the skin as it may occasionally cause irritation. Rubber gloves should be worn when weighing out and mixing simazine; any splashing on to arms, face or clothing should be washed off quickly. Simazine is not poisonous.

(7) **Notes**

(a) Once simazine has been applied to the soil surface, no hoeing or cultivation should take place until it is quite clear from the growth of the weeds that much of the simazine has disappeared. Individual established weeds, overlooked at the time of spraying, should be removed by hand, taking care to disturb the soil as little as possible.
(b) The presence of numerous young *healthy* weeds indicates that most of the simazine has disappeared. A second application may generally be applied up to the end of August (but see 7(c) below).
(c) Applications of simazine in March to May can be expected to have disappeared by August/September, so that should plants have to be re-lined-out on that ground in the autumn, there is no need to fear residues. Applications of simazine in the summer (June to August) should only be made on ground which will not have a new crop lined-out before the late winter or early spring following.
(d) Simazine can also be used to control weeds on paths and waste land. In this case it should be applied at 10 to 15 lb. (50 per cent wettable powder) per acre.
(e) Simazine may clog filters on certain makes of tractor-mounted spray boom. Where this occurs, the filters should be removed.

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WESTONBIRT ARBORETUM

By R. F. WOOD

Westonbirt has been briefly mentioned in previous progress reports. This famous arboretum came into the hand of the Forestry Commission in 1956, and has since been maintained by the Research Branch. It is comprised of two quite separate parts, the arboretum proper of 116 acres, and some 45 acres developed on arboretum lines, in a nearby wood, known as Silkwood, which is 370 acres in extent and forms part of Bradon Forest. The two areas are quite distinct in the manner in which they have been developed.

Westonbirt lies just inside Gloucestershire (part of Silkwood is in Wiltshire), about four miles south-west of Tetbury. The annual rainfall is approximately 35 inches. It is in typical Cotswold country of rather low relief, the arboretum itself being practically level, but separated from Silkwood by a shallow dry valley. The two areas range between 400 and 480 feet above sea level. Westonbirt has, on the whole, a favourable climate. It is near enough to the Severn estuary to receive some maritime influence, and as there is not much higher land in the vicinity, the local frost factor is not excessive. It does not, of course, compare with coastal Devon or Cornwall as regards the length of the growing season or freedom from frost, but is certainly a less restrictive environment than that occupied by the National Pinetum at Bedgebury in Kent.

The arboretum and Silkwood lie on the Jurassic Acton Turville beds, a rather impure limestone which is usually much fractured and fissured at the surface. The soils are rather variable. In the northern half of the arboretum, they are clay-loams of no great depth. Where shallowest, the much-fissured limestone is found at 12 inches from the surface. Soil reaction here is naturally high, in the range pH 6 to 8. Soils increase in depth to the south-west, however, and about the centre of the arboretum clay loams are found some two to three feet deep, with distinctly acid reactions in the top foot. These soils are retentive, and may even exhibit some drainage impedance. They are easily puddled by injudicious treatment in winter. The western third of the arboretum has soils of a very different character, deep, moderately acid (pH 4 to 5), well-drained sandy loams. These may have been derived from a local bed of sandy and easily decalcified limestone. They are so distinct from surrounding soils, and arboriculturally so much more desirable, that it is perhaps not surprising that a local legend recalls that they were specially transported to the site by the founder of the arboretum. The soils in Silkwood are generally not dissimilar to those in the centre of the arboretum. Much of this wood, however, has clay loams which are both deeper and heavier, and in spite of the permeability of the underlying formation, there is even some local gleying. Towards the shallow valley separating Silkwood from the arboretum, the limestone nearly outcrops at the surface. In a narrow belt to the south of Silkwood, rather lighter soils are found which may be related in origin to the sandy loams of the arboretum. Soils at Westonbirt have not seriously restricted the development of a very varied arboretum, but the most important plantations are confined to the deeper soils. They are everywhere of adequate fertility. There is no doubt that the deep acid loams of the arboretum provide the best conditions for subjects sensitive to physical conditions, and also for those intolerant of much free lime in the root-run.

The arboretum was founded by Robert Stayner Holford in 1829, who no doubt planted it as an integral part of the lay-out of his grounds. This is easily seen by the alignment of some of the major rides. The arboretum was sited on agricultural land, not on the site of existing woodland, as none appears here on the contemporary survey maps. The later developments in Silkwood, on the other hand, were carried out in a matrix of old woodland, a typical tract of oak standards with hazel coppice. Robert Stayner Holford lived till 1892, and must be credited with the whole plan of the arboretum and the planting of all the very large trees which today form an invaluable foil and background to the collections. The oldest trees in the arboretum are oaks and Scots pines, some of these having reached very impressive dimensions in 130 years. It appears that the first plantings took place at the western end of the arboretum, on the best soils, and it seems probable that a rather open woodland of big timber with an underwood of yew, laurel, and *Rhododendron ponticum* may have been the first aim. Robert Holford was, however, one of the nineteenth-century planters who were greatly attracted by the north-west American conifers being introduced to the country during his lifetime, and he made an excellent collection of these, and sited them very skilfully, both as single trees and as groups of a dozen or so. The now extremely large specimens of Douglas fir, wellingtonia and Californian redwood are a feature of Westonbirt. A wellingtonia in the grounds of the school is said by Jackson (1927) to be one of the first planted in the country, but generally speaking the conifers in the arboretum do not represent the first introductions of the species. Robert Holford also planted conifers and broadleaved trees from many other parts of the world, and though at first sight the arboretum gives the impression of being predominantly broadleaved, there is in fact an extremely comprehensive collection of conifers, a fair number of which are amongst the biggest specimens of their kind in the country. He had undoubtedly an excellent sense of scale. Many of his rides now appear to be perfect in size with respect to the mature trees beside them.

Robert Holford was succeeded by his son, Sir George Holford, in 1892. Sir George must have multiplied the number of species in the arboretum several times over during his tenure of Westonbirt. His was a period of important botanical exploration in the East, and the Westonbirt collection greatly benefited from his support of expeditions. The rhododendron collection is mainly due to Sir George Holford, and more important, the extensive and imaginative plantings of autumn colouring trees and shrubs which are perhaps the most notable feature of Westonbirt. The *Acer* collection is perhaps the best and most comprehensive in Europe, and the use of the Japanese species and varieties forms the core of the autumn colour display. But many less well-known trees have been planted for colour, such as *Cercidiphyllum*, *Parrotta*, and *Stewartia;* the use of which must have had a considerable influence on arboriculture in Britain. Much attention has also been paid to coloured fruits in trees and shrubs, and also to bark colour. Great ingenuity has been displayed in grouping the smaller subjects against the background of the larger trees. Sir George Holford died in 1926, and his nephew, the fourth Earl of Morley, succeeded to the estate. The third in this series of gifted arboriculturists, Lord Morley continued to plant and diversify the collections, ably assisted by his curator, Mr. W. J. Mitchell.

When Lord Morley died in 1951, Westonbirt Arboretum had a history of over 130 years of sustained endeavour, and equally important, of personal skilled attention. The Second World War brought grave burdens to the estate, and there is no doubt that the arboretum declined somewhat, largely due to shortage of labour. It also suffered from the very success of the planters, who provided an embarrassment of riches, and often (not surprisingly) lacked the necessary ruthlessness to choose between them. The arboretum and Silkwood, together with 117 acres of parkland, were acquired from the fifth Earl of Morley in 1956.

The Commission, on taking over Westonbirt, appointed an Advisory Committee of distinguished arboriculturists and botanists, the Chairman being the Hon. Lewis Palmer, Treasurer of the Royal Horticultural Society. A Research Forester (Mr. E. Leyshon) and an assistant Forester provide the local supervision, and it has been possible to recruit a fairly adequate labour strength, including some of the experienced men employed under the previous management. On taking over the management of the arboretum, the most immediate tasks confronting us have been the following: bringing back the rides and avenues to respectable condition, suitable for regular machine maintenance; salvage operations throughout the arboretum and Silkwood, to free valuable subjects from intrusive growth of natural regeneration or less worthy trees and shrubs; the provision of adequate propagation facilities and nursery space; the mapping and cataloguing of the collection; and the provision of further planting space for new or under-represented subjects by clearing some of the overgrown thickets of common material such as cherry-laurel, *Rhododendron ponticum*, and yew, much of which has spread greatly since it was originally planted as background material. The latter has also required the felling of some heavy timber, where the canopy has been too dense.

The first two tasks require little comment, being reasonably straightforward operations. The rides and much of the ground cover are now in a condition which permits economical maintenance by the appopriate machines. It has been found important to make as much use as possible of machines which will cut herbage efficiently without the need for any raking up afterwards; for example, gangmowers for the main rides, and horizontal rotating-knife types for the herbage between trees and shrubs. Old hardwood stumps present something of a problem, since it is not always convenient to blast, and other methods of extraction are costly, and much damage is done getting the stumps off the ground.

Concerning the provision of propagation and nursery facilities, the position is now very satisfactory. Lord Morley maintained a number of small temporary nurseries scattered about the arboretum, which also served as trial grounds. During the period of acute labour shortage, a number of these became seriously congested and overgrown. Much effort has been required to salvage the best material in these nurseries, a good deal of which had lost its labels, and we have been greatly assisted by members of the Committee in deciding what were the most profitable things to keep. Inevitably there have been losses from crowding and suppression. A new nursery of about half an acre has been prepared close to the offices, and the largest of Lord Morley's nurseries has been cleared out and used to bring in plants from some of the scattered ones. In some of these, large stocks have been root-pruned to make them fit for planting in the near future.

Three sizeable glasshouses were available near the offices. As these were in poorish condition, one was demolished to provide material to bring the other two into good repair. The smaller of these has been converted for propagation, and 'mist' frames installed, with thermostatically controlled soil-heating. Soft water is available from the very large underground tanks storing rainwater from the roofs. The larger house has been fitted with heated plunge beds for grafting work, and is used by the Genetics Section for the production of plants for seed orchards and tree banks. A range of cold frames and plunge pits is being provided for the hardening-off of material vegetatively propagated in the 'mist' frames.

Much progress has been made on mapping and cataloguing, but at the time of writing the work is still not complete. Westonbirt was one of the several arboreta catalogued by Bruce Jackson, this particular catalogue being published in 1927. An interleaved edition of the catalogue with very detailed lists of subsequent plantings was kindly made available to us, and has been invaluable. Unfortunately, neither Jackson's original catalogue nor Mitchell's subsequent planting records were specific enough about the planting site for us to run down the specimen in all cases. Also, a large number of labels had been lost, especially the lead ones, which were often gnawed to illegibility by squirrels. Mr. W. J. Mitchell, now living in retirement nearby, has been most kind in giving us the benefit of his encyclopaedic knowledge of the arboretum. The number of entries in the catalogue and subsequent planting lists totalled over 5,000 items. These entries were transferred to individual cards, which were sorted by locality of planting as far as possible. The arboretum was divided up into a number of sections, and outline maps prepared for each section to the scale of 40 feet to the inch. Each section was then surveyed systematically, all specimens being marked with a number on the plan and entered in a field book. At this stage temporary labels were affixed wherever the identity of the specimen was reasonably certain. Wherever possible, specimens were connected with the original record, as this gave the date of planting and sometimes the source of the plant. It has not yet been decided what form the new catalogue should take, but it seems probable that the local record should be a card index. Much permanent labelling, using an engraved plastic medium, has now been done. Doubtful material has been sent to Kew for identification, or the assistance of visiting botanists obtained on the spot.

The remaining item, the provision of further planting space, has absorbed a great deal of the attention of the Advisory Committee. Certain parts of the arboretum had an almost continuous canopy of sizeable oak, under which masses of yew, cherry laurel, and rhododendron formed an almost impenetrable thicket, interspersed with valuable specimens, many of which were almost impossible to see. The work carried out so far has greatly lightened the overwood to produce the effect of open glades, and yew, laurel, etc., has only been kept where necessary for side shelter on the boundaries, or, where desirable, to provide backgrounds. Felling large timber in an arboretum as crowded as Westonbirt has not been an easy operation, but it has been managed so far with little damage, and the scars of extraction have healed rapidly.

The policy for future planting at Westonbirt has been the subject of much discussion. While representation cannot be considered in detail till the catalogue is completed, several broad decisions of policy have already been taken. The collection will be maintained, and where possible extended. It is not thought practicable to aim at a comprehensive collection over a very wide field, but it is felt that Westonbirt might well attempt to be comprehensive in a few large genera as well as some small ones. *Quercus* and *Acer* have been suggested, in both of which Westonbirt has already very good collections. It has also been decided that Westonbirt should complement the National Pinetum at Bedgebury by representing species of conifers which have not proved successful there. The more fertile soils and lesser frost hazard at Westonbirt should extend the range materially. An area of suitable soil in Silkwood, which already has the nucleus of a conifer collection established on it, has been set aside for this purpose. Silkwood is of considerable extent, and it has not yet been decided how much of it should be kept in reserve for extensions to the arboretum.

The ageing of an arboretum as complex and fully stocked as Westonbirt brings many problems. Many of the finest specimen trees are 100 years old or more, and a number of species are clearly declining. This is most noticeable at present amongst the silver firs (*Abies*). Obviously the policy must be to have younger trees on the ground to take over, but it is plainly going to be difficult, if not impossible, to maintain some of the most attractive groupings by providing a succession of younger trees, simply because there is now not room for potentially large trees to develop without grievous sacrifices. To maintain the collections is one thing, but to maintain the existing aesthetic effect is quite another. Certain of the most successful arrangements at Westonbirt cannot be maintained indefinitely, and can only be reproduced by starting afresh elsewhere. There should be two different sorts of rotation carried on in such an arboretum, one concerned with the progressive replacement of ageing trees and shrubs throughout the arboretum, the other involving more drastic replanning of whole sections. For this it is essential to have adequate reserves of land.

Westonbirt is becoming increasingly popular with the public, and it has been necessary to provide parking facilities for up to 800 cars. A leaflet guide (Forestry Commission 1961) has been printed, but it will be desirable to publish a more adequate description of the arboretum in the near future.

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THE PROTECTION OF REPLANTED GROUPS WITHIN CONIFEROUS FOREST AGAINST ROE DEER

By G. G. STEWART and S. A. NEUSTEIN

The roe deer, *Capreolus capreolus* L., which is native to Great Britain, for preference inhabits thickets, scattered woodlands and the outskirts of large forests. It damages young trees in two ways – by browsing the shoots, and by fraying the stems. The latter form of damage usually occurs on a small scale and though it is conspicuous, it is of little importance; it is caused when the bucks are cleaning their antlers, or demarcating their territories. However, browsing damage can be very serious, and may prevent the establishment of planted groups within standing crops. Normal deer fencing will exclude deer from these areas, but is very expensive. Consequently, cheaper means of excluding deer from small areas under regeneration within standing crops, are required. In 1958, a series of trials was begun with this object, and this paper summarises the results.

Sites

The first experiment was at Grizedale Forest, Lancashire, and was laid down by the Conservator for North West England with assistance from Research Branch. Three other experiments were established the following year (1959) – at the Forest of Ae, Dumfries-shire; Newcastleton, Roxburghshire; and Portclair, Inverness-shire. In all cases, deer were known to frequent the selected areas. A description of the sites is given in Table 29.

Table 29

Description of Experimental Sites

Forest	*Grizedale*	*Ae*	*Newcastleton*	*Portclair*
Elevation (feet)	700	900	1,200	150
Vegetation	Coarse and soft grasses, with some rushes and bracken	Patches of coarse grasses and rushes	Only small patches of rushes	None
Soil	Clay loam	Peaty gley	Peaty gley	Sandy loam
Area	Felled area of about 2½ acres	Area of about two acres, windblown in 1956–58	Two areas of one acre each windblown in 1956–58	Area of about three acres, windblown in 1957
Surrounding crop	Sitka spruce 33 years Sitka spruce/Japanese larch 18 years; European larch/Japanese larch 18 years; Scattered individuals of Scots pine and European larch 36 years, in gap in which replanting was done	Sitka spruce 30 years	Sitka spruce 30 years	Douglas fir 31 years
Species replanted	Norway spruce and Western hemlock (alternate plants)	Lodgepole pine and Sitka spruce (alternate plants)		
Size of plants	Not recorded	3 to 10 inches	4 to 9 inches	6 to 12 inches

Protection Methods

The methods used in the experiments were based on the assumption that deer dislike going where it is difficult for them to walk; and if an area were made sufficiently unpleasant to walk into or through, young trees planted in that area would not be damaged. In the trial at Grizedale the experimental treatments were as follows:

(1) Individual plants protected by branches placed over them forming a tangled layer.

(2) Groups of 300 plants protected by a barrier of branches laid around the perimeter of the group to form a band of branches about 10 feet wide. The main axis of each branch was placed in line with the boundary of the group protected, so that to enter the group, deer had to walk over the branches and not between them.

(3) Unprotected control.

In 1959 the same treatments were used at Ae, Newcastleton and Portclair, with the addition of one further treatment, viz.:

(4) Groups of plants protected with old wire-netting laid on the ground to form a strip 10 feet wide around the edge of the group.

There were slight variations between treatments in the different forests. At Grizedale, the branches (freshly-cut Norway spruce) were laid in spring, but later it was thought that the layers were too thin and they were increased in the summer (with fresh Sitka spruce brash) to make the layers three to four feet high. This was done in both Treatments (1) and (2), which are regarded as extreme treatments. At the other three sites, the protection treatments of branches round the perimeter were constructed mainly of Sitka spruce lop-and-top and the layer was about 18 inches thick. The material was approximately two years old.

At Newcastleton, in the treatment designed to protect individual plants (Treatment (1)), alternate rows were protected with from six to nine branches placed with butts in the ground round each plant to form protecting 'wigwams'.

At Ae and Portclair, the wire-netting in Treatment (3) was placed loosely on the ground, but in places stumps and branches helped to raise it to 12 inches. At Newcastleton, the netting was stretched tight over stumps and pegged down at the edges. This method made walking across the netting, which was about six inches above the ground, much more difficult.

Two species were planted in each trial; at Grizedale, Norway spruce and Western hemlock were used, and at the other three sites, Lodgepole pine and Sitka spruce were planted. It was believed that Lodgepole pine would be attractive to deer and Sitka spruce unattractive.

Because of the small size of the available sites, treatment replication was impossible, except at Grizedale, where the three treatments were laid down in the form of a Latin square with 10 to 20 feet wide strips between treatments. At Ae and Portclair all treatments were in one area, but at Newcastleton two treatments were in one area and two in a second area in the vicinity. The number of plants used in each treatment varied between forests, but was never less than 100 (50 of each species). In all experiments it was assumed that all parts of the area were equally attractive to deer. It is appreciated, however, that the shape of the replanted area in relation to surrounding shelter, wind, compass direction and possible thinning operations may have been of importance.

Assessments

Assessments of damaged and undamaged plants were made in the autumn after planting (1958 or 1959), and were repeated periodically until May 1960. It was considered that degree of damage was a matter of chance – the essential point being whether or not a deer visited the tree. (Deaths from natural causes were excluded.)

Table 30 gives the percentage damage for the various protection methods and species used.

Discussion

Relative Effectiveness of Protection Measures. Comparison of damage between forests depends on the local deer population, disturbance due to timber operations, etc., and these factors have not been assessed. It is seen, however, that

Table 30

Roe Deer Damage on Trees Protected by Different Methods (May 1960)

Forest	Grizedale		Forest of Ae		Newcastleton		Portclair	
Species	Norway spruce	Hem-lock	Sitka spruce	Lodge-pole pine	Sitka spruce	Lodge-pole pine	Sitka spruce	Lodge-pole pine
No. of protected plants per treatment	150	150	50	50	120	120	145	145
Treatment			Percentage of Damaged Plants					
Unprotected control	92	87	54	78	56	81	45	63
Brash round individuals	95	74	42	62	13	24	54	73
Brash round groups	85	83	39	38	21	90	46	74
Wire-netting round groups	—	—	55	94	17	24	21	53
No. of years after planting and protection	2		1		1		1	

total damage over two years at Grizedale is roughly twice that for the one-year period at the other forests. Even the most successful treatments allowed approximately 20 per cent of the trees to be damaged in one year, and without removal of brash, it can be assumed that damage in subsequent years will be at least as great and possibly much greater, since it was noted at Grizedale that the effectiveness of the brash deteriorated after one season.

The concentration of various treatments in a small area might have had the effect of herding deer into the least protected area. This would tend to accentuate the differences between treatments but there is nothing in the results to support this.

No treatment gave consistent effective protection. Only at Newcastleton did the unprotected control (in Sitka spruce) suffer more damage than any of the other treatments.

Costs. These were not recorded separately for each protection method, but taking all treatments together, they were considerably less than for a standard deer fence for the small areas concerned. At Grizedale, where brash had to be transported to the site, costs were almost 10 times as high as where brash was readily available. For larger areas the costs of standard fencing will decrease with increasing extent, whereas the need to transport additional brash from a distance will increase the cost of this form of protection.

Incidental Difficulties. The 'complete cover of brash' constituted a major obstacle to weeding, and if this was delayed led to rotting of the plants under their roof of brash and grass.

Season of Greatest Damage. Damage was first noted in mid-August at Newcastleton and in October at the other forests, although deer were recorded as traversing the area and grazing the heavy grass sward within the plots in summer 1958 at Grizedale even where the brash was three to four feet thick and eight to 10 feet wide. Damage reached a peak in January and February and ceased generally in spring.

Palatability of Different Species. After one year, Sitka spruce was less severely attacked than Lodgepole pine, at the three forests where these species were planted. This confirms the original assumption that Sitka spruce is less attractive to roe deer. At Grizedale, where Norway Spruce and Western hemlock were planted, both species were equally damaged after two years.

Conclusions. In spite of the limitations of these experiments, it can reasonably be concluded that none of the treatments has given effective protection against roe deer. It is not intended to pursue protective measures of this type, but alternative cheap forms of fencing (nylon and polythene netting and electric fencing) are now being investigated (*see* Part I, page 37).

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FECUNDITY OF THE PINE LOOPER MOTH, BUPALUS PINIARIUS

By D. BEVAN and A. PARAMONOV

The results of an investigation into the relationship between the fecundity of female *Bupalus piniarius* L., and the pupae from which they emerged, appeared in the *Report on Forest Research*, 1957 (Bevan and Paramonov 1957). Since that time weights of pupae collected during the routine annual surveys have frequently been greater than those in the range there published, and it would seem to be of practical value to make more widely known an extension of this relationship to include pupae of weights up to 0·26 grams.

The pupae used in this experiment were all derived from larvae bred in the laboratory during 1956, and, although the topmost weight for which data was obtained is in excess of anything so far found in the field, individuals weighing more than 0·2 grams are not rare in British pine forests.

Method

The technique and conduct of this experiment, and the apparatus used, were the same as described in the previous article, apart from the fact that the pupae were not, on this occasion, separated into weight classes, but were bred individually; it was hoped by this modification to avoid any chance of fungal or bacterial infection of a single pupa spoiling a whole weight-class.

Results

The data for Probable Fecundity from this extension experiment is displayed graphically in Figure 10, together with that from the earlier published paper. A total of 220 females were used, 132 in the former and 88 in the latter experiment. Probable Fecundity was before defined as: That quantity obtained by adding the number of eggs laid in the experiment to the number of fully-formed eggs left in the ovary. This measure has been chosen as it is considered by the authors to lie most closely to the true egg-laying potential of the field female.

For Figure 10: Relationship between Fecundity of Females of the Pine Looper Moth, *Bupalus piniarius*, and their pupal weights.

Also for Figure 11: Distribution of Compartments with High and Low Pupal Numbers of *Bupalus piniarius*, Cannock Chase Forest, 1960.

See Oversize Diagrams at end of Text.

Discussion

Following the suggestion made concerning the earlier data, it was decided to test the hypothesis of the relationship of Probable Fecundity to pupal weight, $n = kw^m$ (where n = number of eggs, k and m are constants, w = weight in milligrams). It was found that although this accounted for 43·8 per cent of the variability in possible fecundity, a linear relationship would account for 63·2 per cent. The linear function thus not only gave the better fit but is a simpler expression and has, therefore, been adopted in the form $F = -42 \cdot 34 + 1330\ W$ (where F = probable fecundity, W = weight in grams).

The regression line approximates closely in slope to that published recently by Oldiges (1959), but gives a constant value for egg production, some 10 eggs more for a corresponding weight. Oldiges' 'line', however, is an almost perfect fit to that obtained for the quantity previously defined as Experimental Fecundity (Bevan and Paramonov 1957).

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THE PINE LOOPER MOTH, BUPALUS PINIARIUS, AT CANNOCK CHASE IN 1960

By J. M. DAVIES

In the annual pupal survey 1960, the population density in one forest, namely Cannock Chase in Staffordshire, showed a marked increase over previous years' counts. An extension of the normal survey confirmed the increase in widely separated compartments of this forest. Since pupal counts can only provide a warning, as instanced in the population collapse of both Rendlesham and Sherwood IV forests (Bevan and Brown 1960), it was obvious that a more detailed investigation would have to be carried out at Cannock. The techniques applied were those that had been developed over the years, both at the permanent experimental plot at Thetford, and where threatening infestations had occurred in other forests, e.g. Tentsmuir 1957. At Cannock in 1960 the population did not collapse, but was reduced to such a level that defoliation was no longer a danger, or control a necessity. The following article records the information gathered, and attempts to explain the part played by one parasite, *Cratichneumon nigritarius*.

Cannock Chase Forest lies in an area where the annual rainfall is about 28 inches, and the soil is derived from thin local drifts, especially material from the Bunter sandstone and pebble beds. In the main, the crop is Quality Class II and III Scots and Corsican pine, from 20 to 40 years old.

In 1954 the *Bupalus* population reached infestation proportions and some 2,500 acres were sprayed with D.D.T. Since this operation, there has been a slow increase in the pupal numbers. Table 31 presents a general picture based on forest figures from 1954 to 1960. Examination of this data, in terms of laboratory sorted and sexed pupae for the last two years, showed that in 1959 the average number of pupae per square yard was 1·61 ± 0·10. At this stage in the life history of the moth, 10·3 per cent were parasitised by the Ichneumon fly, *C. nigritarius*. As 38·5 per cent were males, the estimated population of healthy females was therefore 0·89 ± 0·07 per square yard. In 1960, the average number of *Bupalus* pupae was 7·64 ± 0·16. Of these, 22·6 per cent were parasitised, and 46·4 per cent were males. Hence the estimated population of healthy females was 3·35 ± 0·10 per square yard. The extension survey, carried out later in 1960, gave an average number of pupae of 16·2 ± 0·8. There was an 11·6 per cent parasitism, with 46·5 per cent males. The estimated number of healthy females was 8·0 ± 0·6 per square yard.

Table 31

Pupae per Square Yard by Compartments, at Cannock Chase

Compartment Means Pupae/sq. yd.	No. of Compartments in Class							
	1954	1955	1956	1957	1958	1959	1960	1961
0·0 – 0·9	34	100	32	31	34	13	4	2
1·0 – 1·9	7	6	3	4	2	11	13	7
2·0 – 2·9	8	—	—	—	—	4	39	5
3·0 – 3·9	12	—	—	1	—	5	6	6
4·0 – 4·9	6	—	—	—	—	—	7	8
5·0 – 5·9	7	—	—	—	—	2	3	3
6·0 – 6·9	1	—	—	—	—	1	4	3
7·0 – 7·9	5	—	—	—	—	—	1	1
8·0 – 8·9	1	—	—	—	—	—	5	2
9·0 – 9·9	4	—	—	—	—	—	6	2
10 – 19	12	—	—	—	—	—	7	13
20 – 29	4	—	—	—	—	—	5	3
30 – 39	6	—	—	—	—	—	2	—
40 – 99	15	—	—	—	—	—	—	—
100 – 299	7	—	—	—	—	—	—	—
Forest average	35·48	0·17	0·29	0·37	0·25	1·61	7·64	7·13

In May 1960 the material from 100 quarter square-yard pupal plots in L5 was carefully examined. The results are summarised in Table 32.

Table 32

Healthy and Parasitised Pupae

	Pupae		
	Healthy	Parasitised	Total
Males	465	114	579
Females	419	100	519
Total	884	214	1,098

There was, as might be expected, considerable variability in the number of pupae per square yard found in different compartments, ranging from none to 33·2. The distribution of compartments with high and low pupal numbers is indicated in the map, Figure 11. There is a suggestion that the high populations are concentrated at certain points in the forest, particularly in the northern block around compartments L5, L7 and L10 (black), where there were 33·2, 30·0 and 26·4 pupae per square yard respectively. Of these, L5, the compartment containing the highest number of pupae during the forest survey, was selected for more detailed study.

The average number of pupae per square yard was 43·92 ± 0·03. Of these, 19·4 per cent were parasitised, and 19·6 per cent males. This gave the number of healthy females as 16·76 ± 0·012 per square yard. The mean weight of the female pupae was 0·124 milligrams. Hence, with an expected fecundity of 122 eggs per individual, and assuming successful adult hatch, it was quite evident that infestation proportion could be reached with subsequent severe defoliation at the larval stage.

It was obvious that adult and parasite hatch must be checked. In order to do this, 100 (0·1245 square yard) emergence traps were laid down throughout the study plot (L5). Due to lack of time and available staff, this was not completed until after the commencement of adult hatch of male *C. nigritarius*. Daily collections were made from May until November. Every two days the traps were moved a standard distance, to ensure that the second generation of parasites were traced.

Figure 12 indicates the host and parasite numbers over the whole period of emergence and collection.

The main point of interest here is the continued appearance of parasite adults after the initial peak emergence of the overwintering population. In the past it was known that *C. nigritarius* laid its eggs during the autumn in the *Bupalus* pupae. The following year, during April, May, June, depending on the season, this generation emerged. However, at this point, the parasite apparently disappeared from view until again, in September, October, November, parasitised pupae were found. *C. nigritarius* is not specific to *Bupalus*, but the availability of an alternative host in any field area has never offered a solution to this gap in the insect's life history. The hypothesis of repeated parasitism in the later-hatching pupae of the same season had been, in the past, impossible to verify at the then very low host population levels. However, laboratory experiments carried out in previous years, and field data obtained during the Rendlesham Forest infestation of 1959 have supported this idea. At Cannock Forest in 1960, pupae collected towards the end of July, through August and September, were almost all parasitised, with the last larval stage, or developing pupae of *C. nigritarius*, present. On these occasions, adults were also observed in flight, except for one period towards the end of June till the third week in July.

Trap emergence for host and parasite are recorded in the following Tables 32, 33, 34. Table 33 represents the total possible emergence of the winter generation, while Table 34 summarises the second generation of parasites that had developed in the later-hatching *Bupalus* pupae.

At the completion of adult *Bupalus* hatch only 9·9 ± 0·4 per square yard of the expected 43·92 ± 0·03 had successfully emerged, whilst 13·85 ± 0·5 parasites had appeared by July 10th. Thereafter, the number per square yard

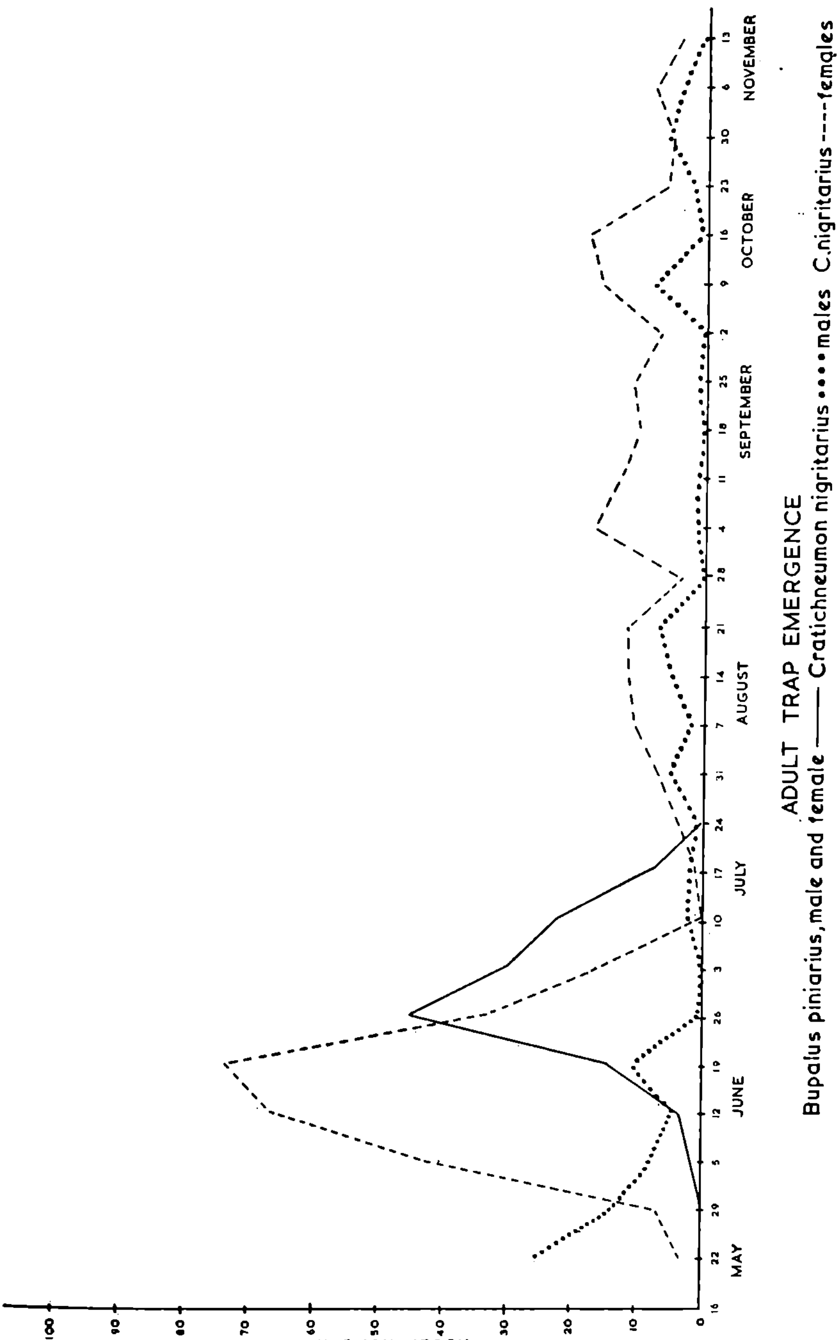

FIG. 12.—Emergences of Pine Looper Moth, *Bupalus piniarius*, and its parasite *Craticheumon nigritarius*, at Cannock Chase Forest in 1960.

Table 32

Bupalus piniarius Adult Emergence

	No. recorded	per sq. yd.
Total emergence . .	123	9·90±0·4
Males	55	4·42±0·3
Females	68	5·42±0·3

Table 33

Cratichneumon nigritarius Adult Emergence Before July 10th

	No. recorded	per sq. yd.
Male	52	4·22±0·3
Female	120	9·64±0·4
Total	172	13·85±0·5

Table 34

Cratichneumon nigritarius Emergence After July 10th

	No. recorded	per sq. yd.
Male	57	4·62±0·3
Female	270	21·70±0·7
Total . . .	327	26·20±0·7

of parasites was 26·2 ± 0·7. This suggested that the major portion of the potential number of host adults (43·92) had been destroyed by this parasite.

Subsequent egg sampling in L5 gave a mean number of eggs per tree of 2,469, a figure below that set as the critical infestation level. The effect of egg parasitism was negligible, since it only amounted to about one per cent. It was at this stage that control measures were confirmed as being unnecessary.

However, the study of this population continued and the wastage during the larval stage is illustrated in Table 35 below. The figures represent the results from 50 head-capsule collecting-funnels. In addition, periodic larval collections confirmed the examination of winter pupal and cocoon material in that the larval parasite, *Campoplex oxyacanthae*, was not present in this part of the forest, nor was it observed in the foliage during adult flight.

Prior to *Bupalus* larval drop and pupation, 100 (0·1245 square yard) trays were put down in the compartment, and each day throughout September, October and November, the number of larvae was counted.

At this time the parasite *C. oxyacanthae* leaves the host larvae to spin its cocoon and overwinter in the soil. Breeding and dissection of this tray material gave no evidence of the presence of this parasite; hence in this study *C. oxyacanthae* was not an important factor in larval mortality. The results from these larval drop trays gave a figure of 22·8 possible pupae per square yard for the

Table 35

Head-Capsule Data

Cannock 1960 – Compartment L5

Week Ending	No. of Collections Received	Head-Capsules					Larvae			Prepupae			Pupae	
			Instars				Instars			Instars				
		I	II	III	IV	V	IV	V	VI	IV	V	VI	IV	V
8.7.60	48	6	—	—	—	—	—	—	—	—	—	—	—	—
29.7.60	50	17	—	—	—	—	—	—	—	—	—	—	—	—
12.8.60	46	92	6	—	—	—	—	—	—	—	—	—	—	—
8.9.60	50	405	367	69	6	—	—	—	—	—	—	—	—	—
4.10.60	50	5	88	317	223	73	1	6	1	—	—	—	—	1
2.11.60	50	—	—	16	104	5	5	10	—	1	26	—	1	5
10.11.60	47	—	—	2	2	2	—	15	1	2	27	2	—	1
30.11.60	49	—	—	—	1	—	—	—	1	—	9	—	—	—
		525	461	404	336	80	6	31	3	3	62	2	1	7

1961 population, while those collected incidentally from the funnel traps during fourth, fifth, and sixth instars, etc., gave an additional probable pupal average of 16·37 per square yard (Table 35).

In late November 1960, when pupation would have been completed, another 100 quarter square-yard pupal plots were examined in the study area. These produced a mean of 17·0 pupae per square yard with 9·9 per cent parasitism. At this time the annual survey was also carried out in the forest, and it appears from these figures that the overall distribution has altered, so that the centre of high population in the northern block has shifted and spread to other compartments.

Discussion

One feature of general interest emerged from this investigation, that of the complexity of factors that must influence the host, *C. nigritarius* played a part in controlling the potential infestation at Cannock Chase in 1960. It was suspected that the success and relative abundance of this parasite was not solely due to availability of host numbers, but also to favourable effect of high atmospheric humidity on survival rate.

Summary

(1) Adult *Bupalus piniarius* emergence amounted to only one quarter of those expected from the results of the winter pupal survey.

(2) Comparison of parasite spring and summer emergence with host emergence suggests that *Craticlineumon nigritarius* played an important part in the control of *B. piniarius*.

(3) Subsequent egg and larval sampling, together with field observations of foliage damage, indicated that the threat had been largely reduced, and control measures were therefore unnecessary.

(4) Pupal counts in November 1960 indicated that the population had been reduced from the threatening level in the previous spring.

(5) Later counts in the annual survey suggest that the centre of high population has moved from the northern block to other parts of the forest, and will probably form part of the investigations during 1961.

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THE EFFECT OF HIGH-PRUNING ON THE COST OF BARK-PEELING SCOTS PINE THINNINGS

By D. W. HENMAN

The study reported here is a parallel one to that published earlier for Douglas fir (Zehetmayr 1952).

An experiment was laid down in 1939 at Tentsmuir Forest, Fife, to investigate the costs of high-pruning Scots pine and the effects of this high-pruning on the costs of a variety of subsequent operations such as felling, snedding and peeling, as well as on the value of the produce as poles and saw-timber. The underlying object was to see whether pruning effected any savings, in these routine operational costs, which could be set against the cost of the pruning and thus increase the margin of profit in the pruned produce.

In practice, the costs were examined through the medium of the time taken to perform the various operations. The pruning, felling and snedding operations were timed on a plot basis, a method subject to difficulties connected with the small number of replications of the treatments, variations in the number or size of trees treated, and the spreading of working time over a rather long period, with varying conditions of weather, site, etc. In the bark-peeling study, which is the main subject of the present report, these factors were largely eliminated by selecting for study a limited quantity of uniform material, divided for timing into many replications.

The original experiment included a number of different pruning treatments, but the bark-peeling time study was confined to material from only two of these:

(1) *Unpruned Control.* No brashing or pruning was done.

(2) *All Trees Pruned*, up to and including the second live whorl of branches, on two occasions, separated by an interval of seven years.

The Scots pine crop had been planted in 1922. A cleaning was carried out in the crop in 1939, and light crown thinnings in 1942 and 1946. The third thinning, in 1953, was a moderately heavy (C/D grade) low thinning. Pruning was first done in 1939 when the trees were 18 years old and about 20 feet tall. The second pruning was done in 1946. The bark-peeling investigation was carried out on poles felled as thinnings in 1953, seven years after the second pruning.

The thinnings from all four replications of the two treatments were felled, sned and cross-cut at three inches top diameter, giving poles with lengths ranging from 18 to 27 feet, mean length 22 feet. Snedding was required over the entire length of the poles from the *unpruned* control, but for only the top five to six feet of the *pruned* poles.

The thinnings from the four replications of each treatment were pooled, and 54 pairs of poles were then selected, each pair consisting of one pole from each treatment. The two poles in each pair were approximately matched for girth, length, straightness and general appearance. Three such matched pairs formed a 'pruned group' and an 'unpruned group', for each of which the bark-peeling operation was timed. All the peeling was done by one man. He worked steadily through the pairs of groups, the decision to peel either the 'pruned' group or the 'unpruned' group *first* being made at random.

The results, expressed as time taken per pole, are shown in Table 36, which also includes the times for pruning and for felling and snedding. For comparison, the corresponding times from a Douglas fir bark-peeling study at Bennan, Cairn Edward Forest, have been adapted to the same method of presentation and included in the table.

Table 36

Time Taken for Various Operations on Pruned and Unpruned Thinnings

Treatment	Number of poles peeled	Mean length of poles (feet)	Mean pruned length (feet)	Mean volume of poles (Hoppus feet)	Mean time taken to peel one pole (man/mins)		Mean time taken to prune one tree (two prunings) (man/mins)	Mean time taken to fell and sned one tree (man/mins)	Mean time taken to fell, sned and peel one tree (man/mins)
	Scots pine: Tentsmuir								
Unpruned	54	22·2	0	1·21	12·4	—	0	5·9	18·3
Pruned	54	22·4	16·9	1·21	14·6	—	17·6	4·1	18·7
	Douglas fir: Bennan								
Unpruned	54	21·8	0	1·65	—	20·6	0	12·1	32·7
Pruned	54	22·0	17·5	1·65	—	19·6	19·4	7·7	27·3
Standard error					±0·74	±0·55			
Difference necessary for significance at 5%					2·2	1·2			

Contrary to expectation, the *pruned* Scots pine poles actually took longer to peel than the *unpruned* ones, the difference in time, equivalent to over two minutes per pole, equalling that necessary for significance at 5 per cent. This unexpected result was thought to be due to the bulging of the stem which occurs at the branch whorls in Scots pine. These bulges persist for several years after the branches have been pruned, but are largely removed as 'heels' on the branches axed off by snedding, particularly when, as here, an experienced axe-man is employed. The bulges are sufficient to obstruct the smooth passage of a peeling spade even though the actual pruning stub has been occulded or healed over.

In the timing study of felling and snedding, which was less carefully conducted on a plot basis, the operations took longer for the *unpruned* poles. The two operations were not timed separately, but the difference in time taken probably lay mostly in the snedding, since about four times as much snedding was required by the *unpruned* poles. The total time for felling, snedding and peeling was almost the same for *unpruned* as for *pruned* trees, with a slight advantage in favour of the *unpruned* trees.

The additional 17½ minutes per tree initially expended on pruning thus gave no saving in the cost of producing peeled poles. Nor, in this case, was a higher price realised for these *pruned* thinnings, so that the cost of their pruning must be considered a loss which has to be borne by the *pruned* trees remaining in the crop.

It is interesting to compare these results with those previously obtained for Douglas fir. Although the *pruned* Douglas fir poles took one minute per pole less time to peel than the *unpruned* (difference not significant at 5 per cent) and 4½ minutes less to fell and sned, the saving in time was not commensurate with the expenditure involved in pruning, though it may be considered to have reduced the cost of pruning carried by the remaining *pruned* trees.

The studies were made on Scots pine and Douglas fir only, but there is no reason to doubt that similar results would be given by other species. Although management operations, other than bark-peeling, were not costed by very refined methods, the indications are that for these operations, savings in costs as a result of pruning will be small relative to the costs of pruning. The latter, inflated by compound interest, will have to be largely borne by an increase in value of the pruned logs. The importance of this conclusion is that no more trees should be pruned than are expected to reach a size at which their increased value will at least cover the cost of their pruning, compounded to the time of felling.

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PRELIMINARY TRIALS OF CHEMICALS FOR DE-BARKING HARDWOOD PULPWOOD

By G. D. HOLMES

Difficulties have arisen in supplying adequate quantities of hardwood pulping material on account of the narrow specification for straightness and size imposed by existing de-barking machines. An easing of this specification, through development of more versatile peeling machinery, or the use of effective chemical de-barking agents, would permit utilisation of large quantities of crooked hardwood material, much of which is unmerchantable as pulpwood at present.

The existing pulpwood specification is dictated by the capabilities of rotary-cutter de-barkers of the 'Cambio' type, requiring straight billets within a diameter range of 3½ to 12 inches and minimum lengths of three feet six inches. Within this specification such machines are very efficient, but so far there is little or no promise with any mechanical method of de-barking crooked pulpwood.

Straight billets can be peeled with the 'Cambio' and similar machines at a cost of about 1*d*. per hoppus foot, a remarkably low figure compared with hand-peeling methods. Clearly from the outset, chemical methods applied by hand cannot compete with, or undercut, this figure for straight material. Thus, the present enquiry rests entirely on the possibility that chemical methods may permit utilisation of a large additional volume of pulpwood, i.e. crooked material, both in the form of branchwood of large trees, and crooked stems of maiden or coppice origin.

With this background, it was decided, in spring 1960, to proceed with small-scale trials of chemical methods of preparing pulpwood for easier de-barking by hand or machine.

The Nature of the Trials

Choice of Chemicals

Earlier work with chemical de-barking agents (Holmes 1955) was concentrated largely on sodium arsenite, as this was found to give consistently good bark-loosening over a wide range of species, both hardwoods and softwoods. However, this compound is now unacceptable for any large-scale forestry or agricultural use in Britain on account of its high mammalian toxicity, and the attendant risks to operators and wildlife. Accordingly, the present trials were concerned, in the first instance, with assessing the effectiveness of a number of possible alternative compounds to arsenic.

In essence, the process of 'chemical de-barking' involves killing the tree quickly, at a time when the cambium is in an actively dividing, thin-walled condition. If successful, the thin-walled, undifferentiated cambium cells break down and decay rapidly, resulting in a line of weakness freeing the bark and bast from the sapwood.

A *rapid* kill of the cambium seems to be essential if bark-loosening is to be achieved, presumably because thereby the cambium cells are 'fixed' in a thin-walled condition. Slow death of the cambium seems to involve thickening of cell walls resulting in firm attachment of the bast and sapwood, and difficult peeling. These considerations, and the favourable results achieved with sodium arsenite and related compounds, suggested that the desirable properties in a de-barking agent for application to the standing tree, include:

(i) *High Solubility*. It seems important that the chemical is distributed rapidly throughout the tree, which can be achieved by application of a soluble chemical to a basal stem girdle during the period of maximum sap-flow, i.e. late May to early July.

(ii) *Rapid Toxic-action*. Speedy distribution must be followed by rapid toxic action to 'fix' the cambium in a thin-walled condition.

(iii) *Low-mammalian Toxicity*.

On this basis, a short list of 12 compounds was prepared from existing herbicides, for trial in comparison with a 'standard' sodium arsenite treatment, as set out in Table 37.

These compounds and application rates were selected from existing herbicides which have been effective in uses where a rapid, non-selective kill of plant growth was required, e.g. potato haulm destruction, non-selective, and pre-emergence, weed control applications. Application rates were bound to be somewhat arbitrary in the absence of dosage trials, and in most cases generous, near-saturated solutions were used.

Amongst these compounds, the only ones previously tested as de-barking agents were sodium arsenite, sodium monochloracetate, sodium chlorate, ammonium sulphamate, and ammonium bifluoride.

All chemicals, with the exception of 2,4,5-T, were tested both as solution and thin paste applications. The 'paste' treatments were introduced as a possible means of increasing the quantity of chemical retained in contact with treated girdles. The solutions were thickened into a thin paste using carboxymethyl cellulose as a thickening agent.

Table 37

Short List of Herbicides

Compound	Abbrevi-tion	Concentration Used (lb. active ingredient per gallon of water)	Notable Properties
1,1[1]-ethylene-2, 2[1]-dipyridilium dibromide	'Diquat' or 'DQ'	'1' – ¼ lb. '2' – 1 lb.	A new highly soluble, quick-acting, non-selective herbicide (L.D.50 = 400 to 580 mg./kg.)
Sodium mono-chloracetate	'MCA'	4 lb.	A highly soluble but somewhat slow-acting non-selective herbicide. (L.D.50 = 650 mg./kg.)
Sodium arsenite	'SA'	4 lb.	A highly soluble, *quick-acting*, readily translocated, non-selective herbicide. (L.D.50 = 10 to 50 mg./kg.)
Sodium chlorate	'SCL'	6 lb.	A highly soluble, quick-acting, non-selective herbicide. (Low mammalian toxicity.)
Ammonium sulphamate	'AMS'	4 lb.	A highly soluble, easily translocated, non-selective herbicide. (L.D.50 = 3,900 mg./kg.)
Disodium octaborate tetrahydrate	'Borate'	6 lb.	A soluble, but slowly translocated and slow-acting non-selective herbicide. (Low mammalian toxicity.)
Ammonium bifluoride	'AB'	4 lb.	A soluble, quick-acting, non-selective herbicide.
Cresylic acid	'CA'	4 lb.	A quick-acting, non-selective herbicide.
Sodium penta-chlorphenol	'PCP'	1 lb.	A soluble, quick-acting, non-selective herbicide. (L.D.50 = 78 to 210 mg./kg.)
3,Amino-1, 2,4-triazole	'ATA'	½ lb.	A soluble, readily translocated, non-selective but slow-acting herbicide. (L.D.50 = 1,100 mg./kg.)
2,3,6-trichloro-benzoic acid	'TCB'	1 lb.	As the sodium salt, a soluble, readily translocated, slow-acting herbicide. (L.D.50 = 705 to 1,500 mg./kg.)
4,6-dinitrobutyl phenol	'DNBP'	½ lb.	As the ammonium salt, a moderately soluble, quick-acting, non-selective herbicide. (L.D. 50 = 40 m.g/kg.)
2,4,5-trichloro-phenoxyacetic acid (ester)	2,4,5-T	0·15 lb. in *oil*	An oil-soluble, slowly translocated, selective herbicide. (L.D.50 = 350 to 500 mb./kg.)

Note: The figures quoted under 'L.D.50' represent the acute oral toxicity to rats of each chemical, showing the minimum lethal dose expressed in terms of mg. active ingredient per kg. bodyweight. It is, of course, impossible to state whether such data for rats would also apply to humans, but in general, those materials having the lowest 'L.D.50' (the highest toxicity to rats), are also those which give the highest risk of casualties to humans.

Application Methods

All treatments were applied to test trees during the period of maximum sap-rise in June to early July 1960. The method used was to remove a strip of bark at the base of each tree immediately before application of the chemical. These 'band-girdles' were made to completely encircle the stem about 12 inches above ground level, *without* cutting deeply into the sap-wood. Earlier trials on soft-woods indicated that incision of the sap-wood affects the transpiration stream and slows up the upwards movement of the chemical (Holmes 1955). In preparing the girdles, which were six to eight inches wide, a short curved reap-hook was used to incise the top and bottom edges, the resulting 'sleeve' of bark being stripped-off with a small peeling iron.

Chemical solutions were applied immediately, using a 2-inch paintbrush, to saturate the girdle, including the upper and lower edges. In all cases methyl-violet was added to the solutions as a colouring agent and marker. All applications were timed and the volumes of material required recorded.

Crops Treated. The peeling problem relates to a wide range of hardwood species, but for the purpose of this enquiry the scope had to be restricted, and oak was selected as the species most likely to give rise to large quantities of crooked, potential pulpwood material. The trial plots were established in two oak plantations, at Alice Holt Forest, Hants., and Bernwood Forest, Oxon., both consisting of maiden trees averaging four inches Q.G.B.H., and a top height of 35 to 40 feet. Perforce, unit plots were small, consisting of three trees selected to cover the existing girth range, with three replications; thus a total of nine trees per treatment, and 252 trees in each experiment, were employed.

Assessments. The trees were inspected at intervals throughout the season of treatment, recording the extent of foliage and shoot death, and other visible effects. The main assessments were concerned with bark-looseness, which was 'measured' at three stages, viz.:

(i) Standing trees. Interim assessments of bark-looseness in August and October 1960, using a 'Wilcox Bark Gauge' on standing trees (Wilcox 1954).

(ii) Felled trees. The whole of one block was felled in November 1960. Each tree was assessed by taking four sampling points equidistant along the stem, starting 12 inches above the girdle and finishing 12 inches below the three-inch diameter point of the main stem. Each sampling point consisted of an 18-inch length of stem from which a 'sleeve' of bark was removed and assessed for ease of peeling.

(iii) Felled trees. In April 1961, a further block was felled to provide material for drum-de-barking tests. These tests were done in an industrial plant through the generous co-operation of the Bowater Pulp and Paper Company Ltd. (Kemsley Division).

These drum-de-barking tests were restricted to the treatments shown to be effective in (ii). Each log, depending on the length, was cut to provide two or three 3 foot 6-inch sample billets, as shown in Figure 13 below.

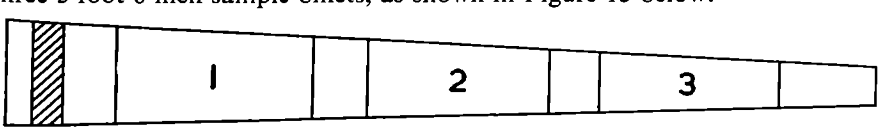

FIG. 13.—Method of Cutting Sample Billets for Drum Debarking Tests.

In the case of short logs, i.e. less than 12 foot 6 inches from girdle to three inches diameter limit, billets (1) and (3) only were taken.

Table 38

Early Effects Assessed as Intervals as Percentage of Crown Killed

Treatment	Alice Holt				Bernwood		Notes
	Percentage Crown Killed On (Days After Treatment)						
	27.6.60	20.7.60	22.8.60	10.9.60	20.7.60	10.9.60	
	11 days	34 days	67 days	86 days	11 days	63 days	
Diquat (¼ lb./gal.)							
Solution	10	60	100	100	20	80	Highly effective, crowns dead within two months
Paste	20	60	100	100	20	100	
Diquat (1 lb./gal.)							
Solution	40	80	100	100	40	100	Higher rate, slightly quicker acting.
Paste	40	80	100	100	60	100	
'MCA' (4 lb./gal.)							
Solution	60	80	80	80	80	40	Very quick-acting, but parts of crown alive two months after treatment.
Paste	80	80	80	80	80	80	
'SA' (4 lb./gal.)							
Solution	80	100	100	100	80	100	Very quick-acting, and completely effective within one month.
Paste	80	100	100	100	100	100	
'SCL' (6 lb./gal.)							
Solution	40	60	60	80	60	60	Quick-acting, but effect incomplete within two months.
Paste	80	80	80	80	80	100	
'AMS' (4 lb./gal.)							
Solution	40	60	60	80	40	60	Quick-acting, but effect incomplete within two months.
Paste	60	80	80	80	40	60	
Borate (6 lb./gal.)							
Solution	2	5	10	15	10	5	Effects irregular and unimportant.
Paste	2	10	20	15	10	5	
'AB' (4 lb./gal.)							
Solution	60	100	100	100	60	80	Quick-acting and effect generally complete within one month.
Paste	60	100	100	100	80	100	
'CA' (4 lb./gal.)							
Solution	0	2	10	7	0	0	Effects negligible.
Paste	2	2	4	7	10	5	
'PCP' (1 lb./gal.)							
Solution	0	0	10	10	20	5	Effects negligible.
Paste	0	0	15	10	10	0	
'ATA' (½ lb./gal.)							
Solution	5	10	20	20	5	5	Effects negligible.
Paste	0	5	20	20	0	0	
'TCB' (1 lb./gal.)							
Solution	5	20	25	30	0	20	Effects slow and incomplete.
Paste	20	25	40	40	15	40	
'DNBP' (½ lb./gal.)							
Solution	0	5	10	10	0	10	Effects negligible.
Paste	0	10	10	10	20	10	
Control –No treatment	0	0	0	0	5	0	No crown deaths.
'Control' girdled only	0	0	0	0	0	0	Trees indistinguishable from complete controls.

Treatments were applied on June 16th at Alice Holt, and July 14th at Bernwood, and this difference has had no notable effect on the final crown-kill achieved. However, comparing results 11 days after treatment, it seems that the later application may have given more rapid distribution of the chemical.

Results of Trials

(i) Early Effects on Tree Crowns. The results of scoring the extent of crown death at intervals for three months after treatment are presented in Table 38.

There are no major discrepancies in the pattern of effects between the two sites, and the treatments group themselves fairly clearly into 'successes' and 'failures'. Thus, Diquat, ammonium bifluoride, and sodium arsenite are quite outstanding, and there is little to choose between them, except that the arsenite solution was quicker-acting. Sodium chlorate, ammonium sulphamate, and sodium monochloracetate were somewhat intermediate, both causing rapid, but incomplete, death of the crowns.

Results with these materials showed no striking difference between solution and paste applications, although there is a suggestion in the early scores that the paste form is slightly superior.

The results with borate, cresylic acid, PCP, Amino-triazole, TCB and DNBP were poor, and it is unlikely that they will be of interest for use in this way. From past experience, it seems certain that a speedy and complete kill of tall crowns is an essential stage in effective bark-loosening, so that interest can probably be confined to the first-mentioned compounds.

(ii) Ease of Bark-peeling in the Forest. Bark looseness was assessed on standing trees, and on felled sample trees in winter 1960–61, as described under 'Assessments'. For standing trees, the 'Wilcox Gauge' was used, recording the force required, in grams applied to a 24-inch beam to twist-free a disc of bark 1·5 inches in diameter at heights of two feet and 10 feet above the treated girdle. These results, together with visual assessments on ease of peeling felled trees, are summarised in Table 39 overleaf.

The treatments listed above are those which produced a fair degree of bark-loosening. The remaining treatments had little or no effect and were assessed as having normal tight bark. On most failed treatments the movement of the chemical seems to have been confined to within a few inches above the treated girdle, or restricted to narrow strips extending some six to 10 feet up the tree.

Inspection of Table 39 shows that the only completely successful treatments, i.e. showing an overall bark-looseness score of four to five, were:

(1) *Diquat, ½ lb. per gal.* – in paste only, at Bernwood.
(2) *Diquat, 1 lb. per gal.* – in solution at both centres, and in paste at Bernwood only.
(3) *Sodium arsenite* – in solution and paste at both forests.
(4) *Sodium chlorate* – in paste only, at Bernwood.

These treatments resulted in near-complete freeing of bark from wood along the whole length of log. However, in most cases, the bark 'sleeve', or cylinder, remained intact after felling; but once broken or slit longitudinally, the bark could be sloughed-off with ease in large sheets. Very little bast fibre remained adhering to the sapwood, even at knots and concavities in the logs. In short, de-barking was easy and clean.

The Wilcox gauge readings added little to the scoring data, though there was fair agreement between the two sets of figures, showing that Wilcox gauge readings of 200 grams or less indicate good bark-loosening.

Paste was conspicuously better than solution treatment for Diquat ½ lb., sodium chlorate and 'MCA', all at Bernwood. At Alice Holt, with the exception of sodium chlorate and ammonium bifluoride, the reverse seems to be true. Such inconsistencies between experiments are hard to interpret. More precise

Table 39

Bark Looseness Assessed in the Forest on Standing and Felled Trees, Winter 1960–61

Treatment	Alice Holt						Bernwood						Notes
	Standing Trees[1] (Nov. 1960)		Felled Trees[2] (Nov. 1960)				Standing Trees[1] (Jan. 1961)		Felled Trees[2] (Jan. 1961)				
	Wilcox Gauge (grams)		Ease of Peeling (Score 1 to 5)				Wilcox Gauge (grams)		Ease of Peeling (Score 1 to 5)				
	2 ft.	10 ft.	1	2	3	4	2 ft.	10 ft.	1	2	3	4	
Diquat (¼ lb./gal.)													
Solution	300	30	4	3	3	2	1,100	400	2	2	2	3	Only *paste* treatment at Bernwood fully effective.
Paste	700	70	3	3	3	3	30	0	4	4	5	5	
Diquat (1 lb./gal.)													
Solution	400	130	4	4	4	4	170	130	5	5	5	5	Solution highly effective at both centres; paste only at one.
Paste	700	300	2	2	2	2	0	0	5	5	5	5	
'MCA' (4 lb./gal.)													
Solution	700	800	3	2	2	2	1,500	1,500	2	1	1	1	Tight strips. Results variable but on the whole, poor.
Paste	800	1,100	2	1	1	1	500	1,500	3	3	3	3	
'SA' (4 lb./gal.)													
Solution	350	100	4	4	4	4	0	0	5	5	5	5	Outstandingly good.
Paste	500	150	5	4	4	4	200	0	5	4	5	5	
'SCL' (6 lb./gal.)	500	1,000	1	1	1	1	800	1,000	2	2	2	2	Paste better than solution at both centres, but especially Bernwood.
Paste	230	570	3	2	3	3	70	0	5	5	5	5	
'AMS' (4 lb./gal.)													
Solution	500	500	2	2	1	1	1,500	1,500	1	1	2	2	Variable but generally poor results.
Paste	1,400	1,400	1	1	1	1	1,500	1,400	1	1	2	2	
'AB' (4 lb./gal.)	0	500	3	2	2	2	1,000	500	3	3	3	3	Moderately effective but leaves remains of bast fibres on peeled logs.
Paste	800	500	3	3	3	3	800	800	3	3	3	3	
Control – No treatment	1,400	1,200	1	1	1	1	1,500	1,500	1	1	1	1	
'Control' – Girdled *only*	1,400	1,400	1	1	1	1	1,500	1,500	1	1	2	2	No effects apparent.

Notes: [1] Figures represent the force (grams) required to twist free a 1½-inch diameter disc of bark at two feet and 10 feet above girdle level.
[2] Visual scores of bark-looseness (score '1' = normal tight, to '5' = completely free), at positions 1 to 4 along the log length.

(See footnote for units)

comparisons between paste and solution preparations are desirable. Among the other treatments, *Ammonium bifluoride* was intermediate, giving moderately easy peeling, but detachment was not so clean as in the foregoing treatments, and stringy remnants of bast fibres remained on many logs. *Sodium monochloracetate* showed variable results, and tight strips of bark remained on many trees, suggesting incomplete distribution of the solution through the tree. *Ammonium sulphamate* was unsatisfactory, despite the high degree of crown-kill achieved (Table 38).

2,4,5-*T*, mentioned in the first list of treatments, in fact occurred in a separate experiment concerned primarily with methods of controlling oak coppice by basal-bark spraying with several herbicides. These treatments were applied in early May 1960 at Bernwood, and by October it was noted that 2,4,5-T ester at 0·15 lb. (acid) per gallon diesel oil, as a basal-bark spray, had loosened the bark appreciably on many stems. Accordingly, it was decided to include log samples from this treatment in the drum-debarking trials reported below.

(iii) **Drum Debarking Tests.** As described under 'Assessments' earlier, trees were felled in April 1961 from all promising treatments in one block of the experiment, to provide material for drum-debarking tests. Drum-debarking is a possible method of dealing with crooked pulpwood on an industrial scale, provided the bark can be loosened in advance. The purpose of these trials was to test the effectiveness of selected chemicals in this respect.

Each log was cut into two or three 3 ft. 6 in. billets, depending on length, and each billet marked to enable the tree and billet positions to be identified after processing.

An eight-foot diameter, ribbed and inclined drum, operated by the Bowater Pulp and Paper Co. Ltd. (Kemsley Division), was used for the tests. This drum, which is currently used for final cleaning of partially de-barked imported softwoods, is fed by conveyor belt, and the actual duration of tumbling any one log under the conditions at test ranged from 10 to 30 minutes. The drum rotates in a water trough so that all logs are thoroughly wetted and detached bark can be floated away for separation.

For the purposes of the test, the sample billets were fed into the drum conveyors in random order along with the normal flow of softwood material.After passing through the drum, the billets were grouped according to the quality of de-barking achieved, with the results shown in Table 40.

Table 40

The Number and Percentage of Oak Billets Successfully De-barked following Wet Drum Tumbling for 10 *to* 30 *Minutes*

Treatment	No. of Sample Trees	No. of Test Billets	No. of Billets			Percentage No. of Billets Satisfactorily Peeled (i.e. Cols. 4+5)
			Completely Peeled	Almost Completely Peeled	Peeling Negligible or Nil	
1	2	3	4	5	6	7
Control (no treatment)	18	54	1	0	53	1·8
'Control' (girdled only)	6	16	0	0	16	0
Diquat (¼ lb./gal.)	12	34	12	10	12	65
Diquat (1 lb./gal.)	12	31	23	5	3	90
'MCA' (4 lb./gal.)	12	32	4	1	27	15
'SA' (4 lb./gal.)	12	31	16	0	15	52
'SCL' (6 lb./gal.)	12	32	6	2	24	25
'AB' (4 lb./gal.)	12	33	17	4	12	64
2,4,5-T (0·15 lb./ gal. diesel oil)	6	15	6	3	6	60
Total	102	278				

The drum-debarking process failed completely with billets from untreated trees, and trees which had been girdled only. The bark was hardly marked at all, and it is most unlikely that more prolonged tumbling could achieve the desired result.

The results with treated logs were disappointing when compared with the bark-looseness assessments in Table 39. No treatment gave 100 per cent success, the best being Diquat ¼ and Diquat 1 lb., with 65 and 90 per cent success respectively. Sodium arsenite, with only 52 per cent of billets successfully debarked, failed to come up to expectations, as did sodium chlorate, with only 25 per cent success.

Ammonium bifluoride, on the other hand, with 64 per cent success, was better than early results suggested.

2,4,5-T, at 60 per cent success, was not as good as log inspection had suggested, and MCA was a complete failure.

The position of origin of billets along the length of the original log had some influence on ease of drum-debarking, as shown by Table 41.

Table 41

Number and Percentage of Billets Successfully Peeled from Top, Middle and Butt Sections of Treated Logs

Treatment	No. and Percentage No. of Billets Peeled from:					
	Butt-lengths		Mid-lengths		Top-lengths	
	No.	%	No.	%	No.	%
Control	0	0	0	0	1	5
Girdled only	0	0	0	0	0	0
Diquat (¼ lb./gal.)	6	50	7	70	9	75
Diquat (1 lb./gal.)	9	75	7	100	12	100
'MCA' (4 lb./gal.)	1	8	2	25	2	20
'SA' (4 lb./gal.)	4	33	3	43	9	75
'SCL' (6 lb./gal.)	1	8	2	25	5	42
'AB' (4 lb./gal.)	7	58	5	55	9	75
2,4,5-T (0·15 lb./gal.)	4	33	2	50	3	60

Thus, quite consistently, for each treatment, butt-length billets were less successfully peeled than billets from higher up the tree, and in some cases there is a suggestion that mid-lengths were more difficult than top lengths. This general pattern is not confirmed by the figures for ease of peeling at various heights in Table 39, and it is felt that the differences between types of billet in the drum may be an effect of billet diameter and bark-thickness rather than differences in bark-looseness.

As noted earlier, the bark must be *fractured* or split on treated logs before it can be removed, and unfortunately the de-barking drum as used was not very efficient in this respect. There was a marked absence of abrasion and *sharp* impacts during the process, i.e. the softwood logs were largely barkless and smooth, and all the drum ribs were smooth and rounded. The thicker bark on the butt-length billets was evidently more resistant to fracture than other material.

This idea that the lack of actual fracturing of the bark 'sheath' was a major shortcoming in the drum so far as hardwoods are concerned, is supported by comparison of results on crooked and straight billets (Table 42).

Table 42

Number and Percentage of Crooked and Straight Billets Successfully Peeled in the Drum

Treatment	Crooked Billets		Straight Billets		Overall Percentage of Billets Peeled (From Table 40)
	No. Peeled	Percentage of Total	No. Peeled	Percentage of Total	
Control	0	0	1	3	1·8
'Control' – girdled only . .	0	0	0	0	0
Diquat (¼ lb./gal.) . . .	13	77	9	53	65
Diquat (1 lb./gal.) . . .	17	95	11	85	90
'MCA' (4 lb./gal.) . . .	4	25	1	6	15
'SA' (4 lb./gal.). . . .	14	82	2	14	52
'SCL' (6 lb./gal.) . . .	4	29	4	22	25
'AB' (4 lb./gal.). . . .	10	72	11	52	64
2,4,5-T (0·15 lb./gal.) . .	7	64	2	50	60

Approximately one-half the total number of billets tested were classified as crooked. Comparison of results for crooked and straight material in Table 42 shows clearly that the percentage of successfully peeled billets was substantially greater amongst crooked material than amongst straight. For ease of comparison, the overall percentage success for each treatment is added as a final column in the table.

Observations during de-barking suggest that the reason for the more successful peeling of crooked billets, lies in the fact that the bark on the outside of angles and bends of crooked billets is more exposed to impact and fracture. Once fractured, the rest of the bark disintegrates, and falls off fairly readily.

Table 43

Percentage of Billets Successfully Peeled in the Drum Following 'Solution' or 'Paste' Treatments

Treatment	Percentage No. of Billets Peeled	
	'Solution'	'Paste'
	Per cent	Per cent
'Diquat' (¼ lb./gal.) . .	59	70
,, (1 lb./gal.) . .	94	87
'MCA' (4 lb./gal.) . .	31	0
'SA' (4 lb./gal.). . .	44	60
'SCL' (6 lb./gal.) . .	13	35
'AB' (4 lb./gal.). . .	65	62

This all adds up to a suggestion that much better results could be achieved in drum-debarking of treated hardwoods:

(a) If the drum ribs and liners were sharper to increase impact incisions and bark fracture.

(b) If the drum contents consisted entirely of unbarked hardwood material giving greater abrasion.

Examination of results with solution and paste forms of application of chemical treatment showed no consistent difference in peeling properties between the methods during the drum tests, as shown in Table 43.

Similarly, a break-down of the data according to tree size, within the three to five inches quarter-girth at breast-height range covered, revealed no marked difference in treatment effect between size classes.

Samples of treated logs were taken in November 1960, five months after treatment, and weighed to assess water loss. Results showed no apparent loss in weight during this period, so that moisture content and probable pulping properties of treated wood should be unaffected, viz.:

Treatment	*Wood Weight per Hoppus foot (lb.)*
Control	63·6
'Diquat' (1 lb./gal.)	62·6
Sodium arsenite	60·2
Ammonium bifluoride	64·7

(iv) **Labour Requirement and Direct Cost of Chemical Treatments.** Labour requirements could not be estimated accurately on such an elaborate small-scale experiment, but treatment times were recorded, and their general order agreed with earlier experience of large-scale treatment of softwood stems. Employing a team of three 'girdlers' and one 'painter', trees within the girth range three to six inches quarter-girth at breast-height can be girdled, peeled

Table 44

Estimated Average Chemical Requirements and Costs

Compound	Cost per lb. (active)	Concentration Used	Cost per Gallon	Average Cost per Tree†	Average Cost per Hoppus ft.‡
1	2	3	4	5	6
'Diquat'	36*s.* 8*d.*	¼ lb./gal.	9*s.* 2*d.*	0·48*d.*	0·24*d.*
,,	,,	1 lb./gal.	36*s.* 8*d.*	1·93*d.*	0·96*d.*
'MCA'	2*s.* 3*d.*	4 lb./gal.	9*s.* 0*d.*	0·48*d.*	0·24*d.*
'SA'	2*s.* 0*d.*	4 lb./gal.	8*s.* 0*d.*	0·42*d.*	0·21*d.*
'SCL'	8½*d.*	6 lb./gal.	4*s.* 3*d.*	0·22*d.*	0·11*d.*
'AB'	1*s.* 9*d.*	4 lb./gal.	7*s.* 0*d.*	0·37*d.*	0·18*d.*
2,4,5-T	10*s.* 0*d.*	0·15 lb./gal.	2*s.* 6*d.*	1·00*d.*	0·50*d.*

Notes: †*Col.* 5. 'Cost per tree' is calculated on the use of an average of 20 ml. solution per tree = 227 trees per gallon to prepared girdles.

For 2,4,5-T, applied as a basal bark spray, the average volume was taken at 150 ml. per tree = 30 trees per gallon.

‡*Col.* 6. 'Cost per hoppus foot' – assumes an average tree of four inches B.H.Q.G. and 25 feet of pulpwood, = about two hoppus feet per tree.

and painted at the rate of 20 to 30 trees per man-hour = *about 2d. per tree* on average, i.e. *roughly 1d. per hoppus foot.*

Basal bark spraying, as employed with the 2,4,5-T treatment, is a good deal cheaper, as no preparatory girdling is required. Depending on conditions, some 50 to 100 trees per man-hour can be treated, at an average labour cost of, say, *¾d. per tree*, or roughly *½d. per hoppus foot.*

The quantities and costs of chemicals required in the treatments as applied are presented in Table 44.

Thus, the total direct cost of chemical treatment, including application will be approximately as follows:

2,4,5-T sodium chlorate = 1*d.* per hoppus foot.

'Diquat' (¼ lb.), sodium arsenite, sodium MCA, ammonium bifluoride = 1½*d.* per hoppus foot.

'Diquat' (1 lb./gal.) = 2*d.* per hoppus foot.

These costs will, of course, be additional to the cost of hand- or machine-peeling of the treated material.

Conclusions

(1) The results presented show that chemical treatment of standing oak pulpwood can greatly ease subsequent bark-removal, either by hand or machine.

(2) Amongst the compounds tested, only 'Diquat' 10 per cent, sodium arsenite 40 per cent (and possibly 2,4,5-T ester 1·5 per cent (acid) in oil) gave consistently good results as judged by manual peeling tests on felled trees in the forest. There was no consistent advantage from using a paste preparation instead of a plain water solution for 'Diquat' 10 per cent and sodium arsenite.

(3) Sodium arsenite was merely a 'standard' in these trials and its high mammalian toxicity prevents its use in practice. 'Diquat', on the other hand, has a low toxicity and would be acceptable on these grounds.

(4) The rate of effect achieved with 'Diquat' (Table 38) indicated that felling for peeling could probably commence about six to eight weeks after mid-summer treatment. Although this aspect was not investigated, it seems likely that, like sodium arsenite, 'Diquat' will be most effective applied during the period of maximum sapflow in late May to early July.

(5) Mechanical drum-debarking tests were completely ineffective on untreated logs. Results with treated logs showed that, with the exception of 'Diquat' 10 per cent, which gave 90 per cent success, no treatment gave more than 65 per cent successful peeling after passage through the drum. However, observations during drum-debarking, and the better results obtained with smaller, thin-barked and crooked billets (Tables 41 and 42), suggest that provision of sharper edges and ribs in the drum to cut and fracture the bark will greatly improve the quality of peeling on treated material. Given these features of drum design, it seems certain that 'Diquat' solution at a concentration of five to 10 per cent will enable this method to be used in the de-barking of crooked and straight oak pulpwood.

(6) Chemical treatment had no apparent effect on wood moisture content and weight within five months of treatment.

(7) The indicated costs of treatment, including application, ranged from 1*d.* to 2*d.* per hoppus foot, depending on the compound used. The best treatment, Diquat 10 per cent, cost about 2*d.* per hoppus foot; 2,4,5-T, which showed

promise, was the cheapest at 1*d*. per hoppus foot, but effects were rather inconsistent.

Subsequent peeling of treated logs was not costed, but it is estimated that manual peeling costs in the forest would be less than 50 per cent of normal costs for untreated material, a saving which could appreciably outweight the costs of treatment, especially on crooked lengths. If mechanical peeling is to be done, a de-barking drum of suitable design seems to offer the only method at present for dealing with treated crooked logs.

(8) Any practical extension of these findings is dependent on whether pulp manufacturers are prepared to accept an additional charge of about 2*d*. per hoppus foot to permit peeling and utilisation of crooked hardwood pulpwood. For straight pulpwood, which can be peeled with rotary-cutter type de-barkers at around 1*d*. per hoppus foot, chemical pretreatment is clearly of no practical interest.

If chemicals are applied in hardwood areas, containing a *high proportion* of crooked lengths outside the scope of rotary-cutter peelers, there is a choice of several courses of action, depending on the cost of the drum-debarking methods, i.e.:

(i) Peel both straight and crooked material in a drum-debarker.
(ii) Use a drum-debarker for crooked lengths, and a rotary-cutter peeler for straight lengths.
(iii) Hand-debark crooked lengths, using a rotary-cutter peeler for straight lengths.

All courses would permit relaxation of the present size and straightness specifications, and make available an additional volume of raw material.

(9) Several of the chemicals described, including Diquat, have not been tested on hardwood species other than oak. However, past results with arsenical compounds indicate that chestnut, elm and birch react in a similar manner to oak. Ash and sycamore were found more difficult to peel with arsenic (Holmes 1956). Further tests with 'Diquat' would be required before general prescriptions could be made.

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THE APPLICATION OF ELECTRONIC COMPUTING TO FOREST INVENTORY

By D. R. JOHNSTON

Introduction

Most of the inventory data in the Forestry Commission are obtained from stratified, randomly distributed, one-tenth acre enumeration plots. Within each plot every tree is girthed and the heights of about 10 sample trees are measured.

Before the introduction of electronic computing, basal areas and volumes of individual trees and of plots were calculated from volume tables and tariff tables. (A tariff table embodies a series of tariff numbers, each of which represents a different ratio between basal area and volume. A high tariff number implies large form factor and/or height for a given basal area (Hummel 1955).) Estimates of increment were derived from yield tables, with appropriate allowances for local departures from the yield tables in the quality class/current annual increment relationship, and for differences in stocking between the enumeration plot and the yield table.

These calculations, together with those of standard deviations and standard errors, were made with the help of simple calculating aids such as slide rules and desk calculating machines, and they were time-consuming and expensive.

Electronic computing was introduced in order to eliminate, as far as possible, this repetitive and laborious hand-work, all of which has to be checked. Automatic data processing, of which electronic computing is one example, does not necessitate or imply basically new methods. Existing methods may simply be speeded up. For example, the electronic computer now uses volume tables and tariff tables in the same way as the human operator, but it uses them very much more quickly and reliably. Ultimately, however, it is possible to process data automatically in a way which would be quite impracticable by hand, due solely to the time and cost involved. It is this greatly increased scope for manipulating data which makes a review of methods and aims a desirable concomitant to the introduction of automatic data processing.

Present Position

The use of electronic computing in forest inventory is still in the early development stage. About a year ago, a simple programme was written in Pegasus Autocode for converting breast-height quarter-girth to basal area. After a short trial period this was elaborated to enable volume to be computed from basal areas and height. In order to do this, form factor tables (volume tables) had to be incorporated into the programme. Fortunately, the Forestry Commission Volume Tables were not prepared by graphical methods but were derived from mathematical formulae which express the relationship between basal area, form-height and volume. These formulae were easily incorporated into the computer programme. This programme was first used operationally in the inventory of Thetford Forest, where an additional complication was the need to compute separately the volume of trees infected with the root fungus *Fomes annosus.*

The data collected in the field were exactly the same as usual, namely, the breast-height quarter-girth of every tree in the one-tenth acre enumeration plots and the heights of about 10 of them selected at random. Each tree was recorded as being 'infected' or 'non-infected'.

The girth and height data from each plot were transferred on to punched tape – a medium for feeding data into the computer. The computer then performed the following calculations which, in the past, would have been done by hand.

(i) Counted the number of trees of each species in each girth class and within each species classified them as 'infected' or 'non-infected' with *Fomes.*

(ii) Converted all girths into basal areas.

(iii) Calculated the volume of each tree, whose height had been measured, using the basic formulae from which the published general volume tables were prepared.

(iv) For conifers – calculated a tariff number from the mean volume and basal area of the sample trees and applied the tariff to each girth class, thus converting basal areas to volumes.

(v) For broadleaved species – calculated the total volume of the sample trees using volume table formulae, multiplied this volume by the ratio: total basal area/basal area of sample trees, and distributed the total volume among girth classes according to the total basal area of each girth class.

(vi) Calculated standard deviation, standard error, standard deviation per cent, and standard error per cent, for the estimate of standing total volume of each stratum.

Current annual increment calculations could not readily be programmed for the computer so long as estimates of increment were derived from yield tables, because the Forestry Commission Yield Tables were prepared graphically and cannot be expressed on punched tape in the form of mathematical formulae. Therefore, calculations relating to current annual increment, were made by hand.

The method of data processing used for the Thetford inventory is now standard practice in the Forestry Commission. Apart from the introduction of a simpler form for the recording of data in the field, there has so far been no change in field technique as a result of the introduction of automatic data processing.

The saving in cost resulting from the use of electronic computing will vary according to circumstances, and there is so far insufficient experience upon which to make generalised estimates. As an illustration, however, the cost of the Thetford inventory is given below.

Field Work

Direct labour: Foresters and Assistant Foresters	£1,100	
Overheads: 24 per cent	204	
Subsistence	90	
Transport	70	
	£1,524	
		say £1,530

Tape Punching and Computing

Direct labour: one operator for five weeks	£40	
Computer time	12	
Overheads: 50 per cent	26	
	£78	
		say £80

Subsequent Computation for Increment, Thinning Forecasts and Yield Control		
Direct labour: two Foresters for one month .	£140	
Overheads: 24 per cent	35	
	£175	£175
	Grand Total –	£1,785

The cost per acre enumerated was 1*s.* per 10-year period, or just over 1*d.* per acre per year. The cost per hoppus foot enumerated was 0·008*d.* In other enumerations the calculating has cost almost half as much as the field work. At Thetford the field work cost about £1,500 and the computing about £80. It is reasonable to conclude, therefore, that without the use of the electronic computer the inventory would have cost something like £500 more.

Future Developments

Increment. Quite apart from the programming difficulties, it is unsatisfactory to derive estimates of increment from general yield tables. Various alternative methods of measuring increment are being investigated. They all depend upon measuring radial increment with an increment borer, height increment either being measured or assumed from yield tables, and form factor increment assumed from form factor tables. The increment may either be calculated directly from the data collected at each enumeration, or obtained from a large number of ready-made calculations presented in the form of a series of local yield or increment tables. Unlike general yield tables, to which a particular stand is referred solely on the basis of age and top height, additional information would be required to enter these local increment tables. The sort of additional information required might be the diameter increment of certain trees (for example: trees having mean basal area, the hundred largest trees per acre, trees from each girth class) over the past five or 10 years, and the mean height increment of certain trees over the same period; or, alternatively, the basal area of the stand before the first thinning.

Although the details of the future method of measuring increment have not yet been decided, the mensurational work will be so planned that all the computations involved, either in preparing increment tables or in calculating the increment at each enumeration, will be done by an electronic computer.

Forecasting Future Thinning Production. Future thinning production depends upon present stocking, future increment, and future thinning intensity. A forecast of future thinning production was calculated by hand for Thetford Forest taking these three factors into account. Owing to the large amount of work involved, the data from all the enumeration plots of each crop type were aggregated together so that 40 plots, each of one-tenth of an acre, were treated as one four-acre plot. Briefly, the method of calculation for each crop type was as follows:

(i) A local 'basal area after thinning/ top height line' (line A–B in Figure 14) was drawn. This was based upon local experience, local permanent sample plots, and those enumeration plots which appeared to correspond with the desired stocking for the forest.

(ii) The average basal area stocking per acre (Point C of Figure 14) of each crop type was calculated and plotted over the average top height (Point E in Figure 14). Allowance was made for the fact that on a thinning cycle of four years the average stand has two years basal area increment since the last thinning.

(iii) The present deficit in standing basal area was calculated. This is represented by the line C–D in Figure 14.

(iv) The anticipated increase in average top height over the next five years, and also that over the next 10 years, were estimated (Points F and H in Figure 14). The desired basal area after thinning in five years' time is represented by Point G, while that after 10 years is represented by Point I.

(v) The increment for the next five, and that for the next 10 years, were estimated by projecting the estimate of current annual increment parallel with the general yield table increment curve.

(vi) The basal area increment required to bring the present stocking to the desired stockings in years five and 10 were calculated. These are represented by the lines C'–G and C''—I in Figure 14.

(vii) The differences between total increments for the next five years and the increment required to bring the crop type to the desired stocking represents the prescribed thinning cut. If the present deficit is large, its elimination may be spread over several thinning cycles.

These calculations were, of necessity, rather crude; in the first place the increment data were unlikely to be very accurate, and in the calculations a variable crop was treated as one completely homogenous stand in order to keep the computational work within reasonable limits.

A programme is now being prepared which will enable these calculations to be made by the computer for each individual enumeration plot, and to present the results by girth classes or assortment classes. This development is closely linked with the work on increment determination and, it is hoped, will result in a sound, logical basis for the forecasting of future thinning production.

The Collection of Data. At the present time all the inventory data are being recorded in pencil on printed forms. These data then have to be transferred on to punched tape before they can be fed into the computer. Mr. R. Badan, a Swiss Forestry graduate who has been working at Alice Holt during the past year, has initiated the development of an automatic tape punching caliper with the object of eliminating the need to transfer written data on to tape. As well as being time-consuming, copying always introduces the risk of error. The prototype caliper has 5-hole tape which gives 2^5, i.e. 32 code settings. As the caliper is closed against the tree at breast-height, the moving caliper arm comes to rest in one of 32 possible intervals. This interval represents the diameter class within which the tree falls, and the tape is automatically punched, thus producing a permutation of holes and blanks which represent that diameter class. The fully developed caliper will use 7-hole tape, which gives 2^7, i.e. 128, settings, and this will be able to record the following information about each tree:

(a) Species (by a species coding system).
(b) Diameter at breast-height (in one of 128 possible classes).
(c) Angle of elevation to top of tree }
(d) Angle of depression to base of tree } To calculate height of tree
(e) Distance of observer from tree }

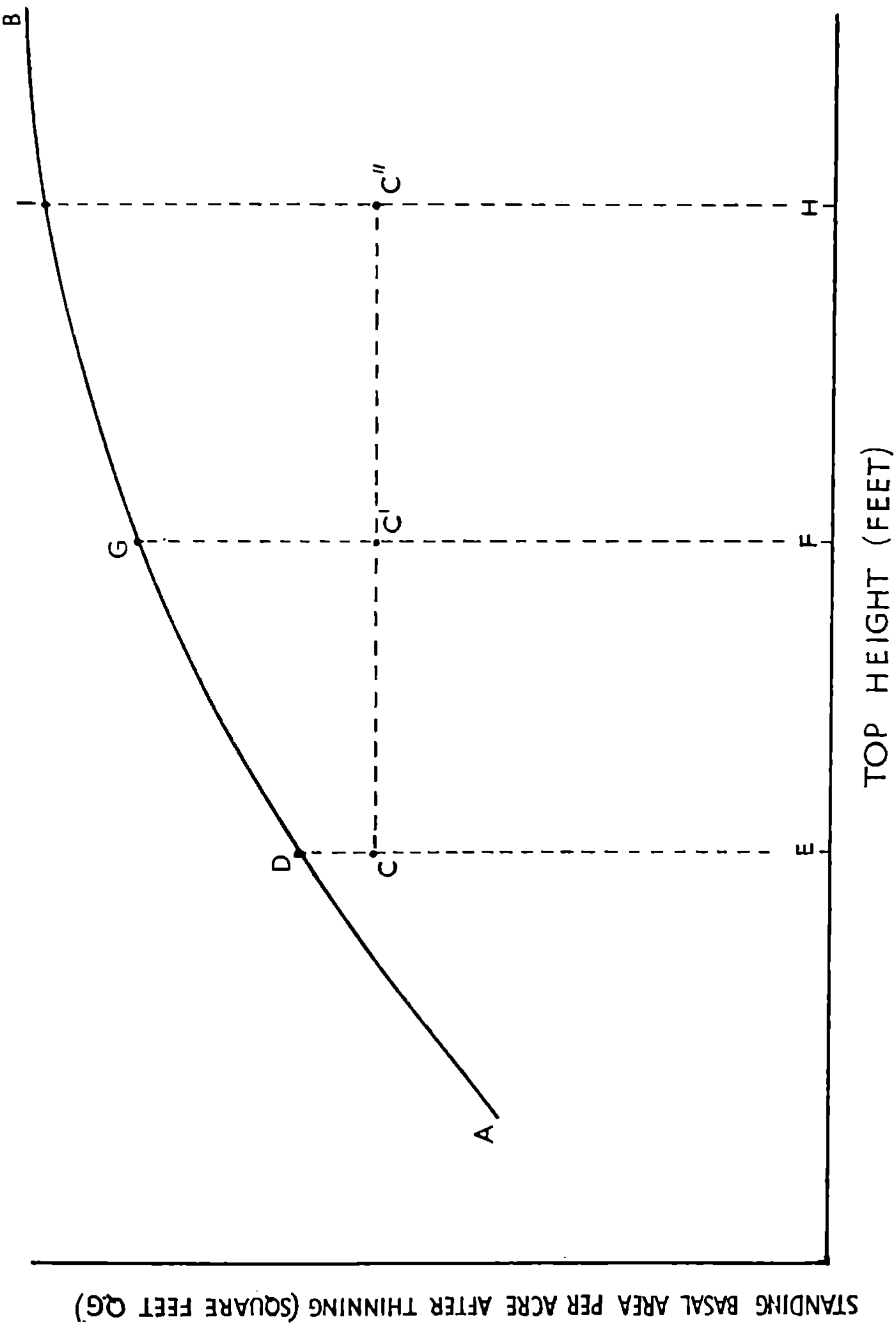

FIG. 14.—Relationship between Standing Basal Area after Thinning and Top Height.

(f) Width of last five or 10 annual rings. (To calculate current annual increment.)

The punched tape will then be ready for the computer, and all subsequent computations will be done automatically.

Conclusions. The most obvious advantages of electronic computing are its speed and economy. Speed is particularly important in forest inventory because of the desirability of completing a working plan in one growing season.

An equally important advantage is the possibility of undertaking computations which would be so laborious as to be quite impracticable by any other method. An example of this is the forecasting of future increment, and future production, by size classes, and also by assortment classes, for every individual enumeration plot measured in the course of a forest inventory.

It is possible that automatic data processing may enable forest inventories to be carried out with rather less experienced staff than would otherwise be necessary. It would obviously be unwise to collect dubious data with inferior staff and then to build an unreliable edifice of results and conclusions upon unsure foundations. Nevertheless, some aspects of hand calculating require considerable experience, particularly the forecasting of future increment and future production, and it would be possible to train field surveyors more quickly if they did not have this work to do also. Although this is perhaps of more importance in under-developed countries, it has some application in more advanced countries where it is often difficult to find staff who combine mobility with experience. Mobility is a condition of service which becomes less acceptable with age, so that a man tends to become less mobile as he becomes more experienced. Therefore, if field surveyors can be trained more quickly, it becomes practicable to retain them on specialised, mobile work, such as forest inventory, for a shorter period of time.

There are also certain difficulties and disadvantages in automatic data processing. It is not possible to carry on with forest surveys in all weathers. Consequently, some clerical work must be reserved for periods of bad weather. If all the computing is done automatically, the surveyors may be left on occasions with nothing to do at all. It has been said that there are risks in relying upon a machine which may go wrong, but this sort of criticism has no doubt been levelled at all innovations for the last few thousands years. A more serious risk is the competition for computer time from other organisations, or sections of the same organisation using the same computer. Before committing a long programme of data collection to automatic data processing it is important to ensure that computing facilities will continue to be available as and when required. Electronic computing is no exception to the general rule that advances in technique are associated with the increasing specialisation of a smaller number of people. This process may require higher standards of organisation, but, in the long run, results in greater efficiency and economy.

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PINE LOOPER FECUNDITY (see page 175)

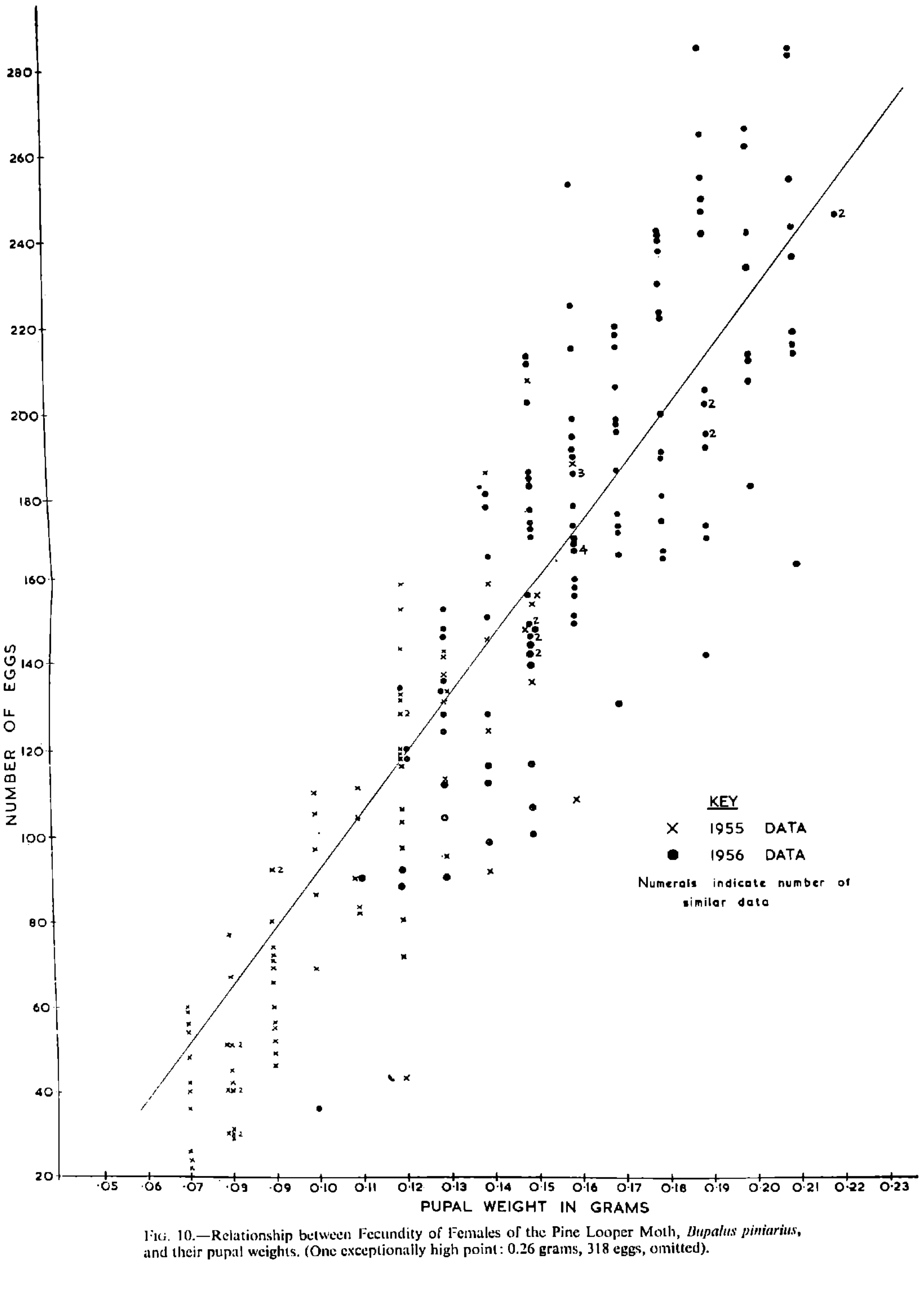

FIG. 10.—Relationship between Fecundity of Females of the Pine Looper Moth, *Bupalus piniarius*, and their pupal weights. (One exceptionally high point: 0.26 grams, 318 eggs, omitted).

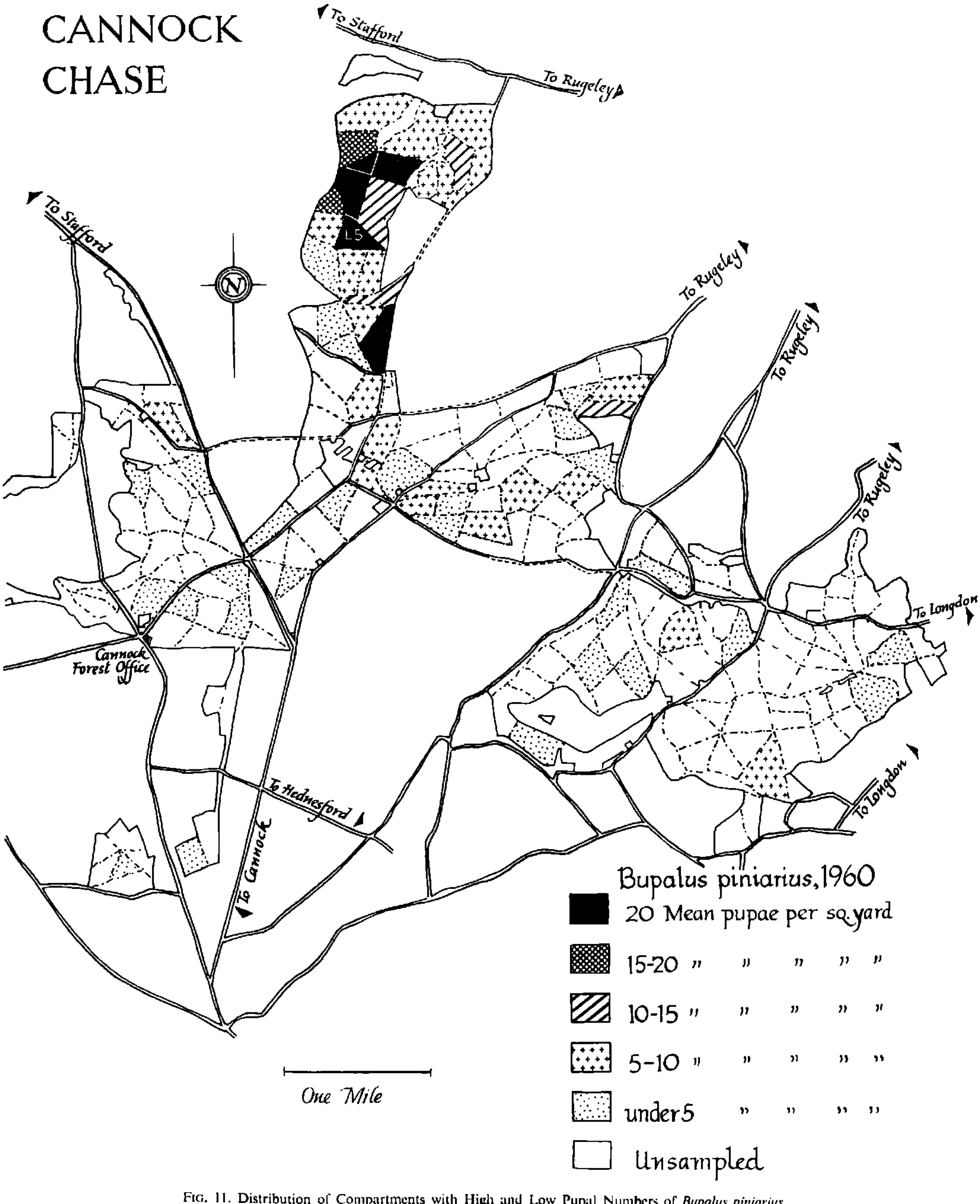

FIG. 11. Distribution of Compartments with High and Low Pupal Numbers of *Bupalus piniarius*, Cannock Chase Forest, 1960 (see page 75).

APPENDIX I

List of Main Experimental Projects and Localities

While most of 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 listed below:

NURSERY EXPERIMENTS

Benmore Nursery, near Dunoon (Argyll)
Bramshill Nursery (Hampshire)
Bush Nursery, near Edinburgh (Midlothian)
Fleet Nursery, Gatehouse of Fleet (Kirkcudbright)
Inchnacardoch Nursery, near Fort Augustus (Inverness)
Kennington Nursery (Berkshire), near Oxford
Newton Nursery, near Elgin (Moray)
Sugar Hill Nursery, Wareham (Dorset)
Tulliallan Nursery, near Alloa (Fife)

AFFORESTATION EXPERIMENTS ON PEAT

Achnashellach Forest (Wester Ross)
Beddgelert Forest (Caernarvon)
Inchnacardoch Forest (Inverness)
Kielder Forest (Northumberland)
Strathy Forest (Sutherland)
Watten (Caithness)—in conjunction with Department of Agriculture for Scotland.
Wauchope Forest (Roxburgh)

AFFORESTATION EXPERIMENTS ON HEATHLAND

Allerston Forest, Harwood Dale (Yorkshire)
Allerston Forest, Wykeham and Broxa (Yorkshire)
Land's End Forest, Croft Pascoe (Cornwall)
Taliesin Forest (Cardigan)
Teindland Forest (Moray)
Wareham Forest (Dorset)

NUTRITION OF ESTABLISHED CROPS

Ardross Forest (Easter Ross)
Bramshill Forest (Hampshire)
Durris Forest (Kincardine)
Exeter Forest, Haldon (Devon)
Tarenig Forest (Cardigan)
Wareham Forest (Dorset)
Wilsey Down Forest (Cornwall)

CONVERSION OF COPPICE

Alice Holt Forest, Marelands (Hampshire)
Cranborne Chase (Dorset)
Forest of Dean, Penyard and Flaxley (Gloucestershire and Herefordshire)

PROVENANCE EXPERIMENTS

Scots pine:	Findon Forest (Easter Ross) Thetford Chase (Norfolk)
Lodgepole pine:	Achnashellach Forest (Wester Ross) Allerston Forest, Wykeham (Yorkshire) Ceiriog Forest (Denbigh) Clocaenog Forest (Denbigh) Millbuie Forest (Easter Ross) Taliesin Forest (Cardigan)
European larch:	Coed y Brenin (Merioneth) Mortimer Forest (Herefordshire) Savernake Forest (Wiltshire)
European and Japanese larches:	Clashindarroch Forest (Aberdeen) Drummond Hill Forest (Perth) Lael Forest (Wester Ross)
Douglas fir:	Glentress Forest (Peebles) Laiken Forest (Nairn) Land's End Forest, St. Clement (Cornwall) Lynn Forest, Shouldham (Norfolk) Mortimer Forest (Shropshire)
Norway and Sitka spruce:	Newcastleton Forest (Roxburgh) The Bin Forest (Aberdeen)
Sitka spruce:	Clocaenog Forest (Denbigh) Glendaruel Forest (Argyll) Kielder Forest (Northumberland) Mynydd Ddu Forest (Monmouth) Radnor Forest (Radnor) Taliesin Forest (Cardigan) Wilsey Down Forest (Cornwall)
Beech:	Queen Elizabeth Forest (Hampshire) Savernake Forest (Wiltshire)

PRUNING EXPERIMENTS

Drummond Hill Forest (Perth)
Monaughty Forest (Moray)

PLANTING EXPERIMENTS ON CHALK DOWNLANDS

Friston Forest (Sussex)
Queen Elizabeth Forest (Hampshire)

ESTABLISHMENT OF OAK

Dymock Forest (Gloucestershire and Hereford)
Forest of Dean (Gloucestershire and Hereford)

POPLAR TRIALS AND SILVICULTURAL EXPERIMENTS

Blandford Forest (Dorset)
Cannock Chase (Staffordshire)
Creran Forest (Argyll)
Doncaster Forest (Yorkshire)
Dyfnant Forest (Montgomery)
Forest of Dean (Gloucestershire)
Lynn Forest, Gaywood (Norfolk)
Quantock Forest (Somerset)
Stenton Forest (East Lothian)
Thetford Chase, Harling (Norfolk)
Wynyard Forest (Durham)
Yardley Chase (Bedfordshire and Northamptonshire)

SPECIES PLOTS

Beddgelert Forest (Caernarvon)
Bedgebury Forest (Kent)
Benmore Forest (Argyll)
Minard Forest, Crarae (Argyll)
Thetford Chase (Norfolk)
Wareham Forest (Dorset)

LONG-TERM MIXTURE EXPERIMENTS

Gisburn Forest (Yorkshire)

GENETICS

Propagation Centres

Alice Holt (Hampshire)
Bush Nursery (Midlothian)
Grizedale Nursery (Lancashire)
Kennington Nursery (Berkshire)
Westonbirt Arboretum, Nr. Tetbury (Gloucestershire)

Tree Banks

Alice Holt (Hampshire)
Bradon Forest (Wiltshire)
Bush Nursery (Midlothian)
Newton Forest (Moray)
Rendlesham Forest (Suffolk)

Seed Orchards

Newton Forest (Moray)
Ledmore Forest (Perth)
Drumtochty Forest (Kincardine)
Archerfield, Stenton Forest (East Lothian)
Whittingehame Forest (East Lothian)
Alice Holt (Hampshire)
Bradon Forest (Wiltshire)
Forest of Dean (Gloucestershire)
Rendlesham Forest (Suffolk)

PATHOLOGICAL RESEARCH AREAS

Knapdale Forest (Argyll)	Top dying of Norway spruce
The Bin Forest (Aberdeen) Lael Forest (Ross) Thetford Chase (Norfolk and Suffolk) Kerry Forest (Montgomery)	*Fomes annosus*
Thetford Chase, Mundford Nursery (Norfolk) Rendlesham Forest, Fen Row Nursery (Suffolk) Lynn Forest, Gaywood Nursery (Norfolk)	Bacterial canker of poplar

ARBORETA

Bedgebury Pinetum (Kent)
Westonbirt Arboretum, Nr. Tetbury (Gloucestershire)
Whittingehame Garden (East Lothian)

RE-AFFORESTATION EXPERIMENTS

Forest of Ae (Dumfries)
Newcastleton Forest (Roxburgh)
Thetford Chase (Norfolk and Suffolk)

APPENDIX II

Staff engaged in Research and Development as at 31st March, 1961

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M. Nimmo	District Officer
J. Jobling, B.Sc.	District Officer
J. R. Aldhous, B.A.	District Officer
A. I. Fraser, B.Sc.	District Officer
W. H. Hinson, B.Sc., Ph.D.	Senior Scientific Officer
G. M. Buszewicz, Mgr. Ing.	Experimental Officer

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R. T. Bradley, B.A.	District Officer

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J. Atterson, B.Sc.	District Officer

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R. J. Affleck	Higher Executive Officer

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WORK STUDY

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S. Forrester, B.Sc.	District Officer
N. Dannatt, B.Sc.	District Officer
J. P. Vérel, B.Sc.	District Officer
J. B. Wharam	Senior Executive Officer

APPENDIX III

List of Publications

Begley, C. D., and Howell, R. S.	Air seasoning softwoods at stump. *Forestry*. 33 (2) 1960 (187).
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Johnston, D. R.	A New Working Plan Code in Great Britain. *Emp. For. Rev.* 39 (1) 1960 (54–60).
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FORESTRY COMMISSION

REPORT
ON FOREST RESEARCH
for the year ended
March, 1962

LONDON
HER MAJESTY'S STATIONERY OFFICE
1963

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Forest Research Station, Forestry Commission, Alice Holt Lodge, Wrecclesham, Farnham, Surrey

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All the photographs are taken from the Forestry Commission's own collection.

INTRODUCTION

By JAMES MACDONALD

Deputy Director General

The serious illness of Mr. T. R. Peace, who was unable to undertake his duties between 2nd January and the end of the period under report, has been a distressing feature of the year. In his absence, Mr. R. F. Wood acted as Chief Research Officer.

In September, Dr. F. C. Hummel, the Management Officer, was released for an assignment with F.A.O. in Mexico. His place was taken by Mr. D. R. Johnston. Dr. D. H. Phillips, who had previously served with the Department of Agriculture, Jersey, was appointed in November to fill the post of Forest Pathologist.

Mr. J. T. Stoakley joined the Entomology section from field duties in North Wales, and Mr. D. Y. M. Robertson came to the Management section on transfer from South Wales, whilst two new scientific officers joined the staff: Miss J. J. Rowe, for work on mammals, and Mr. R. Kitching to the Soils subsection of Silviculture. Mr. D. G. Pyatt joined the Management section, on Mr. R. E. F. Heslop's transfer to field duties. Mr. T. D. H. Morris was appointed Chief Clerk in place of Mr. R. Rendle, who was transferred to the South-west England Conservancy.

The number of visitors to Alice Holt was 470, a very marked increase on the previous year's figure. The visitors' book for the year has a truly international flavour, the following countries being among those represented:

Australia, Brazil, Canada, Canary Isles, Chile, Finland, France, India, Italy, Japan, Kenya, Malaya, Newfoundland, New Zealand, Nigeria, Northern Ireland, Norway, Nyasaland, Poland, Sarawak, Southern Rhodesia, Sudan, Sweden, Switzerland, the Netherlands, Turkey, Uganda, United States of America and West Germany.

Several visitors stayed at Alice Holt for periods of a few days to three weeks, studying particular subjects. These included: Mr. W. B. Armitage of Southern Rhodesia, Mr. A. J. L. Mitchell, prior to taking up post in Hong Kong, Dr. Suad Urgenc of Turkey and Sayed A. A. Mageed of the Sudan. In addition, Mr. E. S. K. Laryea of Ghana worked with Working Plan field parties and at Alice Holt during the period August 1961 to February 1962.

Professor G. Hellinga and Professor J. F. Kools led a party of students from the School of Forestry, Wageningen, Holland, on the first visit of members of this institution to this country. A comprehensive tour of forest areas in the east and south-east of England which was arranged for them included a number of experimental sites, and a special visit was paid to Alice Holt.

Other organised visits included a party of senior forest officers from various colonial services, under the leadership of Mr. C. Swabey of the Department of Technical Co-operation; a party of American foresters; the West German Society of Forest Nurserymen; a small party of Japanese forestry experts and private landowners led by Professor Izito Mine of Tokyo University; the Royal Forestry Society of England and Wales (Southern Division); the British Mycological Society, and the Horticultural Education Association (South and South-eastern branches). In addition, a post-graduate diploma course in Conservation, led by Dr. Newbould of the Department of Botany, University of London, also visited the Station, as well as delegates attending an F.A.O. World Seed Campaign Conference at Northerwood House. Students from the Departments of Forestry at Aberdeen, Bangor, Edinburgh and Oxford paid their usual visits to the Research Station.

An F.A.O. Study Group visited the Geneticists' outstation at Grizedale in Lancashire. The Gardens Tour of the National Trust for Scotland called at the Crarae Arboretum and Forest Plots, and parties from the Royal Scottish Forestry Society, the Whitby Naturalists, and a number of schools visited local experiments. Forestry students from Aberdeen, Edinburgh and Bangor made their usual instructional tours in experimental areas. Botany students from Hull and Bristol Universities and parties from the East of Scotland College of Agriculture and the Glasgow Royal College of Science and Technology also paid visits.

Mr. T. R. Peace (Chief Research Officer) attended the Congress of the International Union of Forest Research Organisations held in Vienna. Mr. J. R. Aldhous, Mr. A. I. Fraser, Mr. A. S. Gardiner, Mr. D. W. Henman, Mr. G. D. Holmes, Dr. F. C. Hummel, Mr. J. N. R. Jeffers and Mr. J. D. Matthews also attended.

Mr. Matthews also served for two months as a Technical Assistance Expert of the Food and Agriculture Organisation. His assignment was to follow up the mission he began in 1960 by continuing to advise on the formation of a Forest Genetics Section at the Indian Forest Research Institute, Dehra Dun. In March 1962 Mr. R. Faulkner began a similar assignment in East and Central Africa to advise on work on forest genetics at the East African Forest Research Organisation at Kikuyu, Kenya, and also in Rhodesia and Nyasaland. Mr. Faulkner's mission is sponsored by the Department of Technical Co-operation in London.

Mr. Holmes took part in the Interconvention Meetings of the Executive and Rules Committee of the International Seed Testing Association at Wageningen, Holland, and Mr. Buszewicz took part in a training course on biochemical test methods held at Stuttgart, Germany. He also took the opportunity of visiting the large seed extraction plant at Wolfgang, and the Forest Seed Testing Station at Munich.

Mr. J. W. L. Zehetmayr attended the Special Meeting on the Utilisation of Small-sized Wood held in Geneva in March 1961 under the auspices of the Economic Commission for Europe. He also attended the 4th Session of the joint F.A.O. and E.C.E. Committee on Forest Working Techniques and Training of Forest Workers held in Prague in June 1961.

Mr. J. Christie visited Finland, Denmark and Holland in September 1961 to study forest mensuration techniques, and Mr. A. I. Fraser paid a short visit to Holland to study drainage research in December 1961.

Mr. D. R. Johnston was awarded a Travelling Fellowship by the Nuffield Foundation, and toured in a number of African countries studying the management of fast growing coniferous plantations.

The Advisory Committee on Forest Research met at Nairn in July 1961. The Committee of Management of the National Pinetum at Bedgebury held three meetings and the Advisory Committee on Westonbirt Arboretum held two meetings during the year. Liaison meetings with the Nature Conservancy were held in August and November.

A notable event during the period under report was the final meeting of the Research Advisory Committee's sub-committee on Nutrition in Forest Nurseries. This sub-committee, firstly under the Chairmanship of the late Professor

F. T. Brooks, and latterly of Professor H. M. Steven, has kept all the work bearing on nursery fertility under review since 1945. This has been a period of most important development, starting with the micro-biological studies of the late Dr. M. C. Rayner, and embracing the unique series of experiments directed by the late Dr. E. M. Crowther of Rothamsted Experimental Station. The termination of the Sub-Committee reflects the success of the experimental programmes, but while fertility problems in forest nurseries do not present themselves with the critical urgency of the years after the second World War, there are still many long-term questions to be answered, and a joint programme of future work has been agreed between the Forestry Commission and Rothamsted Experimental Station. Forestry is indebted to all those who have influenced nursery research by their service on this committee.

The Research Branch maintained its valuable contacts with the Universities and Institutes mentioned in recent reports. We have long been indebted to the Royal Aircraft Establishment for facilities in computation, and we should also mention here the valuable assistance received from the Establishment in another field, the testing of small trees in the wind tunnel to measure wind resistance. In this same project we are also grateful to the National Physical Laboratory for co-operation in model studies in the wind tunnel.

It is pleasant to record that the names of two of our senior Research foresters appeared in the New Year Honours List, Mr. J. Farquhar being awarded the M.B.E., and Mr. E. Fancy the B.E.M.

MR. T. R. PEACE

The death of Mr. T. R. Peace, Chief Research Officer, which took place on 16th September, 1962 at the early age of 55, is a great loss to forestry and to forest research in particular. He had held the post of Chief Research Officer for only three years but in that short time had shown great gifts of leadership and a marked capacity for administration and the planning of scientific programmes.

He had been actively engaged in forest research ever since he left Cambridge with an honours degree in botany in 1928. His first post was at the Imperial Forestry Institute in Oxford where he worked on tree diseases for the Forestry Commission under W. R. Day. During this association, which lasted until the outbreak of war in 1939, he was engaged in many important investigations, notably of the elm disease, the disease of larch caused by *Meria*, and the effects of frost on various species of tree. When war broke out he became a district forest officer, serving in the Forest of Dean and subsequently in south-eastern England. In this capacity he proved a great success, surprising many people by the talent he showed for organisation and administration, by his ability to handle men and by his resourcefulness.

When the Research Station was opened at Alice Holt in 1946, Peace became the first head of the Pathology section, which he developed very greatly. At the same time, he took a great interest in poplars, becoming well known internationally as an expert on this far from easy genus. In 1959 he succeeded Professor M. V. Laurie as Chief Research Officer and it is tragic that so soon after his appointment he should have been stricken by his fatal illness.

Peace will be widely missed in scientific circles, but his loss will be felt most severely by his colleagues and numerous friends, who will long remember his great abilities and his friendliness. They will also remember with affection his little eccentricities.

To his wife and two sons we offer our sincerest sympathies.

SUMMARY OF THE YEAR'S WORK

By R. F. WOOD
Acting Chief Research Officer

Mr. T. R. Peace was unfortunately prevented by illness from completing this Report.

There are no major changes in the form of the document, but the Silvicultural work in Part I has been arranged under the principal subjects, and is not divided (as previously) into specifically Northern and Southern sections. The location of the work is indicated in the text. Greater use has been made of authors' own summaries in the Summary of the Year's Work.

In Appendix I, a map has been included with the list of experimental projects and localities. It is hardly possible to show the distribution of our field work in a satisfactory manner on a map of this scale, but it is hoped that the map will be of use, especially to prospective visitors from overseas, who may wish to see what travelling is involved in a tour of the principal experimental sites.

It is not always easy to illustrate the trends which may be taking place in research by calling attention to the contents of an annual report. Certainly however the comment by the Chief Research Officer in the last issue, that "we are tending to pay increased attention to the below-ground parts of the tree," holds good for this year's *Report*. There are also changes in approach, and it is noticeable that there is a searching for ways to *measure*, to obtain quantitative values where previously we have had to depend on the qualitative. This is partly due to increasing interest in methods of measurement and instrumentation, but also to our growing ability to handle great quantities of numerical data. The article by Mr. J. N. R. Jeffers on the Electronic Digital Computer, in Part III, illustrates this point.

The Season

Fairly extensive damage was caused by the late frosts of May 27th and 28th, 1961, but otherwise the growing season was not abnormal in any respect. The most important climatic vicissitude of the year was the cold wind of late February and early March 1962. While no exceptionally low temperatures were recorded, a great deal of damage was done to newly planted trees, and the browning of susceptible species such as *Sequoia sempervirens* and *Pinus radiata* was very noticeable.

PART I

This part of the report deals with current work carried out by the various sections of the Forestry Commission Research Branch.

Forest Tree Seed

Responsibilities in connection with Seed supply for the Forestry Commission and Nursery Trade have become an important part of the duties of the Research Branch, and now include seed imports, advice on home collections, seed processing and storage, seed testing and distribution. A major feature of the year's work was a special study of seed extraction and processing methods in Britain as a result of which plans are now being made to construct a new extractory at

Alice Holt to serve Commission needs in England and Wales. Routine seed testing of Commission-owned seed continued as a main service of the seed laboratory.

Research work included trials of seed cleaning and de-winging equipment, methods of seed moisture measurement, and an extensive series of laboratory tests on the germination requirements of *Abies* species. Research on seed storage, notably for beech, *Abies* species, and recently elm, was continued.

Nursery Investigations

Most nursery investigations continued to be concentrated at Kennington, Oxford and Wareham, Dorset, in England, and at Bush, Edinburgh, Inchnacardoch, Tulliallan and Newton in Scotland. Other nurseries used for experiments included Ringwood, Dorset, and Bramshill, Hants.

A considerable amount of work on nutritional problems continues.

The other major project in the nursery programme continues to be the control of weeds. The investigation into methods of control of weeds in transplant lines continued, but at a lower level of intensity now that simazine is becoming generally used for this purpose. The object of the current studies is to find suitable alternatives should simazine become ineffective on certain sites.

Experiments on pre- and post-emergence control of weeds in seedbeds showed simazine to be unsuitable for *post-emergence* use. 'Alipur' was found to be unsuitable as a *pre-emergence* weedkiller, but 'Amiben' showed promise in this role. Experiments with 2,6-DBN as a pre-sowing weedkiller were disappointing compared with previous years, as there was heavy loss of seedlings on almost all treated plots.

Other experiments continued on the effect of date of sowing and irrigation on the yield of seed stored for different periods; and on means of protecting seedbeds from birds.

Field trials of cold-stored plants showed that this technique could be used on a large scale both to store surplus plants for use in the following year, and to delay commencement of growth until after transplanting, where this is unavoidably delayed.

Silvicultural Investigations in the Forest

Afforestation of Difficult Sites

No new projects on the afforestation of difficult sites were started during the year. A number of northern and southern sites continue to be studied. At Land's End Forest in Cornwall, experimental plantings on the Serpentine rock formation are now far enough advanced for provisional conclusions on the value of the site to be made. The evidence from the pilot plantations in the Northern Isles of Scotland is not encouraging for economic forestry.

In the afforestation of heathland, the advantages of complete cultivation are becoming progressively more apparent. A further trial to compare complete deep ploughing with normal spaced-furrow tine ploughing has been established, and a start has been made in developing an implement which will reduce the time and cost of complete deep cultivation of hard mineral soils.

Improvement of Forest Stands

In the general project dealing with the improvement of forest stands, new experiments on rates and placement of phosphates have been laid down on south-western heaths, where it seems likely that greater-than-normal dosages may be justified. Notable potash responses, which are of rare occurrence in this country, have been obtained on certain Welsh peats.

In the north, the results of applying phosphate mechanically at the time of ploughing are under investigation.

Much work has been done in the south in recent years on the improvement of checked plantations. Experiments continue on a number of sites, manurial applications and the control of vegetation by herbicides being the main approaches. Successful experiments on Culm soils in south-west England have led to aerial applications of phosphate in several forests. Poor Douglas fir crops on Tunbridge Wells and Ashdown Sands in south-east England have failed to respond to manurial applications, despite the low levels of phosphorus in the soils.

Checked Sitka spruce in the Border forests is responding to amelioration treatments, and no further work is needed to confirm or amplify the results of the survey of 1950. The problem of loss of health and increment in spruce crops on the north-east side of the country is still receiving attention, though an early answer is not expected.

The experiments on the manuring of pole-stage crops both in the north and south of the country have thus far given rather disappointing and puzzling results, in that while increased levels on nutrients in the foliage have been observed, no sizeable growth responses have yet been determined. The very obvious effects of nitrogenous manures on the litter in nine stands is now being investigated by means of a grant-aided study at the University of Aberdeen. The apparent stimulation of coning by manures is also under study.

Artificial Regeneration

Studies in regeneration are now bulking large in the silvicultural programme. In the artificial regeneration of Sitka spruce, cultivation seems to be of at least short-term advantage in dry sites but less so on moister sites. A major experiment comparing various sizes of felling-area, in their effect on the stability of the marginal trees and the growth of the second crop, has been planned for planting in 1962, and preliminary fellings have been done.

Sites have been chosen for work on the replacement of larch crops in Scotland and Wales. In Thetford, work proceeds on various aspects of regeneration. Trials of a machine for chopping up felling slash are promising. New trials of species on representative soil types have been started.

Natural Regeneration

A lesser amount of work is being done on natural regeneration. Natural seed-fall in Scots pine in central Scotland during 1961 was very sparse, but a heavier fall is anticipated during the summer of 1962, when the natural regeneration of a plantation destroyed by fire in 1960 will be studied.

In the south, attention is being paid to the design of seedtraps.

Provenance

In the large collection of provenance experiments, work continued with routine assessing and maintenance of the older projects. Planting of the Sitka spruce collection made in 1958 was completed; these provenances are represented on a full range of sites on which this species is planted. The bulk of the planting of the 1959 collection of Western hemlock was also completed, and planting of a collection of Western red cedar started.

Twenty-seven provenances of *Abies alba* were sown.

Collections of seed of *P. nigra* were made both from the Pennines and from Central Europe.

Weed Control in the Forest

Experimental work on weed control in the forest continues on a considerable scale. The control of grasses in plantation by the herbicide dalapon applied during the dormancy of the trees appears to have distinct prospects. The control of a number of woody species by herbicides is now established practice. Work continues on some of the more obdurate species, especially *Rhododendron ponticum*. An important line is the control of broadleaved weeds in conifer plantations by the use of overall sprays of 2,4-D and 2,4,5-T, replying on differing stages of growth to enhance natural differences in susceptibility. The technique has been successfully used on some scale against birch and gorse in conifer plantations.

Peat vegetation on firelines can be effectively controlled by a mixture of dalapon and monruon, with the addition of 2, 4-D where ericaceous plants are present.

Exposure and Wind

The relative exposure of 36 sites has been estimated over a period of three years by comparing the rate of tatter of unhemmed cotton flags. The results enabled objective comparisons to be made between the exposure of sites for which previously only very approximate subjective estimates were available. It was also shown that the growth rate of Lodgepole pine was highly correlated with the relative exposure, as expressed by the rate of flag tatter.

Shelter experiments with lath screens have shown that shelter from wind appreciably improved height growth of some tree species on exposed sites.

In the studies of wind-blow and the stability of trees, a system of recording wind-blow has now been extended to all forests. Further work using the 'tree pulling' technique has been done at the Forest of Ae, in connection with regeneration experiments which examine the size of the felling area. Advance evidence on the stability of marginal trees has been obtained.

A fresh approach has been the study of small trees in the wind tunnel, to measure the drag exerted by winds of measured velocities. This study is reported fully in the paper on wind tunnel studies by A. I. Fraser, Part III.

Drainage

Increased attention is being paid to drainage, and new work has been carried out or is being planned on both mineral and peat soils.

A plan is under preparation for a large-scale experiment on draining and cultivation and planting deep peat. Experiments to measure the shrinkage of peat as a result of ploughing and planting are well established. A number of large blocks of pure Lodgepole pine have been established on deep peat as sites for future experimentation on this species.

A hydraulically-controlled drain excavator has been acquired which will facilitate the digging of deep drains for experiment or demonstration. Useful preliminary experience has been obtained with mole drains at Halwill Forest in Devon.

Miscellaneous Problems

Other subjects noted in the progress report are: the loosening of young trees from wind on certain types of heath; the exclusion of deer from plantations, in which synthetic fibre fences are under trial; fire retardants, several substances (notably ammonium phosphate solutions, clay suspensions and viscous water) having shown promise for particular applications; and the chemical debarking of hardwood pulpwood, which has the aim of extending the utilisation of this material to crooked poles which cannot readily be debarked by mechanical means.

Poplars and Elms

The planting and assessment of poplar varietal trial plots and experiments continued as in previous years, though planting was carried out on a smaller scale than for some time. Cuttings of standard varieties were again distributed to outside growers, and, at the Research Station, the national populetum was further extended. Work on elms was again concerned mainly with the selection of 'plus trees' and comparative methods of propagation in the nursery, though a disease trial and a clonal stool bed were started during the winter.

Forest Ecology

During the year, the field surveys of Corsican pine in the study of its growth and health in relation to environment were completed. The records are being assembled and a full report prepared. Provisionally, there appears to be a critical level of summer warmth for this species, roughly corresponding with a mean July temperature of 13.5° to 14°C.

The late frosts of May 1961 provided some exceptional instances of damage to Corsican pine. Equally remarkable were the heavy cone crops stimulated by the hot dry summer of 1959.

Forest Soils

There has been increased attention to soil moisture and drainage during the period.

Foliar analysis has continued on an increasing scale.

Further studies on soil moisture have been carried out in collaboration with Dr. A. J. Rutter of Imperial College, University of London. Girth measurements of pine trees in the study plots, taken at weekly intervals, suggested that stem hydration (rather than soil moisture or temperature) might be the cause of short-term fluctuations in the rate of girth increment. This is being pursued further by the development of a technique for the measurement of electrical resistance in the stem.

The season's records from a Garnier Gauge installation at Alice Holt are discussed.

Soil analyses on comparative plots in the long term fertility trial at Bramshill Nursery suggest that prescription of fertiliser rates on light soils of this type cannot usefully be made on the basis of such tests.

Forest Genetics

1961 was International Seed Year and much of the work done by the Genetics Section was linked with the World Seed Campaign as it affected forestry in Britain. Lectures on the value of better forest tree seed, and demonstrations and short training courses in seed collection, were given to a wide audience. A five days course on forest genetics, tree breeding and seed production was attended by nineteen delegates, nine of whom came from eight countries overseas. The first country-wide survey of seed sources was completed in 1961. An analysis of the content of the register revealed shortages of seed sources of several exotic species and the resurvey of Britain begun during the year is intended to provide more seed sources of Norway and Sitka spruce. Lodgepole pine and Western hemlock, and replace older seed sources of larches and Scots pine as they are lost through felling. The conversion of seed sources into seed stands was greatly accelerated during the year.

More than 3,100 Plus trees have been selected, marked and recorded, and just under one half of these are represented in tree banks as clones of grafted plants or rooted cuttings. The plus trees of Sitka spruce are being graded for their wood characteristics at the Forest Products Research Laboratory on the basis of large diameter increment cores taken at breast height. More than seventy plus trees, most of which were Lodgepole pine, were selected in the Irish Republic and Northern Ireland, and special thanks are due for the facilities provided by the Forest Services concerned. Vegetative propagation by grafting and the rooting of cuttings continued, as also did the work on controlled pollination and progeny testing, the emphasis being on controlled pollination in Lodgepole and Scots pine. Four pounds of seed were collected in two Scots pine seed orchards and a Scots pine tree bank (all in Scotland), and 170 acres of seed orchard are now being managed on sites throughout Britain.

Forest Pathology

In the Pathology Section work continued on death and decay caused by *Fomes annosus*. For several years freshly cut conifer stumps in Commission forests have been treated with creosote to minimise the entry of *Fomes* through stump colonisation. In tests to find materials more satisfactory than creosote, various substances, including formaldehyde, sodium carbonate, polybor, and the weedkiller diquat, have shown considerable promise. Biological control of the fungus was also investigated, stumps being inoculated with the wood-rotting saprophytic fungus *Peniophora gigantea*. *F. annosus* failed to colonise the inoculated stumps. In attempts to eradicate the fungus from felled trees before replanting, mechanical removal of infested stumps was carried out. Results were good, though stump removal is expensive, and cannot be recommended for general use.

In nursery experiments on needle blight (*Keithia thujina*, syn. *Didymascella thujina*) of *Thuja*, spraying with cycloheximide and its derivatives gave good control.

Investigations were begun on a stem canker of checked pine trees in Ringwood and Wareham Forests. The fungus *Crumenula sororia* was found associated with the cankers, although it may not be their primary cause.

Work continued (some in association with other bodies) on damping-off in nurseries, Group Dying of conifers, Top Dying of Norway spruce, Bacterial Canker of poplar, and various other diseases.

Forest Entomology

The Pine looper survey shows that a high population level at Cannock Chase is being maintained, and a rise in density at Tentsmuir Forest is also observed.

Epidemiological investigations into Pine looper and the larch sawfly *Anoplonyx destructor* continue.

Increment loss studies connected with the above sawfly and green spruce aphid also continue. A further successful air operation over an 18 acre experimental plot was carried out at Drumtochty against the sawfly.

A practical control prescription can now be made for Ambrosia beetle. Certain biological aspects of this insect are now being studied.

Other investigations include one into Springtail damage to nursery plants, one into Winter moth damage to young Sitka spruce in North Scotland, and one into the distribution of larch feeding insects, including *Ips cembrae* and sawfly species.

Grey Squirrel Research

Trials of the poison Warfarin conducted in Scotland have been encouraging, and further work is in process. The bark stripping habit of squirrels is under study, and the degree of protection afforded by trapping during the damage period is being investigated. Returns to questionnaires indicate an increase in population sizes and in damage during 1961.

Management

During the year under review, the distinctions between the main sub-divisions of Management, i.e. Working Plans, Economics and Mensuration, have become less clear cut, since all at one time or another have been collaborating on topics connected with the current working plan programme of the Commission.

Economics

Assistance to field officers in various forms of economic appraisal has cut the time available for economic research; this research however becomes increasingly necessary as new problems in management are encountered. A considerable amount of work has been done in connection with a study group concerned with the revision of the Zuckerman Committee's report on land use. A number of minor studies have been concluded.

Working Plans

Some changes in the organisation of working plan field parties are reported. Further very valuable co-operation has been received from H.M. Ordnance Survey, especially in the timing of their map revisions and the provision of advance prints of revised maps. The section is likely to become more involved in advising field officers on various points in the writing of plans.

Mensuration

Progress has been made on the revision of the general yield tables for conifers. Tables for different intensities of thinning in various species are being analysed from the aspect of the probable profitability of the thinning method, and this should provide guidance for the thinning method on which new published tables will be based. Stand tables are also receiving attention. A new thinning experiment in Douglas fir is being intensively measured by means of vernier girth bands.

Work Study

The Work Study Section completed the four assignments reported on last year and commenced work on four new ones. For the first time forest maintenance operations have come under review; brashing, drain maintenance, weeding and cleaning, which are being studied in the Border area of England and in North Wales. In Scotland, work is under way in comparing potential specifications and working methods for pulpwood, for the proposed mill at Fort William.

The work on forest testing of machinery, after its mechanical development and testing by Machinery Development section, has been extended.

Management techniques for labour control, and the costing of production operations, have been under trial during the year, with a view to their adoption in the Commission as a whole.

A considerable training programme at all levels has been undertaken and the section has helped in the development of a new Forest Workers' Training scheme.

Utilisation Development

Most of the section's work was concerned with the joint programme of testing home-grown timbers at the Forest Products Research Laboratory, Princes Risborough. Other items were the continuing tests of fence posts, and investigations into the use of wood chips for cattle and poultry litter. A report on the fence post trials by Mr. Aaron is given in Part III of this *Report*.

No new major investigations were initiated during the year.

Machinery Research

Many of the current machinery research projects are dominated by the progress being made in hydraulic power transmission, which is becoming commercially available earlier than expected. The increasing rate of output from the Commission's forests stresses the importance of efficient loading and timber handling machinery both of which are receiving attention. The double-drum winch, successfully exploited in Scandinavia in recent years, is being introduced with encouraging results.

The hovercraft in very simple form is the subject of an experiment to determine if there is anything in this idea for timber haulage on soft ground.

Design and Analysis of Experiments

The demand for advice on the design and analysis of experiments and surveys, and for the analysis and interpretation of numerical data, has increased as the staff and the scope of the Research Branch has itself increased, and these services have continued to be provided by the Statistics section. A Ferranti Pegasus computer and a Ferranti Sirius computer have again been used by the section to cope with the very heavy load of computing implied by these services. A full description of the application of these computers to problems of forest research and management is given in Mr. Jeffers' paper on the Electronic Digital Computer in Part III of this *Report*.

In addition to the usual services of advice, analysis, and interpretation, a start has been made on the difficult problem of making foresters aware of the many methods of statistical analysis and electronic computing capable of solving problems of forest research and management. Attention has also been given to the work for the Advisory Group of Forest Statisticians of Section 25 of the International Union of Forest Research Organisations.

Library and Documentation

The extension and re-organisation of the Library premises were practically completed and the advantages are already apparent to library staff and users alike. Documentation work, despite improved working techniques, is still behind schedule; but it is hoped to extend the usefulness and flexibility of this service. The general work of the library continues to increase—in some cases quite spectacularly. The day-to-day use by Alice Holt staff, although not demonstrable by statistics, shows the largest and most encouraging increase of all.

Photography

Large numbers of slides and prints were again loaned for various purposes. New equipment obtained has included apparatus suitable for the preparation of dyeline transparencies from opaque originals.

PART II

This part reports progress by workers at Universities and other institutions. Much of this work is aided by grants from the Forestry Commission.

Research on Scottish Forest and Nursery Soils

Dr. W. O. Binns, of the Forest Soils Section, Macaulay Institute, Aberdeen, provides a further report. In recent years the emphasis of the work has moved towards a study of the nutrient requirements of forest stands. Difficult sites like the Culbin sand dunes and the Lon Mor peat area of Inchnacardoch Forest have been studied in detail. Experience gained from the latter investigation is being applied in a chemical survey of afforested peat areas in an attempt to predict nutrient deficiencies before they occur, and to help to prevent wasteful fertilisation.

Foliage analysis continues to be a major part of laboratory work, and foliage from fertiliser trials laid down in conjunction with the Research Branch is analysed for major and minor nutrients as required.

Greenhouse work of both applied and fundamental nature is being developed.

Nutrition Experiments in Forest Nurseries

Miss Benzian of the Rothamsted Experimental Station has been chiefly engaged in the writing of the account of the large series of experiments directed by the late Dr. E. M. Crowther. Till this task is completed, progress reports on current work are not being made. However, much consideration has been given to the continuation of nutritional research in forest nurseries, and an agreed programme has been drawn up jointly by the Research Branch and Rothamsted Experimental Station.

Effects of Disease Control Measures on Soil Microflora of Sitka spruce

A brief abstract from Mr. Ram Reddy's unpublished thesis is given. The object of Mr. Ram Reddy's study at Rothamsted has been to elucidate the mode of operation of soil sterilants under differing nursery conditions.

Protein-fixing Constituents of Plants

Further progress at the Dyson Perrins Laboratory, Oxford, is described in two reports; that by Professor B. R. Brown, Mr. C. W. Love, and Dr. W. R. C. Handley (of the Commonwealth Forestry Institute), describes a comparative survey of a variety of species with regard to the nature of the protein-fixing constituents (if any) of their leaves; while that by Miss Sheila Bocks, Professor B. R. Brown and Dr. W. R. C. Handley deals with the use of certain enzymes to break down the complex tannin molecules in order to throw light on their structure.

Biology of Forest Soils

Mr. G. W. Heath of Rothamsted Experimental Station has continued his studies of the rate of break-down of leaf litter.

The rate is highest in early spring, and appears to be related to moisture conditions and earthworm activity. Interesting differences in the percentage of hydrolysable carbohydrates have been found. The rate of disappearance of leaf discs from nylon mesh bags buried in the soil, and designed to exclude different portions of the soil fauna, is also being determined. It has again been found that earthworms are the most important agents in causing litter disappearance, but if they are excluded their role is filled by Enchytraeids.

Soil Fauna Research

Mr. D. R. Gifford of the Department of Forestry, Edinburgh University, has now completed his account of the ecological surveys of mite fauna at the Forest of Ae. Considerable information has been gained on the balance of effect on environmental conditions of such factors as vegetation type, profile character and season, for a wide spectrum of the commoner *Acarina.*

The remainder of the year has been devoted to preliminary work for the new programme, which is to combine mycological studies with those on the fauna, in particular the inter-relationships between the mites and the microflora in the formation of the organic profile.

Soil Mycology

In the Forest Botany Section at the University College of North Wales, Dr. C. G. Dobbs and Dr. Nancy Carter have continued their work on soil mycostasis by the preparation of sterile filtered soil extracts. Results have been very variable, but a consistently inhibitory extract of mineral soil under spruce has been obtained, and it has been shown that periodic 'feeding' of this soil with washed spores of the test fungus (*Mucor ramannianus*) resulted in an increased inhibition. This supports the view of some American workers (Lingappa and Lockwood) that the spores may be able to act as nutrient microsubstrates in the soil. At the same time, there is no evidence that the actual spore surface is colonised.

The evidence for the microbial origin of the inhibitor(s) is outlined, and the use of cellophane as a test material discussed. The conclusion is drawn that this kind of unstable, microbially-produced inhibitor can be present in the soil only under conditions which permit of microbial activity, and can limit fungal germination and growth only under conditions which would otherwise permit such growth, and in the absence of sufficient sugars to mask the inhibition. In temperate climates such conditions probably exist in most soils over the greater part of the year. From a forestry point of view there is need for a study of the influence of mycostatic micro-organisms upon the fungi of forest soils, especially root pathogens.

Hydrological Relations of Forest Stands

Dr. Leyton and Dr. Reynolds of the Commonwealth Forestry Institute, Oxford, have continued their investigations into the different phases of the hydrological cycle in a pole stage plantation of Norway spruce. Analysis of the catches of various types of gauge mounted above and at canopy level suggest Nipher shielded gauges to be the most promising so far for the measurement of rainfall above the stand, and tests of different designs are being made; however, more information appears necessary on gauge behaviour under controlled conditions before the problem can be entirely solved. Substantial progress has been made in the routine measurement of transpiration based on the automatic recording of sap flow in tree stems using a modified heat flow technique. Other investigations begun this year include detailed studies of the fate of rainfall intercepted by tree crowns and of the factors influencing stem flow.

Shelter Research

The third three-year period of the programme of shelterbelt research was extended by a further three months, to 31st December, 1961, to enable Mr. R. Baltaxe of the Forestry Department, University of Edinburgh, who has been engaged on this work since 1958, to complete the analysis of his investigations.

Dr. J. M. Caborn reports that the last nine months of this project were devoted to experiments with model shelterbelts under field conditions, as an extension of earlier wind tunnel work. The model belts were constructed of Scots pine tops so as to simulate actual windbreaks, whilst allowing maximum control of the many variables involved in field studies of living belts.

The results demonstrated the effect of changing atmospheric stability in altering the shelter pattern created by a belt, and especially by the more open type of structure. The level of turbulence in the incident wind, caused by atmospheric stability and surface roughness, exerts a considerable influence on any measurements of wind velocity conducted in the vicinity of shelterbelts and is, therefore, of primary importance in determining the similarity of experimental conditions in studies on shelter and in obtaining information of real value from short-term observations. This total turbulence can be readily estimated by measuring the velocity profile of the free wind at three heights above the ground.

Research on Forest Fires

Dr. P. H. Thomas and Miss Roberta Scott of the Fire Research Station, Boreham Wood, Hertfordshire, provide a further report on the investigations commenced last year. They deal with some of the fundamental relationships between heat transfer and the characteristics of fuels and flames.

Oak Populations in Scotland

Mr. Cousens and Mr. Malcolm of the Department of Forestry, University of Edinburgh, have continued the studies initiated by the former. Emphasis has been placed on variation within populations. The main effort was directed to woods of reported *Quercus robur* affinity. Flowering was relatively poor, while late frost in June reduced fruiting. In all, 780 specimens from 51 woods were added to the collection, bringing the total to 1,420 Scottish specimens. Nine hundred and forty specimens were pressed, mounted, measured and recorded by the end of the year.

An analysis of the data, by pictorialised scatter diagrams, revealed massive gene exchange among Scottish oaks. Only 4 of 54 population samples were homogeneous *Q. petraea*. They form the basis of the tentative definition of *Q. petraea* in Scotland. Twenty per cent of all fertile specimens are diagnosed as probably good *petraea*, and about 5 per cent as possible good *robur*. The remainder are introgressed to varying degrees.

The species diagnosis problem has now been resolved sufficiently for the survey of indigenous, or possibly indigenous, oak populations to commence; while the botanical study will be intensified in Scottish and other populations. Further resolution may involve a genetical investigation of the fertility of interspecific and backcrosses with hybrid forms.

Physiological Studies on the Rooting of Cuttings

Professor P. F. Wareing and Mr. N. G. Smith of the University College of Wales, Aberystwyth, have carried out investigations into the seasonal periodicity in the rooting ability of cuttings of poplar (particularly *Populus robusta*), with particular reference to the effects of (a) environmental conditions, including temperature, and daylength, and (b) endogenous changes within the plant, viz. whether the shoots are actively growing or dormant. It was found that little rooting of non-dormant hardwood cuttings of *P. robusta* occurs with disbudded cuttings or with intact cuttings at temperatures which are too low to permit bud-growth (e.g. 5°C). Dormant (unchilled) cuttings form few roots, but after a period of chilling (at 3·5°C), which removes the dormancy of the buds, rooting occurs readily. It is evident from the foregoing results that rooting is greatly stimulated by the presence of actively growing buds. In a further experiment it was found that cuttings taken in October subsequently rooted much better than those taken in December, despite the fact that few roots were formed by the earlier cuttings during the period October–December, i.e. before they had received a chilling treatment. Rooting of *P. canescens* (Clone S.A.), which is normally difficult to propagate by cuttings, was greatly improved by giving a long period of chilling of 16 weeks at 3·5°C.

Juvenility Problems in Woody Plants

In another study at Aberystwyth, Professor Wareing and Mr. L. W. Robinson describe further experiments demonstrating the importance of the 'size factor' in the attainment of the flowering condition by seedling trees are described. Flowering was successfully obtained in 4 to 5 year-old seedling Japanese larch by first growing the plants rapidly in a greenhouse until they attained a height of 9 to 10 ft. and then planting them in the open in a horizontal position, to promote flower initiation. A series of grafting experiments suggests that scions taken from juvenile trees and grafted on to mature trees flower more readily when derived from larger seedlings (which are aproaching the mature condition) than from smaller ones. Attempts to determine physiological and biochemical differences between the tissues of juvenile and adult ivy have so far given negative results.

Effects of Stump Treatments on Fungal Colonisation of Conifer Stumps

Mr. D. Punter, working with Dr. J. Rishbeth of the Botany School, Cambridge, gives a short progress report on the effects of various stump treatments on fungal colonisation of pine stumps and on the killing of stump tissues.

Chemical Changes in Forest Litter

Dr. J. Tinsley and Mr. R. J. Hance of the Department of Soil Science, University of Aberdeen, have commenced field and laboratory studies on the effects of nitrogenous fertilisers (with and without lime) on the litter of pine crops. A suitable forest site has been found in Bramshill Forest, Berkshire, adjacent to manurial experiments established by the Research Branch. Initial treatments comparing forms of nitrogenous fertilisers have been applied. Laboratory work will attempt to reproduce some features of the field experiments under controlled conditions. Attention has been paid to methods of analysis of litter for the, determination of substances important in various stages of the breaking-down process.

Dieback Disease of Corsican Pine

Mr. D. J. Read of the Botany Department, University of Hull, has conducted field and laboratory studies into the 'die-back' disease of Corsican pine. He found incidence of the disease to be closely correlated with topography, and meteorological observations showed that sites where the disease is most common are those suffering from the most severe climatic conditions.

Field and laboratory experiments suggested that the disease cannot be caused by direct frost shattering of the buds.

The fungus *Brunchorstia destruens* has consistently been found in association with the disease, and inoculation of buds with conidial suspensions of this fungus have produced typical disease symptoms. The pathogen has been shown to grow best at low temperatures, and to be generally more vigorous under severe conditions than is true of most fungi. Some factors involved in host resistance have been investigated.

Further work will attempt to increase knowledge of factors involved in the host-parasite relationship.

PART III

As usual, Part III contains articles by Research staff, and these are commonly accounts of completed investigations, which have extended over several years. They are not progress reports on the year's work, and only brief notes on the contents of the papers are given here.

Mr. J. R. Aaron gives preliminary results for an extensive series of durability trials of round fence posts made from readily available timbers; the posts being tested both untreated and treated by creosote and proprietary water-soluble preservatives, applied by simple methods suitable for use at the farm.

Mr. C. W. T. Young describes experiments to test the susceptibility of certain North American pines and poplars to the rust *Melampsora pinitorqua*; the trials being undertaken to provide American workers with advance information on the likely behaviour of their species should the disease in fact arrive in their country.

Mr. S. A. Neustein deals with the effects of phosphate dressings applied at the time of establishment, on the later growth and yield of a plantation of Lodgepole pine, *Pinus contorta*.

Mr. D. W. Henman gives an account of an unusual thinning treatment, involving the isolation of young dominant trees from an early age in plantations. The effects of the treatment on height growth, branch and crown development and stem form are described, and the probable effects on yield discussed.

Mr. G. D. Holmes deals with the experiments, which have only proved partially successful, on the 'pruning' of epicormic shoots by the use of the growth substance 2,4,5-T, a method which has shown some promise in Germany.

Mr. Balfour and Mr. Kirkland give a short account of an investigation into the breeding habits of the ambrosia beetle *Trypodendron lineatum*, with special reference to its behaviour in stumps creosoted as protection against the entry of the fungus *Fomes annosus*.

Mr. J. N. R. Jeffers discusses the impact of the electronic digital computer on forest research.

Mr. A. I. Fraser reports on a new approach in the investigations on the stability of trees against wind. This is the exposure of small trees to winds of measured velocities in the wind tunnel. Some interesting relationships between wind velocity, 'drag', and the characteristics of the trees are described.

PART I

Reports of Work carried out by Forestry Commission Research Staff

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FOREST TREE SEED INVESTIGATIONS

By G. M. BUSZEWICZ and G. D. HOLMES

Service Work

Seed Supply and Storage

During the year under review, the Organisation and Methods Section collaborated with the Research Branch in a study of existing procedures for production and distribution of seed by the Commission. With the continuing policy of increasing the proportion of seed obtained from home rather than overseas sources, a revision of the seed supply organisation was found necessary. Responsibilities in seed supply have become an important part of the service function of Research Branch, involving close collaboration between the Genetics and Silviculture Sections. This work now includes collation of seed requirements, arrangements for imports, advice on home-collection targets, collection methods and seed-stand management, development of improved extraction and seed processing methods, management of the refrigerated store, seed testing, seed distribution and sales to the seed and nursery trade.

During the season, the main seed store at Alice Holt despatched 7,981 lb. of conifer seed to Commission nurseries, and 4,640 lb. to the seed trade and private nurseries. In addition to the main programme of seed despatches, some 5,000 measured and packeted small lots of seed were prepared for use in Research Branch nursery experiments.

Seed Testing

The quality of all seed lots held in Commission stores is examined each year at the Licensed Seed Testing Station at Alice Holt. During the year under review, 911 seed samples were received for testing, and the following analyses completed:

Purity Tests	333
Seed Weight Tests	380
Germination Tests	1,428
Tetrazolium Tests	57
Moisture Content Tests	711
Cone Tests	92

The majority of these were service tests for reports on samples submitted, but some 800 tests were carried out as part of research programmes mentioned below.

Research Work

Seed Collection

Inspection of coning in young pine stands receiving a range of mineral fertilizer treatments designed to stimulate growth, has suggested that cone production may also be increased, particularly by nitrogen, or nitrogen + phosphorus dressings. In view of the possible importance of such effects in seed stand management, detailed assessments of cone production were recently carried out in five such experiments in Scots pine, Corsican pine and Lodgepole pine. Over 200 cone samples have been collected and are now being examined to measure effects on cone number, cone size and seed production and quality.

Seed Extraction and Processing

As part of the enquiry mentioned earlier, a study was made of current methods of seed extraction and processing with a view to increased efficiency and production. This was accompanied by a review of the latest methods in use abroad. Arising from these enquiries, plans are now proceeding for construction of a new central seed extractory serving England and Wales, to be situated at this Research Station in close proximity to the main seed store and seed laboratory facilities.

A new development in seed processing at the store has been the installation of a small gravity-table type cleaner. This machine permits accurate sorting of particles according to their density, enabling many empty, broken and light seeds remaining after normal cleaning to be removed from seed lots. This is of special importance in larch and *Abies* lots, which frequently contain up to 50 per cent empty seeds which cannot be removed by ordinary screen and air-blast cleaners. Higher standards of seed purity and soundness should make for more accurate sowing density control and more regular seedbed stocking. Moreover, if necessary, sound seed can be accurately graded by weight, and sowing of graded seed could reduce variations in seedling height growth, facilitating stock-taking and reducing wastage by production of undersized plants. The practical advantages of such grading will be examined in trials in the coming season.

In addition, a laboratory machine has been installed for dewinging and cleaning small amounts of seed, up to 300 gm. per operation, for dealing with experimental collections. Previously all such seed was laboriously dewinged and cleaned by hand.

Trials continued with a range of dyestuffs for use in colouring seed prior to sowing as a cheaper and simpler alternative to the existing practice of applying red lead dressings. Trials of 'Waxoline' dyes applied in oil have been moderately successful, but the intensity of colouring is inadequate. Better seed marking is achieved using a solid marker such as aluminium flake. Further trials will be made with a view to developing a simple method which can be applied centrally before seed is issued to sowing nurseries.

Seed Moisture Content Measurement

The high content of non-aqueous volatile substances in many conifer seeds makes it difficult to measure moisture content accurately by normal oven drying methods. Work started in 1961 on three *Abies* species (*A. alba*, *A. grandis* and *A. procera*) comparing oven methods against the accurate, although time-consuming, toluene-distillation method of moisture measurement, has been completed. Results showed that oven drying at 105°C for one hour gives a close approximation of moisture levels as shown by the toluene test. This will be extended to other species with the object of defining the most accurate oven testing method in each case. The initial investigation was carried out jointly with the Official Seed Testing Station at Wageningen, Holland, and a report will be published in the 1962 Proceedings of the International Seed Testing Association.

Seed Storage

(a) Beech and Noble fir. The existing long-term storage trials with seed of beech and *Abies procera* are being continued. Further tests of germination quality confirm the previous indications (see Parts I and II *Rep. For. Res. For. Comm.* 1961).

(b) Elm. A good crop year in 1960 provided an opportunity to examine the germination and storage characteristics of the seed, on which there is little published information in this country. Seeds were collected in May 1960 from *Ulmus procera*, *U. carpinifolia*, and *U. glabra*. All the *U. procera* seeds were found to be empty so further observations were confined to the latter species. The seeds were dried at room temperature for several days and placed in sealed containers for storage at 3°C. The results of annual germination tests are shown in Table 1.

Table 1

Elm – Seed Germination Percentage During 2 *Years Sealed Storage at* 3°*C*

	Storage Period			Moisture Content Percentage
	0 (1960)	1 Year (1961)	2 Years (1962)	
Ulmus carpinifolia	30 (34)	37 (32)	59 (14)	15·7
Ulmus glabra	40 (18)	50 (8)	57 (6)	9·4

The germination tests were carried out at an alternating temperature of 20° to 30°C without any pre-treatment. The figures in brackets represent the percentage fresh seeds remaining ungerminated at the end of the 35-day test period. Results show that actual germination percentage increased during the storage period. The high proportion of fresh ungerminated seed in each case suggests that the seeds have rather variable dormancy, the extent of dormancy decreasing during dry cold storage. Additional tests in 1962 showed that wet prechilling of the seeds at 3°C for 21 days failed to increase germination.

(c) Rhododendron. A small storage test with seed of *Rhododendron ponticum* carried out in 1953 as part of a species study by the Ecologist is worth reporting.

Table 2

Rhododendron ponticum – Seed Germination Percentage During Storage 1953–62 *in Sealed Containers at* 3°*C*

	Storage Period (Years)					
	0 (1953)	2 (1955)	3 (1956)	5 (1958)	7 (1960)	9 (1962)
Lot A . .	80	87	82	79	62	Nil
Lot B . .	64	70	57	51	11	Nil

Two separate seed lots, air-dried and stored in sealed containers at 3°C, remained germinable for 5 years, as shown in Table 2.

Germination Test Methods

Improvement and standardisation of test methods continued to be a major subject of investigation. Experimental work was devoted mainly to comparative tests on a series of referee samples of *Abies alba* and *Pinus pinaster* issued to members of the Forest Seeds Committee of the International Seed Testing Association. The reports on this work, which include several proposals for changing the test methods prescribed in International Rules, will be published in the Proceedings of the International Seed Testing Association.

In addition, a study was started to examine the value of hydrogen peroxide as a means of stimulating germination and controlling seed-borne fungi. Initial tests have been confined to Douglas fir and *Abies* species.

Interpretation of Seed Analysis Results

It is most desirable that detailed records of all seed sowings throughout the Commission should be examined in relation to seed test results reported. Plans are in hand to permit this through modification of stocktaking procedures. Given such statistics each year, a clearer picture should be obtained of the relative productivity of nurseries related to viable seeds sown.

In many nurseries, actual total seedling production remains low in relation to viable seeds sown, and there exists considerable scope for improvement.

NURSERY INVESTIGATIONS

By J. R. ALDHOUS and J. ATTERSON

By the end of the 1950s, most aspects of nursery technique had been investigated, and practical recommendations based on the results of these studies were summarised in the 7th edition of Forestry Commission Bulletin No. 14, *Forestry Practice* (H.M.S.O., London, 1958). The experiments mentioned here are concerned mainly with screening new chemicals for weed control; and with an important new technique, storage of seedlings at low temperatures, which promises to facilitate late lining-out, and to allow surplus plants to be carried over to the following year without becoming too large.

In England, Miss Benzian of Rothamsted Experimental Station continues to supervise the work on nutrition problems in forest nurseries, in close co-operation with Forestry Commission staff. The greater part of Miss Benzian's time is directed to the completion of a comprehensive account of the results of the nutritional work to date, and to the continuance of the two big 'long-term fertility trials' and associated experiments.

Weed Control

Note.—Please refer to the *Weed Control Handbook*, 2nd Edn., Blackwell Scientific Publications, Oxford, for the full names and other details of the herbicides mentioned here.

Pre-sowing Treatment of Seedbeds

2,6-dichlorobenzonitrile (2,6-DBN) was applied at ½-4 lb. per acre (active ingredient) to seedbeds 1, 2 or 3 months before sowing in experiments at Kennington and Bramshill. At Kennington, 2,6-DBN was either dug into the top 3-4 inches of soil or raked into the surface. At Bramshill, it was only dug in. There was serious crop damage, apparent as a reduction both in number and height of conifer seedlings, at both nurseries where 1 lb. per acre or more of 2,6-DBN had been dug in. Control of weeds was satisfactory at rates of 1 lb. or more of 2,6-DBN.

Pre-emergence Weed Control of Seedbeds

'Alipur', a 3:2 proprietary mixture of OMU and BiPC, was applied as a spray to seedbeds 1 and 7 days after sowing four conifers (Sitka spruce, Scots pine, Japanese larch and Western hemlock) at Kennington nursery. One to 3 lb. of the mixture was applied in 60 gallons of water per acre. Almost all the seed on all treated plots failed to germinate, though controls were fully stocked. This complete failure of seedlings was unexpected as 'Alipur' had been successfully used on seedbeds in Germany; but there, the seed was almost certainly covered with soil, whereas at Kennington seed was covered with a silt-free grit.

Amiben was also applied at Kennington to seedbeds of the same species. It was sprayed on in 60 gallons of water at 2 to 8 lb. active ingredient per acre, 7 and 21 days after sowing. Germination and growth of all conifer species was normal; weed growth was controlled for 3 weeks by application of 4 lb. or more.

Post-emergence Weed Control of Seedbeds

Seedbeds sown with Scots pine, Japanese larch, Sitka spruce and Western hemlock were sprayed with simazine at ½ to 2 lb. (active ingredient) per acre. Treatments were repeated at Kennington and Bramshill nurseries and were applied approximately 6, 9 and 12 weeks after sowing.

Height growth and yields of all species were reduced by simazine at all dates of application. The reduction of growth and yield was less for the lower rates and the later dates of application. Nevertheless, there was some reduction whatever the application.

Weed Control in Transplant Lines: Simazine

Simazine was applied as an inter-row or overall spray to transplants of nineteen species at Kennington, Wareham and Bramshill. The rates of application ranged from 1 to 8 lb. active ingredient, applied either within seven days of lining out, or four weeks after lining out. The species treated were: Norway and Sitka spruces; *Picea omorika*, Scots, Corsican and Lodgepole pines; European, Hybrid and Japanese larches; Douglas fir, *Sequoia sempervirens*, *Sequoiadendron giganteum*, *Cupressus macrocarpa*, Lawson cypress, Western red cedar, Western hemlock, oak, ash and beech.

One species, ash, not previously included in experiments with simazine, was found to be susceptible to simazine and to be damaged by rates of 2 lb. (active) or more; the method of application had little effect on the severity of damage. Otherwise, the only damage to be seen on any hardwood or conifer species, was where the highest two rates of application (4 and 8 lb.), had reduced the height of European larch, and caused some losses in Western hemlock transplants; however in the latter instance, plants were very small when lined out, so that their roots were mostly in the surface 3 inches of soil.

Weed Control in Transplant Lines: Other Herbicides

Work on the breakdown of 2,4-D and MCPA (Audus, 1960) suggests that herbicides applied repeatedly in a nursery may become increasingly rapidly broken down by the soil micro-fauna. The phytotoxicity of several herbicides which could be used as alternatives to simazine was therefore tested in experiments at Bramshill and Kennington. The herbicides were: neburon, at 2 to 8 lb. per acre, diuron at 1 to 4 lb. per acre, propazine at 1 to 4 lb. per acre, atrazine at 1 to 4 lb. per acre, prometryne at 1 to 4 lb. per acre, 2,6-DBN at $\frac{1}{2}$ to 2 lb. per acre and amiben at 2 to 8 lb. per acre. All rates given refer to the amount of active ingredient per acre; each material was applied as a spray in 60 gallons of water per acre to plots lined out with eleven conifer species.

The experiment at Bramshill was badly damaged by frost at the end of May and no clear separation could be made between frost and herbicide damage. At Kennington, the only species affected by any of the herbicides was Western hemlock (again, very small plants were used), which was scorched by the highest rates of propazine and neburon.

Weed Control in Poplars

Lines at Kennington containing cuttings of *Populus* 'robusta' and *P.* 'TT.32' inserted in late April, were sprayed with simazine at 1, 2 and 4 lb. active ingredient either in April, May, June or July. The height growth and survival of both varieties were reduced by all applications, though effects were more pronounced where simazine had been applied in May and June, and at the higher rates of application. *P.* 'robusta' appeared more susceptible than *P.* 'TT.32'.

Storage of Plants at Low Temperatures

Work continued on the storage of plants with two ends in view; firstly to enable surplus seedlings to be carried over the subsequent growing season, and secondly, by keeping plants dormant in cold storage until required, to avoid the losses that are associated with transplanting in April and May after plants have started to break bad.

At Tulliallan, one-year seedlings of Scots pine, European larch, Douglas fir, Sitka spruce, and Western hemlock were lifted in early March, late March and late April, 1961 and stored in polythene bags in the seed store at a temperature of + 2°C. The plants were lined out at Tulliallan Nursery at monthly intervals from mid-June to mid-October. Control plants were lined out immediately after lifting. Table 3 gives the survival percentages at the end of January, 1962, i.e. after the first winter after lining out.

European larch had started to flush even at the first lift in early March, and survival was very low for all treatments. The four other species had also started to flush at the late April and late May dates of lifting, and this reduced their ability to survive storage. The survival rates of Sitka spruce and Western hemlock lifted in early March and stored until lining-out in July and August were high and similar to those of the control plants. Scots pine and Douglas fir also showed good rates of survival when lined out after storage until July, though the survival of both species was appreciably less than when lined out in early March. These favourable results from July lining-out after storage agree with those previously reported both from previous cold storage experiments and with those from "season of lining-out" experiments.

Table 3

Percentage Survival of Cold Stored Plants According to Dates of Lifting and Lining-out

	Sitka spruce			Western hemlock		
Date of Lining-out	Lifted early March	Lifted late March	Lifted late April	Lifted early March	Lifted late March	Lifted late April
At lifting	98	97	85	87	85	76
June, 1961	97	91	75	83	64	46
July, 1961	97	68	73	85	89	47
August, 1961 . . .	91	64	47	93	86	39
September, 1961 . . .	61	52	33	71	70	54
October, 1961 . . .	82	30	4	96	38	36
S.E.± .	7·2			6·1		

	Scots pine			Douglas fir		
Date of Lining-out	Lifted early March	Lifted late March	Lifted late April	Lifted early March	Lifted late March	Lifted late April
At lifting	96	94	92	91	94	88
June, 1961	77	40	56	53	58	0
July, 1961	87	51	42	75	72	0
August, 1961 . . .	79	30	19	36	64	—
September, 1961 . . .	59	19	5	49	46	—
October, 1961 . . .	36	9	0	48	59	—
S.E.± .	3·9			5·4		

A similar experiment was undertaken at Alice Holt where plants were stored at +2 and —5°C. Included in the experiment were Sitka and Norway spruce, Lodgepole pine, Western hemlock, Douglas fir, Lawson cypress and *Abies grandis*; plants of each species were lifted and stored in early February, and early and late March. Plants stored until July and August at +2°C survived lining-out, and hardened off before the winter without significant loss. Plants tolerated storage at +2°C significantly better than at —5°C. The effect of date of lifting was small, the survival and health of plants lifted in early February being a little better than that of plants lifted in late March.

In addition to these experiments, there were several large-scale field trials of cold storage of surplus stock. In all about one million plants were involved, mostly Sitka spruce and Douglas fir but with some Norway spruce, Corsican pine (poor quality plants) and Western hemlock. These plants were put into cold store in early March and lined out in late July and early August. Considerable effort was made at Wareham to water during and immediately after lining-out to ensure that the ground was moist though the weather was dry. The survival of the spruces and Douglas fir was over 90 per cent, that of Western hemlock varied from 85 to 40 per cent, but the Corsican pine did poorly—only 30 per cent surviving.

In another large-scale field trial, cold storage facilities were used for short-term storage of plants until May to extend the lining-out season. In this trial, plants were stored at Perth cold store, and lined out while dormant at Devilla nursery in mid-May. They survived and grew as well as normally treated plants lined out on the same site three or four weeks previously.

Factors Influencing Yield of Seedlings

Date of Sowing

Experiments comparing the effect of date of sowing were repeated at Kennington, Wareham and Bramshill. At Kennington, certain plots of each date of sowing were irrigated. Western hemlock and Japanese larch seed from three different years collections and seed of Sitka spruce collected in two years (two provenances collected in one year) was used in these experiments; sufficient seed of each source was also put in store to enable the identical experiments to be sown in 1962 and 1963, and so to obtain information on the effect of age of seed in response to date of sowing and irrigation.

The results in 1961 showed the expected advantage in height growth of March sowings, though April and early May sowings yielded more live seedlings. There were no interactions between date of sowing and seed of different ages.

Nutritional Problems

Demonstration of Long-term Maintenance of Fertility

The experiments at Bramshill and Teindland were sown for the twelfth consecutive year. Growth and yield of seedlings were good. The trend observed in previous years for compost plots to yield bigger seedlings continued, though at Bramshill (but not at Teindland) the reduction in number of seedlings on compost plots was very much less marked than usual. There is no evidence of any fall in the fertility of either experimental area as a whole during the period of these experiments, though the plots manured with fertiliser alone have produced slightly smaller seedlings in recent years than compost plots, particularly at Teindland.

Rates and Times of Application of Nitrogen Fertilisers

As reported previously, there has been little experimental evidence to support the commonly held view that heavy or late applications of nitrogen induce frost-susceptibility. The value of previous experiments has been impaired, however, by the absence of early autumn frosts. Six further experiments were therefore sown in Scottish nurseries. In these, four rates of nitrogen fertiliser were applied as one to four equal top-dressings, the first top-dressing being applied in either early July or 14 days later. As in previous years, no severe autumn frosts occurred, but the heavier rates of application delayed the formation of buds for all species (Sitka spruce, Japanese larch and Douglas fir) at all nurseries, except at Devilla, where Japanese larch was unaffected by any nitrogen treatment.

In four of the six experiments, the ratio: root weight/shoot weight was significantly smaller on plots given additional nitrogen. This was particularly so at the heavier rates of nitrogen application.

Japanese larch seedlings in a similar experiment at Inchnacardoch in 1960 (see *Rep. For. Res., For. Comm.*, 1961) were left to grow on to two-year seedlings, and were badly damaged by the late May frost in 1961. By September, however, most of the seedlings were seen to be recovering well except those on plots which had received the heavier dressings of nitrogen in 1960. It is not known whether the heavier nitrogen dressings brought about more rapid flushing in spring, 1961, or whether the state of the seedlings differed in some other way.

Protection Against Birds

Seed dressed with two formulations of thiram was sown at Bramshill and Wareham. Seed dressed with red lead (the present standard practice) was sown on control plots and on plots covered with polythene sheet or wire netting. The polythene sheet was allowed to remain until first germination, or three or six weeks after first germination. Each plot was sown with Scots, Corsican and Lodgepole pines, and Sitka spruce.

Unfortunately, there was little bird damage on any plot at either nursery, though at both places damage in previous years has been widespread. There was no significant ill-effect from any thyram treatment. Seedlings on plots covered with polythene sheet were appreciably more vigorous than those on other plots; this latter response has been observed in previous years and is attributed to the more favourable germinating conditions under the polythene.

REFERENCE

AUDUS, L. J. (1960). Microbiological Breakdown of Herbicides in Soils. *Herbicides and the Soil.* (Proc. 2nd Symposium Brit. Weed Control Council). Blackwell Scientific Publications, Oxford.

SILVICULTURAL INVESTIGATIONS IN THE FOREST

By M. V. EDWARDS, G. D. HOLMES, AND SILVICULTURE STAFF

In this section of the report, a slight re-arrangement has been made for the convenience of the reader. Silvicultural investigations are now grouped under subject heads; the principal geographic division (South and Central England and Wales—Scotland and Northern England) in previous reports being discarded. The location of the work is however made clear in the text. As there are a considerable number of writers, each usually contributing short sections, authorship is most conveniently indicated by initialling the various contributions. Reference may of course be made to the staff list, which appears as Appendix II.

AFFORESTATION OF DIFFICULT SITES

No major new projects were started in the south during the year, work being confined to continued observations at the existing experiment centres.

Cornish Heaths

At Land's End Forest (formerly Croft Pascoe Forest), Cornwall, an extensive series of plots were planted in 1954–57 on shallow heathland soil over Serpentine rock. The pines, notably *P. radiata, P. pinaster*, coastal Lodgepole pine, and *P. muricata*, are the most successful of some twenty species tried on the shallower soils. More extensive plantings were made in 1960 using *P. radiata* and Lodgepole pine, with Sitka spruce in wetter hollows. Complete ploughing has proved much better than normal single-furrow ploughing, and *P. radiata* planted in 1954 on complete ploughing has now closed canopy. The site is very deficient in phosphorus and all species have shown a marked response to additional top dressing of phosphate applied in 1960, six years after planting and initial manuring.

P. radiata is a difficult planting subject, and 1961 trials of methods of reducing planting losses showed some success, particularly using one-year seedlings raised in polythene tubes and planted with little root disturbance. Survival was 100 per cent, a marked improvement over use of normal planting stock.

Mid-Welsh Grasslands

At Taliesin Forest, Cardiganshire, the important group of experiments on afforestation methods on a site representing the steep, freely-drained acidic grassland of mid-Wales, was continued. Here x *Cupressocyparis leylandii* has been oustandingly vigorous at high elevations. In 1962 the hybrid is being planted over several acres in a matrix of Sitka spruce, to provide data on long-term production under crop conditions.

Dorset Heaths

At Wareham, Dorset, trial plots established in 1960, on sites representing the heaped overburden in disused gravel workings, have shown most vigorous growth, notably of Corsican pine, *Pinus radiata*, and x *C. leylandii*. Results are encouraging and suggest that more general planting (with a minimum of levelling of spoil to permit later extraction) is justified. G.D.H.

The Northern Isles of Scotland

The preliminary results of the experimental plantings of 1953 and 1954 in Shetland and Orkney Islands (Hoy) were reviewed, but apart from one sheltered central valley (Kergord) there is no prospect of productive forestry in Shetland. Shelterbelts might be of value to the farmer and, if required, guidance on species and provenance could be given, as has been done for the Meteorological Office in the planting of a shelterbelt at the Lerwick observatory.

Because of better topographic shelter, crops of Lodgepole pine and some Sitka spruce might be grown on parts of Hoy, although probably they would not prove economic due to the transport difficulty.

These experimental plantings are being maintained to continue to provide information about the behaviour of some of our common species in extreme exposure conditions.

Plantations at High Elevations

Advisory work and recording of establishment work continues. The purpose of the project was described in the 1960 *Research Report*. Forty-seven plantations have been recorded to date, the great majority being in Scotland.

S.A.N.

Industrial Sites

The restoration of industrial sites (such as opencast quarries, or tips of mining and other waste materials) does not usually involve tree planting on a forestry scale, but there may be an interest in tree growth for shelter or the improvement of the scene. The Land Restoration Committee of the Ministry of Agriculture is often a clearing-house for such problems. There has recently been some interest in the possibilities of growing trees on pulverised fuel ash, the waste from modern electricity generating stations. The substance is frequently tipped as a wet slurry, and allowed to dry out. It has some unpleasant characters, notably high boron toxicity and fine particle size—which renders it likely to blow when dry. Though it seems probable that much of the substance will eventually be covered with soil, it has been thought worth while to co-operate with the Central Electricity Generating Board in small-scale trials of a variety of species on a deposit of the material at Connah's Quay, near Chester.

R.F.W.

Upland Heaths: Cultivation

Ploughing and planting have been completed in an experiment at Inshriach Forest, Inverness-shire, to compare growth and production of Scots and Lodgepole pines on a fluvio-glacial gravel with different degrees of cultivation. The treatments are direct notch planting (no cultivation), spaced-furrow tine ploughing (the standard practice) and complete ploughing with a single-furrow Solotrac plough to a similar depth to that reached by the tine; i.e. 13–16 inches. This is to study the long-term benefits of increased cultivation on a site where pines could be expected to form a crop without any cultivation. The interaction between these cultivation treatments and the addition of phosphatic fertiliser will also be studied.

The complete ploughing required three times as many passes of the plough per unit area as the spaced-furrow ploughing, and if the benefits of this treatment are found to warrant its wide-scale use, it will be necessary to consider reducing the time and cost of the operation by increasing the area of ground cultivated at each pass. A start was made on this problem by ploughing plots at Inshriach with a two-furrow tine plough (a standard Forestry Commission tine plough carriage as made at Parkgate near Dumfries, carrying two tine plough bodies in echelon). When used at 5 feet spacing this plough turned over the soil in a 3 feet wide strip at each pass and buried the vegetation on the intervening uncultivated strip; when used for complete ploughing it did the work in less than half the number of passes required for complete ploughing with the single-furrow Solotrac plough.

On the 'hard heaths', developed on certain glacial tills as at Teindland, the Black Isle and Speymouth in north-east Scotland, some degree of cultivation is essential for the establishment of trees, and complete ploughing has been shown to confer advantages over spaced-furrow ploughing in both early stability and growth. A proposal has been made for the development of an implement which will achieve disruption of the complete land surface down to a depth of at least one, and preferably two feet, over a strip the width of the planting spacing at each pass.

D.W.H.

Deep Peats (Drainage on peats is mentioned under 'Drainage' page 42).

Peat Shrinkage

Four experiments to measure the amount of shrinkage which occurs following the ploughing and planting of deep peat (over 24 inches) have now had four years' intensive assessment. It was found that vertical shrinkage amounted to 2½ to 6 inches on the ploughed ridges, but to only ¼ inch to 1 inch on the surface between ridge and furrow, and in the bottom of the furrows. On the ridges, almost all the shrinkage occurred during the first two years after ploughing, mostly in the summers; occasionally the ridges were found to have swollen slightly over winter. Further movement has now become very slight and the next assessment will be made ten years after ploughing.

Four similar experiments on peat between 12 and 18 inches deep have been running for one or two seasons; they show movements of the same general pattern as those on deeper peat.

As is to be expected, planting has so far had no appreciable effect on shrinkage.

D.W.H.

IMPROVEMENT OF FOREST STANDS

Manuring Newly Planted Crops

In the South, two new experiments were established to test the effects of method of application, rates, and forms of phosphate fertiliser (i.e. rock phosphate v. triple-superphosphate) on the establishment of pine on South-western heaths.

The trials include comparison of normally 'placed' dressings, applied after planting, and broadcast dressing before or after complete ploughing.

These experiments have the aim of amplifying existing evidence, which suggests that triple-superphosphate or superphosphate applied at higher-than-normal rates may be justified on the poorer mineral soils of the Culm, Serpentine and Tertiary formations of South-west England. Recent trials suggest that on some of these soils, a two–three fold increase in rate, from the normal 25 lb. P. to 50–75 lb. P. per acre, may be warranted in terms of an increased and more persistent growth response.

Striking responses to potassium applied shortly after planting Sitka spruce and Lodgepole pine have been obtained on *Calluna*-dominated blanket peat in Wales. This effect was first noted in a 1959 trial at Dyfnant Forest, when badly yellowed and stunted trees were restored to normal growth following application of potassium chloride at ½ oz. per tree. Potassium is now being tested in factorial combination with N., P., and Mg. on peat at three forests in Wales to permit more general conclusions. Potash responses are rare on mineral soils, as shown by analyses now being made on data from P. x K. factorial tests started in 1956 on a range of soils.

Little work has been done with nitrogen as applied to newly planted trees, largely on account of its limited persistence and stimulation of weed growth, especially grass. Recent development of slowly soluble forms of nitrogen, which may be safe to apply below the plant in the planting hole, may overcome some of these snags, and preliminary trials are being made this season.

G.D.H.

Mechanical Application of Fertilisers while Ploughing

The South Scotland Conservancy has developed a fertiliser hopper for attachment to forest ploughs, enabling fertilisers to be applied during the act of ploughing. Ground mineral phosphate is the fertiliser most used at present on ploughed land, and the machine has been developed to apply this material at a pre-determined rate under the plough ridge. A large experiment at Arecleoch, Ayrshire, has been established to compare the effects on growth (both above and below ground) of phosphate applied as a continuous narrow stream under the ridge, with its application on the surface round the tree after planting. It has been designed to last until the stand has reached the pole-stage, when tree stability studies can be undertaken.

J.A.

Improvement of Checked Plantations

Since 1955, a large number of experiments have been established in the South to test methods of restoring areas of 'checked', or slow growth, to full production. This work has been concentrated in major problem areas which are mainly crops of spruce, pine or Douglas fir, in situations of low fertility and/or severe vegetation competition. Diagnostic trial of fertiliser top-dressings, and in some cases vegetation control, has been the main method adopted, and in several cases this has yielded results justifying immediate extension onto a practical scale. The present position and new developments in some of the main problem areas are noted below.

Fertiliser top-dressings of N, P, K, Ca and Mg. applied in 1959 on poor Douglas fir crops on the Weald (mainly Tunbridge Wells Sand and Ashdown Sand) have shown little positive response, despite the known low nutrient levels of these fine sandy-silts. There has been a slight improvement following nitrogen and phosphorus dressing, but it seems unlikely that this will have practical importance. Very restricted depth of root penetration is general on these sites, and this seems associated with the physical features, notably low pore space, so that the soils are readily waterlogged in winter. This may be responsible for wholesale death of roots below 4 to 6 inches depth. However, surprisingly, enrichment of the shallow rooted zone has had no marked effect on growth to date.

A variety of 'checked' crops, mainly spruce or pine, on *Calluna* heathland in Wales and Southern England are also being studied. A consistent pattern of growth responses seems to be emerging, in that almost without exception, growth can be improved by supplementing supplies of nitrogen and phosphorus. Current work is concerned mainly with working out the most persistent and economical methods of supplying these extra nutrients in practice. Broadcast top-dressing of NP fertiliser has been very effective, notably using diammonium phosphate, or urea + triple-superphosphate. However, nitrogen effects seem unlikely to persist for longer than 3 to 4 years, so that further top-dressings of nitrogen may be necessary to ensure canopy closure. Indirect provision of nitrogen and other elements, by control of competing *Calluna* vegetation combined with phosphate dressing, has produced a marked improvement and is proving more persistent than application of nitrogen fertiliser. These treatments were extended onto a practical scale by aerial top-dressing with diammonium phosphate at Ringwood Forest, Hampshire, in 1961. In 1962 large-scale comparative trials on the cost and effectiveness of the two methods (i.e. aerial application of NP fertiliser *contrasted with* separate aerial applications of P. fertiliser + 2,4-D spraying for *Calluna* control) have been made in unsatisfactory pine areas at Ringwood and Wareham Forests. When the results are available it may be possible to provide a formula applicable for crop improvement in a variety of areas of poor heathland where *Calluna* competition is severe.

Checked 10 to 20 year-old Sitka spruce in a vegetation of Dwarf gorse, *Calluna* and *Molinia*, on the Culm soils of South-west England, have shown remarkable growth responses to top-dressings of phosphate alone. The responses are large and speedy, and the improvement seems to be persistent provided the top-dressing exceeds 60 lb. phosphorus per acre. The first plots treated in 1954 have now closed canopy, and it seems likely that a good quality stand will result from treatment at a stage of complete growth check. Over 100 acres of this type of spruce were given aerial top-dressings of triple-superphosphate in 1959, and these areas are now growing vigorously. A programme of aerial top-dressing with phosphate is now being applied as a practical operation by the Conservancy to other checked areas of this type, including some 200 acres at one forest in 1962.

Current research activities in these areas are now concerned largely with analysis of crop, vegetation and soil for estimation of the fate of added phosphorus, and continuation of growth assessments in experiments to determine the long-term effects of rates and forms of phosphorus and other nutrients.

Similar striking growth responses to phosphate top-dressing have been obtained in species trials planted in 1954 on Serpentine soil at Land's End Forest, Cornwall. Despite standard dressing of phosphate at planting, many species showed declining growth by 1960. Triple-superphosphate, applied in 1960, has resulted in a marked improvement of growth during 1961. The evidence confirms that phosphate deficiency in the early years following afforestation is a critical factor on the Culm and Serpentine soils of South-west England. Top-dressing with a concentrated phosphatic fertiliser appears to be a practical and economical method of sustaining vigorous growth and ensuring canopy closure. The longer-term effects of such dressings on increment are now being studied.

In most of the experiments on this project, regular analyses of foliage samples are made to track the uptake of added nutrients, and to provide data to permit more accurate diagnosis of nutrient deficiencies. Also, in 1960, an experiment was planted on deep infertile and freely-drained Bagshot sand at Wareham, and subjected to unbalanced fertiliser dressings designed to induce deficiency symptoms of major elements. Six species have been planted and it is hoped that the symptoms displayed at various stages of growth may assist more accurate diagnosis. The first result has been complete failure of plants to establish themselves on 'minus P.' plots and it has been necessary to relax this treatment to the extent of applying a minimum dose of phosphate to enable the test plants to survive. 'Minus K.' plots also show symptoms of potash deficiency, most striking in Scots pine as discoloration and early death of needle-tips.

G.D.H.

Young Checked Sitka Spruce in the Borders

In 1950, considerable concern was felt over the progress of several *Calluna*-clad areas in the Borders where Sitka spruce had checked before closing canopy. Most sites were on deep peat and ground preparation consisted of hand-turfing, ploughing at various spacings with spread turves, or ploughing at 5 foot spacing. Some sites had received slag at planting, others as a later top-dressing and others none at all. Selected areas were marked and assessed for height and losses every 3 years until 1960 (10 years). This year the sites were revisited and the data analysed. The results have largely confirmed the effectiveness of current amelioration treatments, i.e. drain maintenance, mulching, and the application of phosphate. Increased confidence in Lodgepole pine has to some extent overcome this problem, and the Conservancies concerned are now using a varying proportion of this species in the afforestation of these bad bogs, which form only a small proportion of the area planted.

S.A.N.

Manuring of Pole-Stage Crops

The feasibility of increasing increment by manuring crops after canopy closure in the pole-stage received little attention until 1958, when the first large-scale experiment was established. In the South during 1958 and 1959, 15 factorial tests of N x P x K x Ca x Mg were laid down in low/middle Quality Class crops of Scots pine, Sitka spruce, Norway spruce and Douglas fir, at the first thinning stage. Effects are more difficult to observe than in crops of smaller trees, but in terms of measured girth increment initial growth responses have been small. Nitrogen and phosphorus have substantially improved growth on the poorest (unclassified) pine stands, but no large effects have been noted in more normal and vigorous stands. However, foliage analyses have shown that N. and P. uptake has been considerably increased following application of the element concerned. Several of these experiments are now being thinned, and measurement of felled trees will provide accurate data or girth and height increment since treatment.

Cone production by pine in these experiments may have been increased by nitrogen and phosphate dressings, and collections are being made to assess the size of this effect in terms of cone and seed production.

One of the most striking initial effects to emerge in these trials has been the effect of nitrogen and lime dressings on litter decomposition. In view of the possible long-term importance of such effects in terms of mineralisation of nitrogen and other elements in litter, a special study of the chemical changes following nitrogen and lime dressing to forest litter is now being made by the University of Aberdeen (Department of Soil Science). Parallel with these studies, comparative trials are being made of the uptake and growth response to nitrogen applied as urea, ammonium sulphate, or diammonium phosphate.

In 1962, four experiments were established on sites representative of the major pine-growing area of East Anglia. In view of the importance of these areas it is considered necessary to assess the responsiveness of Scots pine and Corsican pine to manurial treatment on the major site types. The experiments are simple compared with earlier ones in the series, and are intended as preliminary trials to determine the broad nature and size of crop response, if any, to NPK and Mg. applications. If results show promise, further more detailed experiments may follow.

G.D.H.

In the large factorial experiment in Norway spruce at Durris Forest, Aberdeenshire, significant responses in the nutrient levels of the foliage have been obtained in the first and second years after application of the fertilisers. All nutrients (N, P, K, Ca, and Mg.) gave this response in the first year, and all but potassium gave a response in the second year. Growth data are at present being analysed.

J.A.

ARTIFICIAL REGENERATION

Spruce

Ground Preparation

The cultivation experiments established since 1958 in Scotland are beginning to show results which fall into two distinct categories. On dry heath conditions, where ploughing has improved the availability of moisture by rupturing a competing grass mat, replanted species have responded well to cultivation. Shallow ploughing or 'rooting' with tines is all that is required to facilitate establishment. The possibility of using a pre-planting weedkiller to achieve the same effect is being investigated.

On wet peaty or clay ground, cultivation has shown little, if any, advantage. Ploughing on this type has been too rough to be of much use for drainage, and in the worst case (Lennox, Stirlingshire) the passage of the crawler tractor and plough puddled a very heavy clay to such an extent that natural fissures and percolation channels which had been built up by the previous crop, were apparently clogged, and the ploughing resulted in visibly wetter conditions with extensive *Juncus* growth. The uncultivated plots have reverted to a grass cover. The rapid increase in wetness of these clay and peaty sites after the removal of the transpiring over-crop has been frequently noted, and it is now considered that deep drains are essential, both for the early benefit of the second crop, and its later stability.

It has been decided that special felling for further cultivation trials will not be done, as cultivation effects can be quickly demonstrated whenever sites become available.

Size of Felling Area

Felling has been completed in the new experiment at the Forest of Ae (Dumfries-shire) referred to in last year's report. The felling areas of 10 acres, 1 acre, 0·3 acre and 0·1 acre have been sited to ensure, as far as possible, that all perimeters are similar in tree height and peat depth. The stability of the trees on the margins has been assessed by the 'pulling-down' technique, and will also be classified subjectively. It is confidently expected that windthrow will occur, and it is hoped to relate the incidence of damage to the area of opening and to the length of perimeter.

In addition, this experiment will compare the growth of a second crop planted at various times before and after clear-felling. Previous experiments concerned with times of replanting have been inconclusive due to the confusion introduced by beating-up in subsequent years with larger plants. This made it difficult to estimate the relative amount of weeding required by each year's planting. Re-invasion of vegetation was usually complete two years after felling.

S.A.N.

Japanese Larch

The problem of how best to regenerate the Quality Class III to IV Japanese larch stands, whose volume increment is causing general concern, has been considered and sites have been chosen (Drumtochty, Kincardineshire; Radnor, Radnorshire; Coed Morgannwg, Glamorgan), to compare thinning grades in combination with various replanting species.

S.A.N., A.I.F.

Scots Pine

Plots have been established at Thetford of seven species which are considered to be the most desirable alternatives to pine; and these trials have been replicated on three soil types representing the range in depth and pH of the soils at Thetford.

In addition to the problems of choice of system and species for regeneration, the development of a machine for chopping lop-and-top is continuing, and early results are proving encouraging. The two most important conclusions to date are that the cost of this method of disposing of the brash is less than that of burning, and that the chopped material is having a useful effect in reducing weed reinvasion.

A.I.F.

NATURAL REGENERATION

Scots Pine

Following the severe fire in the Sluggan section of the Queen's Forest, Inverness-shire, in June 1960, a small experiment has been established to see whether part of the cost of re-establishment can be avoided by taking advantage of natural regeneration. Seed trees have survived along the edges of the burned area, and a strip 5 chains deep from one of these edges has been reserved for the experiment. Seed-fall from the 37-year-old parent stand is being assessed by seed traps set out in lines extending at right-angles from the edge. During 1961 four traps only (each of one square foot surface area) caught seeds, and at such a low intensity of seed-fall it would be misleading to draw conclusions as to the amount of seed shed per acre during the year; a considerably heavier fall is anticipated during 1962. In 1961 seed fell in late May and early June. A similarly sparse fall of seed was recorded in mature stands of natural Scots pine in the Black Wood of Rannoch, Perthshire, in 1961.

D.W.H.

In the south, attention is being paid to the design of traps and the intensity of sampling. Some traps have been set out in a stand of Corsican pine in order to confirm whether the design is satisfactory and whether sufficient seed will be caught to make sampling of the seed feasible. Once these trials have been completed, several seed stands will be sampled to cover a range of species and geographical localities.

A.I.F.

SPECIES TRIALS AND ARBORETA

Benmore Forest Garden and Crarae Forest Garden, both in Argyll, have been renamed 'Kilmun Arboretum and Forest Plots' and 'Crarae Arboretum and Forest Plots' respectively. At Kilmun the area has been increased from 166 acres to 180 acres, and it is intended to make a visitors' car park in part of the new area. *Eucalyptus* species were the only broadleaved trees, apart from holly, which did not have their foliage severely scorched by the gale in September, 1961.

The large *Eucalyptus gunnii* at Whittingehame Arboretum in East Lothian had its main stem thrown by a gale in February, 1962. This tree was notable as it is thought to have been the first successful introduction of a eucalypt into Britain. It had reached almost 100 ft. in height at the age of 120 years.

J.A.

At the National Pinetum, Bedgebury, Kent, the increasing numbers of visitors (particularly at holiday periods) has necessitated a search for a more extensive parking site. At Westonbirt, Gloucestershire, a provisional catalogue of the main arboretum is almost complete. A novel feature of the Westonbirt catalogue is that the sorting of the entries has been carried out on an electronic computer. The programme enables the catalogue to be sorted alphabetically, or by individual tree numbers in the various sections. As a catalogue of a large arboretum is never static for more than a month or so, it is expected that there will be great advantages from holding the main record 'on tape'.

R.F.W.

PROVENANCE

Scots Pine

After eleven years' growth on typical poor west coast sites (Glentrool, Kirkcudbrightshire and Grizedale, Lancashire), provenances from the west of Scotland have given a better all-round performance than those from north-east Scotland or Scandinavia. At a recent assessment, the needles of the west coast provenances were blue-green in colour and more resistant to winter-browning than those from north-east Scotland. Provenances from Scandinavia were yellow-green in colour, and were significantly less tall than any of those from Scotland.

Pinus nigra

A further experiment containing eighteen provenances was planted at Haslingden, Lancashire, on a site where measurements of atmospheric pollution by sulphur dioxide have shown high values over a three-year period. Some of these provenances have also been planted by the West of Scotland College of Agriculture as an experimental shelterbelt on Tiree. In freezing trials with the same provenances, Mr. W. R. Day at Oxford found that the Corsican and Calabrian (Italian) origins were markedly more sensitive to frost than Austrian or other sources.

Transplants of Corsican, Austrian and Calabrian provenances lined-out in plots of different soil pH showed no consistent responses; but this trial once more showed the superior survival of Calabrian over Corsican provenances.

The warm summer of 1959 induced more flowering than usual in stands of *P. nigra* in the Pennines, and advantage was taken of the resultant cone crops to obtain six lots of seed. Dr. E. Løfting has also very kindly provided seed from old stands in Denmark, some of which are the healthy survivors from crops affected by die-back in their youth.

Seed is also being obtained from stands on calcareous soils in central and southern Europe for trial on the shallow soils over chalky boulder clay in East Anglia. This seed will probably be sown in March, 1963.

Lodgepole Pine

The pre-war experiments, now at the second thinning stage, show very large differences in volume and increment between the best and poorest provenances. At Wykeham (Allerston), Yorkshire, on a poor heath, the most vigorous Washington coast origins, now 23 years old, have a total volume of 1,900 hoppus feet per acre; the slower-growing provenances from northern British Columbia have a total volume of 1,400 to 1,600 hoppus feet per acre; but the slowest provenance of all from inland Oregon, is not yet ready for thinning, and has not been measured for volume. Current annual increments in the plots which have been thinned range from 135 to 187 hoppus feet per acre. The rate of growth and increment of the better provenances are equivalent to Quality Class I Scots pine, and only the very slow ones fall below Quality Class II of Scots pine, which is the probable best local rate for the latter species.

The 1956 collection of provenances made up mainly from the coastal regions of Oregon and Washington, was planted at several sites in England and Wales in 1958 and in Scotland in 1959. (The three Scottish sites are Borgie, Sutherland, Forest of Deer, Aberdeenshire and Glentrool, Kirkcudbrightshire.) The recently completed third-year assessment of the Scottish experiments agrees with previous assessments of the more southerly experiments and shows that this collection has behaved similarly on almost all sites in Britain. There is little difference in appearance or early growth rate of plants from a wide area of the west coast of Washington and Oregon. All are slightly more vigorous than plants from Puget Sound (Keyport) or Vancouver Island (Ladysmith) and much more vigorous than those from the Cascade Mountains. Plants raised from seed collected in Britain from stands of coastal U.S.A. and interior British Columbia behaved in the same way as plants raised from seed imported direct from these areas.

Pinus banksiana

Experiments at Inshriach, Inverness-shire and Broxa (Allerston), Yorkshire, have been established with negligible losses. The tallest provenances after one growing season are from Ontario (Douglas and Kenora) and Quebec Province (Chapeau and St. Louis de France). Provenances from the most Continental part of the range in Saskatchewan and Alberta made the least growth, and these were the only ones which were not taller than a provenance of Lodgepole pine from north inland British Columbia (Fort Fraser), which is included for comparison. The faster-growing lots of *P. banksiana* already show internodal branching.

European Larch

The first trials of the plants produced from selected seed stands of larch have been assessed three years after planting. On the two better sites, growth was very rapid and the tallest individuals reached six feet in height. At the more exacting sites, growth was much slower and the mean height of all trees was less than two feet.

There are significant differences in height growth between the plants from different seed stands. In general, the tallest ones are from low elevation sources and the shorter ones from higher elevations. The heights after three years are closely correlated with the heights as one-year seedlings, which are even more closely correlated with the seed weight. A small number of apparent hybrids have been noted in various provenances and these must be regarded as a normal characteristic of seed collected from Scottish stands of European larch.

Experiments planted in 1951–1952 on three sites where larch die-back had occurred and on a moderately fertile *Calluna*/grass moorland, were assessed for height growth and incidence of canker at ten years of age.

The overall growth rate and incidence of canker is at a different level from site to site, but at each site the relationship between the provenances is the same. For example, four Scottish provenances had stem cankers on more than half the stems at the worst site, but on only five to seven per cent of the stems at the best site. A Swiss Alpine provenance had cankers on seventeen per cent of the stems at the best site and seventy per cent at the worst. Japanese and hybrid larch were virtually immune, while Polish and Sudeten larch were intermediate between these and the Scottish provenances.

A study at Drumtochty, Kincardineshire, of trees partially affected by die-back, showed clearly the recovery of individual trees in the years between 1951 and 1961. Leader growth had improved, and branch die-back had largely ceased, though the trees still had a scrubby appearance from the earlier dead branches and stem cankers.

Japanese Larch

The twenty-five provenances of plants raised from seed kindly supplied by Dr. Langner are all successfully established at Allerston (Broxa) Yorkshire, and Fetteresso, Kincardineshire. All the fifteen provenances that were available for planting at Ystwyth, Cardiganshire, have also got away to a good start. A height assessment, three years after planting, showed significant but small differences between provenances at the first two sites. At Fetteresso, a standard commercial collection from Nagano Prefecture has grown as fast as any of the special collections, the best of which are from the area of Mt. Yatsugadake. Differences in form are beginning to appear, with many provenances showing markedly up-swept branches. There is a considerable range of variation in twig colour, which suggests that this may not a good criterion for selecting hybrid individuals from seedbeds of Japanese larch believed to be pollinated by European larch.

Douglas Fir

Two introductions of 'intermediate' Douglas fir (var. *caesia*) have recently been assessed. One, introduced from three localities in the montane region of British Columbia, was planted at Lael, Wester Ross, in 1931. The second introduction made in 1950 was of seed from Shuswap Lake, British Columbia. Plants raised from this seed were planted at Glentress, Peebles-shire, and at Kilmun (Benmore) Forest Plots, Argyll. At both sites, coastal Douglas fir was planted for comparison.

The older var. *caesia* plantations grew at 1·9 to 2·1 ft. per annum, compared with 2·4 ft. per annum for the coastal (Lower Fraser River) provenance. The incidence of both needle-cast fungi *Phaeocryptopus* and *Rhabdocline* was less on trees of the Lower Fraser provenance than on 'intermediate' trees, though on none of the provenances was the infection by *Rhabdocline* of any importance. At Glentress and at Kilmun, coastal provenances also grew faster in the first years, though at Glentress the coastal provenance from Oregon has, since the third year after planting, been badly affected by autumn or winter frost and by a heavy infestation of *Adelges*. Neither trouble afflicted the Shuswap Lake trees, which are now significantly taller than those from Oregon. At Kilmun, the coastal provenance (here from Washington) has not been affected in the way the coastal Oregon provenance has at Glentress, and is considerably taller than the Shuswap provenance.

Sitka Spruce

The fourteen experiments planted within the last two years have been successfully established with negligible losses. The late May frosts affected all provenances at most sites. All provenances were equally frosted at the several sites in Wales, and at Shin in Sutherland. At Wark, Northumberland, damage was more severe on the southern provenances; while at Glentrool southern provenances were slightly damaged by autumn frosts.

Phenological studies at three sites continued to show the same patterns of seasonal growth observed in previous years. None of the provenances at the sites where these phenological observations are made was affected by the late May frosts.

European Silver Fir

The big new collection comprising twenty-seven provenances was sown in a replicated experiment in 1961. There was a substantial variation in seedling yield despite the fact that approximately the same number of viable seeds was sown on each plot. The French origins, together with those from Switzerland and Germany, yielded most seedlings. A significant regression of seedling height on seed weight was found, and after adjustment by co-variance had been made to the seedling heights to allow for this, a Black Forest provenance was placed in the lead, with Czechoslovakian and French lots not far behind; provenances from Switzerland, Austria, Yugoslavia and Bulgaria made poor height growth.

Western Hemlock

Thirteen additional experiments were planted with the same 18 provenances used in last year's experiments, and the range of these sites now extends from Naver, Sutherland, to Wareham (Lulworth), Dorset, and includes most of the site types on which Western hemlock is planted. At the six sites planted in 1961, early survival has exceeded ninety per cent despite widespread spring frosts. The winter was particularly severe and on all the exposed sites considerable browning and death of leading shoots has occurred, so that further loss of plants must be expected. At Glenprosen, Angus, where the experiment is at an elevation of 1,400 ft., the Juneau, Alaska, provenance showed the best resistance to the severe conditions, but even this was badly browned.

Observations of the date of flushing and the setting of terminal buds in the nursery, showed that there was only about a fortnight between the dates of flushing of the earliest and latest provenances, but nearly two months difference in the time of autumn bud-setting, the length of the growing season varying from 101 to 170 days. In general, the northern provenances had the shortest growing season while the southern ones had the longest. Latitude only partly accounted for these differences, as those provenances which came from higher elevations some distance from the coast had appreciably shorter growing seasons. For example, Enumclaw, from about 3,500 ft. in the Cascade Mountains, Washington (latitude 47°N) grew for 104 days, while Randle from 2,500 ft. lower down in the Cascades (latitude 46½°N) grew for 153 days. The Shuswap Lake provenance, which is the only northern interior lot, grew for 117 days. The plants from Alberni, Vancouver Island, were exceptional in having a short growing season in spite of their low elevation, coastal provenance and middle latitude.

Western Red Cedar

The thirteen provenances of *Thuja plicata* sown in 1960 at Tulliallan Nursery, Fife, and at Kennington, Oxford, were lined out at each nursery. At Tulliallan there were highly significant differences in height as transplants at the end of the year; Shuswap Lake, British Columbia, was outstandingly tall, followed by

Terrace on the Skeena River, British Columbia. There was no apparent latitudinal cline for vigour as with some North-west American species, but rather a complicated variation in inherent vigour much as is found in Douglas fir. Survival was ninety per cent or over in the transplant lines of all provenances. At Kennington, growth of all provenances was uniform and no significant differences appeared.

These provenances have now been planted at Thornthwaite, Cumberland, and Benmore, Argyll, in forest experiments designed to continue up to the early thinning stage.

R.L., J.R.A.

WEED CONTROL IN THE FOREST

Control of Weed Growth on Fire-breaks

Where tractors can operate, mechanical cultivation offers a cheaper method for maintenance of bare-soil conditions than the available residual herbicides (see *Report on Forest Research* 1960, p. 119). Also in practice, many breaks are allowed to 'grass over' for maintenance by mowing. This is not always easy on steep and rocky ground, and two trials have been laid down in the south this year to assess the value of maleic hydrazide for retarding grass growth in such situations. Firelines on peat provide a special case.

The trials of weedkillers in the north-west of Scotland have shown that on *Molinia* peat, dalapon at 6 lb. (active) per acre produces a vegetation-free fireline by killing the *Molinia*, which is then blown off by strong winter winds. Monuron at 10 lb. (active) per acre, applied at the same time as the dalapon, assists in the initial kill and later prevents recolonisation at least for one growing season and possibly for two.

On *Calluna/Trichophorum* peats, the same combination of weedkillers seems most suitable, but 2,4-D ester at 4 lb. (acid equivalent) per acre must be added to kill the ericaceous plants. Amino-triazole at 5 lb. (active) per acre has proved effective on a soft grass/herb community on mineral soil. This chemical has not been tried on peat as yet. Diquat at 3 lb. (active) per acre has given disappointing results on soft grass/herb vegetation.

In addition to monuron, mentioned above, other residual weedkillers tested on peat and mineral soil vegetations were atrazine, simazine and 2, 6-DBN, each at 5 lb. (active) per acre. On peat none was as good as monuron at the same rate of application, and their effectiveness decreased in the order given. On mineral soil, however, simazine is the longest-lasting material.

G.D.H., J.A.

Selective Weed-Control in Planting Areas

Grasses

Heavy growth of perennial grasses in young plantations presents a difficult weeding problem, and work continued on evaluation of herbicides applied before or after planting. Trials were carried out on a wide variety of conditions; grass covers developing after clearance of existing woodland, established swards on chalk downland, and acidic mountain grassland. The herbicides investigated included dalapon, simazine, diquat and paraquat.

Trials of dalapon have shown most promise, and new experiments have concentrated on assessment of crop susceptibility to treatments required for effective grass control. Grass species vary considerably in susceptibility. Best control has been achieved by spraying in early spring (March to late April) at rates from 5 to 15 lb. (acid) per acre according to conditions. Thus, susceptible species such as *Agrostis tenuis*, *Bromus*, *Deschampsia*, *Nardus*, and *Molinia* are readily controlled at 8 lb. (acid) per acre. More resistant species included *Holcus lanatus*, *H. mollis*, *Agropyron repens*, requiring rates of about 12 lb. (acid) per acre for control. In practice, except for the most susceptible species, a complete kill at one application is rare. Usually the effect persists for only one season, so that annual applications, possibly at reduced rates, may be necessary. Overall strip or 'patch' spraying prior to planting has been very successful, and no residual damage to crops has been observed provided planting is delayed 4 to 6 weeks after spraying. This treatment was extended onto a larger scale in 1961, including aerial application prior to planting on chalk downland. 1960–61 trials have shown that dalapon can be effective for grass control *after* planting at rates not exceeding 8 lb. (acid) per acre if spraying is confined to the dormant season, ideally March to late April, and sprays are directed to avoid contact with the crop. These observations are based on spraying at volumes of 40 to 50 gal. liquid per acre. The first trials of low-volume sprays (10 to 15 gal. per acre) were established in 1962.

In several instances, notably in downland and *Molinia* grass vegetation, grass control by dalapon has resulted in a marked improvement of crop growth.

Trials of simazine, atrazine and propazine, as residual herbicides for more persistent control of grass weeds in young crops, have been disappointing. For reasons of economy, these compounds are mainly of interest as 'patch' treatments for weed control around each tree position. Patch treatments were tested on a variety of newly planted crop species in spring 1960 and 1961 using granular and spray applications at 2½–10 lb. (active ingredient) per acre of treated patches (i.e. approx. 0·9-3·6 lb. per acre gross). As expected, established grasses present at the time of treatment were inadequately controlled. However, where there was little grass present at treatment, as on ploughed ground or newly clear-felled conifer areas, re-development of grass cover was notably retarded. However, marked effects persisted only for 8 to 12 weeks. 5 lb. (active ingredient) per acre of treated patches caused no damage to young Corsican pine, Scots pine, Norway spruce or beech. An interesting point to emerge was that at higher rates (i.e. up to 10 lb. active per acre), propazine was less damaging to pine than simazine or atrazine.

On present evidence, dalapon has been the most effective herbicide tested for grass control, and it can be valuable particularly when dealing with heavy covers of susceptible species. Its practical value is more questionable when dealing with mixed weed populations, and more resistant grasses. In such situations control is likely to persist less than one season and broadleaved weeds may increase strongly.

Woody and Broadleaved Herbaceous Weeds

The use of herbicides for control of many unwanted woody species is now established practice in several Conservancies. Revised and more detailed practical recommendations for use of 2,4-D and 2,4,5-T in forest areas were issued during the year, and widespread use is being made of the substances, notably for control of coppicing stumps. A system of recording and summarising all applications in Commission areas was introduced, and a digest will be published in due course.

Research continued on methods of controlling weed trees and shrubs by treatment of stem bases and cut stumps. Further trials of invert emulsions of 2,4,5-T (i.e. water-in-oil instead of normal oil-in-water emulsions), have shown that for certain species this may be cheaper than the usual oil solution of 2,4,5-T ester, due to the saving of costly oil diluent. The treatment was effective on birch and aspen, but almost ineffective on oak.

In general, results with the invert emulsions were less consistent than with normal oil solutions. Trials of Fenoprop (2,4,5-TP) as a basal bark spray for birch and oak indicated that this compound is less effective than 2,4,5-T on these species. The addition of a colouring agent to stump and stem spray solutions has been suggested by several users. A range of dyes tested proved inadequate, but useful marking of sprayed bark can be achieved by addition of about 0·25 per cent fine aluminium powder to the oil solution.

The main programme during 1961 was concerned with further trials on the application of herbicides as foliage sprays for selective control of herbaceous and woody weeds in young plantations. Recent experience suggests that 2,4,5-T or 2,4-D + 2,4,5-T mixtures can be used for selective control of broadleaved herbaceous and woody weeds in young *conifer* crops, providing spraying is confined to the late summer when conifer shoots have ceased elongation. Application of overall sprays at high-volume is impracticable in most forest areas, and research has been concentrated on evaluating low-volume (5–15 gal. per acre) sprays applied with powered mist-blowers, or from a helicopter. One series of experiments started in 1961 at 10 forests, compares 2,4,5-T at 1½ and 3 lb. (acid) per acre, applied overall in water at high and low-volumes for weed control in young crops of a range of species. First results with low-volumes applied by mist-blower show promising initial weed control with negligible damage to crops of Scots pine, Corsican pine, Norway spruce, Douglas fir and Lawson cypress. However, current needles of Western hemlock and Norway spruce were badly scorched in one trial using the higher rate of 3 lb. (acid) per acre. Further work is required to identify the factors responsible for occasional damage to the crops.

This technique has been used very successfully on a practical scale in 1961 for selective control of gorse, broom, and birch in young pine crops at several forests in England and Scotland. Application of 2,4,5-T ester at 3 lb. (acid) in 10 gal. water per acre in August by helicopter or fixed-wing aircraft has given good weed control with negligible crop damage at a cost well below normal weeding costs.

Similarly, aerial spraying of high cover of scrub hardwoods before or after planting, has been remarkably effective for control of standing birch, oak, aspen and chestnut. At Bernwood Forest, Oxfordshire, 2,4,5-T at 2 lb. (acid) in 5 gal. *oil* per acre was highly effective in controlling high cover scheduled for removal to release underplantings of Norway spruce, Western hemlock and beech. In this case, the beech plantings were damaged by the spray, but the two conifers have shown a marked growth improvement since treatment.

Aerial applications of low-volume sprays have proved extremely effective and cheap in a range of situations and the technique is being applied on a trial basis in 1962 to *Calluna* control in unsatisfactory pine crops using 2,4-D ester. The use of low volume sprays shows considerable promise, but of course special precautions are necessary to prevent spray drift onto susceptible crops.

Further trials were completed on *Rhododendron ponticum* as a special and most difficult forest weed problem. Ammonium sulphamate (AMS) is known to be effective as a cut-stump treatment, but unexpectedly good results at low rates of application of AMS solution were obtained in 1961. It is thought that this may be due to applications to soil in the vicinity of the stumps as distinct from the cut-stump surfaces, and the question of method of placement is being investigated. High-volume foliage spraying of rhododendron with AMS solution has been very successful, but costly. Trials are now in hand testing the effectiveness of cheaper, low-volume spraying with powered mist-blowers for application of foliage sprays to growth stages ranging from young seedlings to large established bushes.

General Weed Control in Young Plantations

The treatments discussed above are directed against particular groups of weeds, i.e. grasses, herbs or woody species. In many plantations, weed growth consists of a complex mixture of these groups, and use of a single herbicide, toxic only to certain weed groups, may permit vigorous development of resistant weeds. In most situations one weed group is of paramount importance, and ideally a herbicide should be capable of controlling this group and at least retarding the development of other groups. To this end, investigations have been made using non-selective residual and contact herbicides, and mixtures of translocated herbicides.

In replanting clear-felled conifer areas, there is frequently a short weed-free period immediately after felling during which residual and soil-acting herbicides could be applied with effect. In this situation, first trials of 2,6-DBN as a soil treatment show promise. Application of 4 lb. (active) per acre, as dry granules, in early spring two weeks before or after planting pine, has given a high degree of weed control with little crop damage throughout the first season. Trials are continuing with several formulations of this chemical, including applications to established grass and herbaceous weeds around individual tree positions. In similar situations, i.e. following clear-felling, simazine has proved disappointing.

Certain contact herbicides such as diquat and paraquat may have value for short-term control of a wide range of weed species. Both these compounds were tested in 1961 at 1–2 lb. (active cation) per acre, applied as directed sprays to herbaceous and grass growth in young pine crops. Results showed a very rapid action and good initial control of a range of species including *Holcus*, *Agrostis stolonifera*, *Rumex*, *Carduus* and *Chamaenerion*. Paraquat was the most effective, although effects were short-lived. Crop damage is negligible provided sprays are directed. This treatment is receiving further trial to assess the required frequency of treatment for weed control.

Mixtures of translocated herbicides, notably dalapon + 2,4-D or 2,4,5-T, are also being tested applied late-summer in planted pine and spruce.

G.D.H.

EXPOSURE AND WIND

Exposure Flags

Exposure is a complex phenomenon, and in some areas it is the chief barrier to the extension of afforestation. Until recently, there has been no objective way of estimating the limiting exposure. The rate of tatter of standard cotton flags (first used by a resident of the Orkney Islands) was thought to be a possible method of assessing the exposure complex, of which wind is the chief component, but which also includes the effects of atmospheric moisture and temperature, etc.

Flags have been exposed on sites at 36 test areas, ranging from Shetland to the Southern Pennines, for two-monthly periods, over a duration of three years; after some preliminary trials to establish the best technique. The results have shown a marked seasonal variation of flag tatter, and a consistently higher rate of tatter on the most topographically exposed sites, as compared with those in the same geographic region which are sheltered by higher ground or existing woodlands. It was also found that the records of tattering at sites near one another were correlated, and that this correlation depended mainly on the physiographic region and the annual mean tatter at each site. There was a close relationship between the mean rate of tatter and the growth of Lodgepole pine (of a standard British Columbian provenance), even without taking into consideration the differences in elevation, soil or vegetation type between the sites. By comparing the average rates of tatter at sites in some younger and older trial plantations some guide is obtained as to the probable future development of the younger crops, though caution is needed in making such forecasts.

These results provide for the first time an inexpensive objective estimate of exposure for a wide range of sites. As a method, it can be compared with the estimates of rainfall obtained from rain gauges. Both have a seasonal and yearly fluctuation on any site, yet it is the mean annual rainfall which is of most value to the practical forester, since in the life of the tree the rainfall which it experiences will approximate closely to the long-term mean. Thus the mean rate of tatter per day over a three-year period is important in so far as it approaches the long-term value which would be obtained over a fifty-year period. Just as early scattered records for rainfall have been extended to cover the whole country and the accuracy of their long-term mean values improved by recording for a great many years, so the records for relative exposure could be extended to cover an increasing range of sites and their long-term mean values improved by maintaining key flag stations over a long period and by correlation of flag records with those for anemometers. (A full account will be published shortly as Forest Record No. 51.) R.L.

Experiments with Artificial Shelters

In June 1957, a provenance trial of Scots pine at Glentrool, Kirkcudbrightshire, was growing very poorly and apparently suffering from excessive wind exposure. To investigate whether this theory was correct, a small plot of 12 trees was protected by a rectangular fence 4 feet high made of nursery laths. The permeability was approximately 50 per cent. A control plot of 12 trees 30 yards away was selected, and the heights of all 24 trees measured. At the same time both plots received a basal dressing of an NPK fertiliser.

The results show that over a four-year period the sheltered trees had a height increment twenty per cent better than the unsheltered control trees.

Although the sheltered plants are now topping the fence, it is still giving protection to the lower branches, and an assessment of needle colour in April, 1961 showed that 60 per cent of the sheltered plants had blue-green needles (a healthier colour than yellow-green with Scots pine), whereas only 40 per cent of the unsheltered plants had blue-green needles.

Trials with similar lath-screens were begun in 1957 at two sites in the southern Pennines, where exposure and atmospheric pollution were believed to be two of the important factors limiting tree growth. Parallel experiments were set up at Broxa, Yorkshire, and at Kielder, Northumberland, on exposed sites where pollution was thought to be unimportant. The plants used were potted-up in good nursery soil using strong paper pots, and these were then sunk into the soil at the test site and either surrounded by a lath-screen or put out in the open nearby. In both cases the surface soil surrounding the plants was kept free of all weed growth by hoeing. The species used were Sitka spruce, Lodgepole pine, birch and sycamore. The two broadleaved species had heavy failures, despite the care in potting them up and transporting them to the sites, and the sycamore suffered shoot die-back in both sheltered and control plots. They have therefore been ignored. The two conifers both showed the beneficial effect of shelter at all four sites. With Lodgepole pine, the improvement due to shelter varied between 10 per cent at the Halifax Corporation catchment area to 46 per cent at Allerston (Broxa). Sitka spruce showed the largest response (50 per cent) to shelter at Allerston and the least at Kielder, Northumberland. The average increase in height was 23 per cent for Lodgepole pine and 37 per cent for Sitka spruce.

Further experiments were begun in 1959 to study the effect of the protection given by lath-shelters, this time using a circular fence 90 ft. in diameter. The fence was erected in the centre of an area 240 ft. by 210 ft. and trees of Sitka spruce and/or Lodgepole pine planted throughout the area. These experiments are at South Pennines Forest (polluted), Harwood Dale near Scarborough, and Forest of Ae, Dumfries-shire. By carrying out periodic height measurements over the whole area it is hoped to be able to correlate the shelter response with position in relation to the circular fence. The response will be estimated by using orthogonal polynomials, calculated from the margins of each area, and mapping contours for the difference between the expected and observed values. So far, this analysis has only reached the stage of plotting the data for tree growth.

At the polluted South Pennines site, the effect of shelter is already apparent in the results from four lead dioxide gauges arranged in a line across the site in the direction of the prevailing wind. The results from these gauges over a period of 24 monthly readings show that, in relation to the most exposed gauge to the south-west of the circular fence, one in the centre of the fence shows a 7 per cent reduction in the pollution. A gauge immediately inside the fence at the south-west side shows a 30 per cent reduction, and one just outside the fence on the north-east side shows a 20 per cent reduction.

R.L.

Wind Studies

The system for notifying windblow has now been extended to all State forests, and has been in operation since the beginning of the forest year. Information has been obtained on the distribution and extent of damage in the three big gales of September 16th, 1961, January 11th, 1962 and February 12th–16th, 1962, and of several other gales which occurred, doing more localised damage. In all about 1,200 acres have been reported as blown.

Further work has been done with 'tree pulling' to test the effect of direction of pull on tree resistance. The area chosen to do this was an experiment in spruce at Forest of Ae, where the size of felling area was being examined for its effect on subsequent windblow. Trees were pulled over alternately inwards and outwards round the perimeter, so that information would be available on the root development, and resistance to windblow, before the plots were felled. No significant difference was found between the direction of pull, but the results again showed clearly the relationship between soil drainage conditions, root development, and resistance to being pulled over.

In addition to this, work has been going on to determine the forces acting on trees as a result of wind pressure. Some work has been done in a 24 ft. wind tunnel, described by A. I. Fraser in detail in Part III, and some has been done on a tree in an exposed situation, which has been fitted up with remote-reading dynamometers, so that the forces can be compared with the readings of wind velocity from a nearby anemometer.

A.I.F.

DRAINAGE

Deep Peat

A plan is being prepared for the establishment of an experiment on part of Flanders Moss, Stirlingshire, in the Forth Valley. The site is a raised bog with peat averaging 15 feet in depth, very soft on the surface and with very little fall for drainage. Not enough is known about the water and nutrient regimes of such crops planted on deep peats. The current methods of site preparation, with ploughed 15-inch drains at 5-foot spacing, make for difficulties in extraction, and the crop may be unstable. Deeper drains at wider intervals, and complete surface cultivation, will be tried, and direct assessments of peat moisture and nutrient characteristics will be made in addition to those of tree behaviour. Studies of water run-off from the different drainage patterns will be included, and also of nutrient supply in rainfall and its loss in drainage water.

D.W.H.

Mineral Soils

Drainage research in the south is continuing on heavy clay soils, and soils of varying texture, where topographical features cause the drainage problem.

With the purchase of a hydraulic excavator, which has been mounted on a crawler tractor, the scope for digging drains is greatly increased, and much of the work this year has involved inspection and selection of sites where drainage is a problem, and where experiments or large-scale trials can be carried out.

The existing mole drainage experiment at Halwill Forest, Devon, has indicated that the moles have an important effect on lowering the level of standing water in the soil in winter, although the mole channels have not proved as long-lived as originally expected. However this may be largely due to inexperience with mole ploughing at the time of establishment, so that the new experiment, which is being laid down at the moment, should be a great improvement.

The deep, machine-excavated drains on heavy soils at Kerry Forest, Radnorshire, are functioning in a satisfactory manner, confirming that a well-laid-out system should maintain itself without weed growth, or conversely, over-much scour.

This work will shortly be extended into young plantations that have not been adequately drained at the time of establishment.

A.I.F.

PROTECTIVE MEASURES

Exclusion of Deer

Various synthetic fibres, originally used in the fishing industry, are now on the market as deer netting. Their main advantages are lightness and low erection costs. In addition to the small user trials dating from 1959, a comprehensive comparison of the four materials (nylon, polythene, polypropylene and terylene) in various colours, gauges, and with various preservative treatments, has been established this year. The critical factor is their sensitivity to ultra-violet light. Strength tests will be carried out periodically and any new materials will be added to the trial.

The electric battery-operated fence continues to give quite promising protection apart from occasional failure for various causes, all of which are being remedied.

S.A.N.

Repellents

Damage by deer to young plantations and regeneration in woodland areas remains a serious problem, and trials of alternatives to costly conventional deer fencing for protection of plantations have continued.

Trials of chemical repellent substances were confined to thiram preparations which have shown promise in earlier trials. A mixture containing 10 per cent thiram (wettable powder) and 20 per cent stable bitumen emulsion as an adhesive, was found to be non-toxic for application to foliage and shoots of pine, spruce, larch, Douglas fir, Western hemlock, and to dormant shoots of oak and beech. Application as a spray to give a fairly heavy 'spotty' cover to upper shoots and foliage of young trees in spring was moderately effective in deterring fraying and browsing in the year of treatment. However, spraying was wasteful of material, and smearing the preparation on leading shoots may be sufficient to prevent serious damage to the main axis of the trees.

G.D.H.

Fire Control

Further trials of fire-retardant additives to water were carried out in spring 1961 on dry *Molinia* in South Wales, and in summer 1961 on dense *Calluna* and gorse in South-west England. These trials have shown that several chemicals are effective for fire-proofing vegetation and could be of value for application to strips to contain accidental fires and as a means of increasing safety in controlled burning operations.

Several materials, including borates, or bentonite clay suspensions and mono- or diammonium phosphate solutions, have been tested, but in terms of cost/ effectiveness and ease of handling, the ammonium phosphate solutions have been most satisfactory. Application in 15 per cent solution at 1,000 gal. per acre to a 3 ft. wide strip produced an effective barrier for stopping fire spread in *Molinia*. However, on heavier growth such as *Calluna* and gorse, which has a low surface-to-weight ratio compared with grass vegetation, ammonium phosphate solution was less effective.

Among new developments, viscous water (water thickened by addition of a gelling agent such as sodium alginate) shows promise as an extinguishing agent and retardant on a range of fuel types. Algin-thickened water could be of special interest on account of efficient retention on the surface of the fuel, and its relative cheapness and ease of mixing compared with other materials. Preliminary trials are now in hand to test its value under forest conditions.

An entirely new development was a trial of rapidly-acting contact herbicides for desiccation of *Molinia* and *Deschampsia* grass to permit controlled burning of fire-breaks in safety during the period of 'green' growth in summer. Paraquat at ½–1 lb. (ion) per acre in August was a most effective desiccant, enabling thorough, safe and almost smokeless burning within two weeks of spraying. This could be important in areas where desirable controlled burning cannot be done at the normal spring period owing to the risks involved. Further trials are planned.

G.D.H.

MISCELLANEOUS PROBLEMS

Poor Growth in Pole Stage Spruce Crops

The study of this problem, which was mentioned in the *Report on Forest Research* for 1960, has been extended by surveys of spruce crops mainly on the east side of the country (to which the problem is almost confined) and by the establishment of assessment plots in stands in which the condition appears likely to develop. We are still far from pin-pointing the agents responsible or the precise course of events leading to the decline in vigour, but unsatisfactory moisture relations between crop and site are clearly important in the early stages, after which the development of other agencies, such as *Neomyzaphis abietina*, may aggravate the condition.

D.W.H.

Loosening of Young Trees by Wind

The investigation into the problem of wind-loosening was continued for a further year to determine the sites on which furrow-planted trees develop the typical shallow root system found on the hard upland heaths. On uncompacted soils, such as river terraces and outwash sands, tree roots do grow downwards, and on such sites wind-loosening is exceptional, and is generally caused by the tree having been planted on top of a large stone or other obstruction.

As the previous investigation had shown little difference between loosened and unloosened furrow-planted trees, this problem was further investigated by recording the pull required to displace the tree stem several degrees from the vertical, and relating these forces to root size and distribution. No consistent distinction was found between trees with markedly asymmetrical root systems and those with evenly distributed roots. The conclusion is, therefore, that all trees on hard upland heaths are liable to wind-loosening if planted in the furrow, and the possibility of determining the limiting degree of hardness where this may happen, is being investigated.

J.A.

De-barking of Hardwood Pulpwood

The trials of diquat for loosening bark of hardwood pulpwood described in *Forest Research Report* 1961, were extended in 1961 to include treatment of large timber. The success of this treatment on small-dimension oak prompted this trial as a possible means of assisting peeling of slabwood and cordwood following felling and conversion of sawlog-size hardwoods. Results with diquat have been only fair. Bark was undoubtedly loosened, but the hoped-for separation of bark and slabwood during sawing and conversion did not occur. Trials are continuing with modified methods of treatment. Also a trial is now under way in which diquat is applied on a larger scale to small-dimension pulpwood material of a range of species. This will permit evaluation of differences in species reaction, and provide data on pulpwood production costs by this means.

G.D.H.

POPLARS AND ELMS

By J. JOBLING

POPLARS

Varietal Trials

Only six plots were planted during the winter. All clones of potential commercial value in the varietal collection, with a few notable exceptions, are now included in field trials; most are located at two or three areas at least.

Assessment of fast-growing plots of six years of age and over continued. At Quantock Forest, volume measurements carried out of trees in 12-year-old plots confirmed that not only are these still the fastest-growing poplars in any British trial, but that some of the taller specimens, now already more than 80 feet tall, may reach a height of over 100 feet in 15 years. The most likely candidates to achieve this distinction are seven trees of *Populus* 'Androscoggin', the largest of which—though not the tallest—is 82 feet high with a breast height girth of 44½ inches after 12 years growth.

The plots for which data are given in Table 4 were thinned for the first time prior to assessment. Some of the bigger stems yielded billets of a size large enough for veneering, and these were given preliminary commercial tests. Although general timber quality fell short of normal standards, none of the defects in the billets could be attributed directly to the fast rate of growth of the trees or their botanical origin. Indeed, the tests showed that Black and Balsam poplars, whether fast grown or not, might be expected to give veneers of similar quality.

Each plot, occupying an area of 0·119 acres, initially contained 16 trees at a spacing of 18 feet x 18 feet (134 trees per acre). The seven clones were planted in December, 1949.

Table 4

Varietal Trial Plots – Quantock Forest, Somerset
Height, girth and volume at 12 years

Clone	Standing Crop						Thinnings vol. per acre o.b. (H. ft)	Tot. vol. prod. per acre o.b. (H. ft)	Mean ann. vol. incr. per acre (H. ft)
	No. of trees		Ave. ht. (ft)	Ave. b.h. girth (ins)	B.A. per acre (sq.ft)	Vol. per acre o.b. (H. ft)			
	per plot	per acre							
Androscoggin	13	109	78½	36	63	1,989	399	2,388	199
Trichocarpa CF	13	109	63½	35½	60	1,540	376	1,916	160
Robusta AE	12	101	58	30½	41	1,479	223	1,702	142
Oxford	14	118	63	33	56	1,485	206	1,691	141
Casale 154	13	109	60½	36½	63	1,401	277	1,678	139
Casale 214	12	101	57½	34¾	53	1,278	299	1,577	131
Robusta PH	15	126	66½	30¾	51	1,305	88	1,393	116

Note.—Populus 'Casale 154' and *P.* 'Casale 214' are natural hybrids of Italian origin. The two Balsam hybrids, *P.* 'Androscoggin' and *P.* 'Oxford' are products of an artificial cross and were imported from the United States.

Varietal Collection

Including the selections introduced during the past winter, for identification or for inclusion in the Populetum, the collection now contains 401 clones, a net increase of seven over the previous year. Of the seven clones obtained from the Continent, four are *P.* x *euramericana* hybrids, two are selections of the Grey poplar, *P. canescens*, and one is a variety of the White poplar, *P. alba*. The replanting of the varietal stoolbed in a nursery in the grounds of the Research Station has now been completed.

Populetum

This contains 274 clones, an increase for the year of 13. The distribution of clones by botanical group is as follows:

White poplars and aspens, species and hybrids	50
North American Black poplars	16
European Black poplars	18
Hybrids between European and North American Black poplars	74
North American Balsam poplars, species and hybrids	27
Asiatic Balsam poplars	32
Hybrids between Black and Balsam poplars	49
Leucoides Section	8

Silvicultural Experiments

Establishment Studies

No new work has been undertaken, but those experiments remaining informative have been maintained and assessed as required. Experiments in this group are concerned with the behaviour of different ages and types of stock after planting out, and the effects of various planting treatments on young poplar during the establishment period.

Spacing

Girth assessments were again carried out in the two oldest experiments, at Gaywood Forest, Norfolk (1953) and Blandford Forest, Dorset (1954). The spacings in the two experiments are 8 feet, 14 feet, 18 feet and 26 feet. The assessments show that the differences in mean girth of trees at the four spacings are still not significant. Crown contact between trees in the 8 feet spacing plots, while appreciably increasing during the past year, is apparently not so intense as to constitute serious competition.

During the winter the first experiment with a clinal layout was planted. This, at Wentwood Forest, Monmouthshire, adjacent to the spacing experiment laid down in 1958, has the trees located along radial arms of a circle. The radii are separated by an angle of 10°. The distance between trees increases from the centre outwards and all the spacings to be compared are represented on each radial arm. Two clones are included in the current planting; *P. trichocarpa* MB, a fast-growing rather wide-crowned form, and *P. tacamahaca* x *trichocarpa* 32, a form with a narrow, upright crown. The clinal layout is extremely economical in both ground requirements and number of trees needed for assessment, so that more than one clone may be included in the same experiment, and a much wider range of spacings compared than is possible with conventional experimental designs. In the current planting, nine spacings, ranging from 6 feet to 36 feet, are being tested, though the whole experiment covers little more than 5 acres.

Mixtures

The planting of blocks of poplar was completed in an experiment started in 1961, at Bradon Forest, Wiltshire, in which P. 'Laevigata' and *P. tacamahaca* x *trichocarpa* 37 are to be underplanted with alder in 1963. The object is to test reports from the Continent that growth of poplar benefits from the presence of alder. This is the second experiment in which alder and poplar are being studied in intimate mixture; the first is at Mildenhall Woods, Suffolk, where planting was carried out in 1956 and 1957.

Pruning

To supplement existing studies, a preliminary trial was started during the year in which the growth of young trees, pruned to different levels, will be accurately compared over two growing seasons by using vernier girth bands. It is hoped that by recording girth at frequent intervals on the vernier bands, the effects of pruning will be more readily detected than if the trees were measured annually by conventional methods.

Nursery Studies

Mist Propagation

Good results were obtained with almost every clone of poplar propagated. Seven softwood cuttings rooted out of every ten inserted. A take of 86 per cent was obtained with *P. canescens*. Survival was high of rooted cuttings bedded out after removal from the mist frame, and it is probable that a good deal of the success was due to the use of peat pots. These almost entirely eliminate damage to roots during transfer of plants from the mist unit to the nursery soil.

Distribution of Cuttings

Of rather more than 26,000 nine-inch cuttings of eight standard varieties distributed during the winter, over 18,000 were taken up by Forestry Commission nurseries. This compares with a total disposal for 1961 of 11,567 cuttings, of which only 1,085 went to the Commission's nurseries. Sales to private estates fell by 3,000 cuttings in 1962, though disposals to the trade at home remained substantially the same. In Table 5 the distribution is shown by variety.

Additionally, cuttings of standard varieties were sent to the Irish Republic and both cuttings and rooted plants of other varieties were supplied to Universities and Research Stations in this country and abroad.

Bacterial Canker Investigations

A survey was made of varietal trials during the summer to study the occurrence of bacterial canker under natural conditions of infection. This work is briefly summarised in the section 'Forest Pathology'. The testing of clones for resistance to bacterial canker on inoculation continued at Fenrow nursery, Rendlesham Forest, Suffolk. Here 167 clones were lined out during the winter, each represented by 10 long cuttings, to be inoculated during the spring with rough bacterial slime.

Table 5

Disposal of Poplar Cuttings: Forest Year 1962

Destination	Standard Variety Number							
	1	2	3	4	5	6	7	8
Forestry Commission .	2,525	685	2,289	2,755	25	2,430	6,865	1,025
Private Estates . .	800	—	1,600	400	100	1,250	500	—
Trade Nurseries . .	200	—	500	1,300	200	740	200	100
Total . . .	3,525	685	4,389	4,455	325	4,420	7,565	1,125

Key to Table 5

1. *Populus* 'Eugenei'
2. *P.* 'Gelrica'
3. *P.* 'Laevigata'
4. *P.* 'Robusta'
5. *P.* 'Serotina'
6. *P. tacamahaca* x *trichocarpa* 32
7. *P. tacamahaca* x *trichocarpa* 37
8. *P.* 'Berolinensis'

ELMS

Clonal Collection

This now contains rather more than 70 clones. Of these, 10 are hybrids received some years ago from the Netherlands for disease testing, 17 are selections from the Himalayas, collected by Ir. H. M. Heybroek, Phytopathologisch Laboratorium 'Willie Commelin Scholten', Baarn, during a recent visit to India, and the remainder are selections of 'plus' elm trees made in this country during the past three years. The Himalayan clones are essentially of botanical and pathological interest; it is doubtful if they have any silvicultural value in this country. They will be tested for resistance to elm disease, *Ceratocystis ulmi*, and in the Netherlands it is likely that they will be crossed with European elms in the hope that resulting progeny will be disease-resistant, frost-hardy and exposure-resistant. Most of the clones in the collection have been included in a stool bed planted during the winter in a new nursery established in the grounds of the Research Station. The stools will mainly provide softwood cuttings for rooting under mist, but they will also be used as a source of hardwood and root cuttings for studies of propagation by other methods. Stools of a few outstanding local clones have also been planted in the nursery at Westonbirt Arboretum, Gloucestershire, where it is hoped that elms will be propagated on a reasonably large scale.

Disease Testing

During the winter, rooted cuttings of 14 clones were planted in the elm disease trial in a nursery at the Research Station, where they are to be inoculated from cultures of the causal fungus, *Ceratocystis ulmi*, when growing with reasonable vigour in a year or two. It is hoped to pass the Himalayan clones and all selections made in this country through the trial as plants become available. Work in the field was confined to the replacement of dead trees at the natural infection trials at The King's Forest, Suffolk, and Eltisley Wood, Huntingdonshire.

Cultural Studies

Preliminary investigations have been started on the propagation of elm from hardwood cuttings. From work carried out in the Netherlands and the United States, it is known that hardwood cuttings root only with difficulty. The method of storage and treatment of cuttings before insertion are apparently factors likely to influence rooting more than any other, and early studies have been concerned mainly with a comparison of pre-insertion treatments on material subsequently planted in a cold frame.

During the winter a short-term establishment experiment was planted at Alice Holt Forest in which the early field behaviour of two ages of rooted cuttings are being compared with and without application of a balanced N.P.K. fertiliser. Little is known about the establishment of rooted elm cuttings, which have only recently been used for the first time to supplement supplies of grafted plants or suckers for general planting, and it is particularly important to compare the survival and early growth of different ages of rooted cuttings which may vary in size from a few inches to seven or eight feet. A clone which has recently been released in the Netherlands to the trade has been used in this experiment; it is also being raised on a substantial scale for use in later experiments. It is a hybrid between the Huntingdon elm, *U. hollandica* 'Vegeta' and the Smooth-leaved elm, *U. carpinifolia*, with the name *U. hollandica* 'Commelin', or the Commelin elm.

FOREST ECOLOGY

By J. M. B. BROWN

Ecological Study of Corsican Pine

The year under review saw the completion of field survey and a start was made with assembling the records and preparing a full report. While no fresh instances of disease (i.e. the characteristic death of shoots commonly associated with the fungus *Brunchorstia destruens*) came to notice during the year, there was a notable increase in deaths and die-back in certain stands (e.g. in Kerry Forest, Montgomery, and Pitfichie Forest, Aberdeenshire) previously observed in the active early stage of disease. An examination of the collected Scottish records suggests that the most significant climatic factors are summer temperature and ventilation of the stand. The critical level of summer warmth for healthy development of Corsican pine roughly corresponds with a mean July temperature of 13·5°–14°C, but this may be modified by aspect and perhaps by proximity to the coast. Repeatedly it has been found that a warm south, or south-west, slope may partly offset the effects of increase in latitude or altitude: while the increased sunshine of coastal sites may perhaps have a similar favourable influence. The harmful effect of stagnant air, which is manifest during the development of the stand as well as in the comparison of topographically dissimilar stands, is doubtless associated with the humidity factor.

In the widespread late frosts of May 27th–28th, 1961, young Corsican pines in a section of Bramshill Forest, Hampshire, were seriously damaged and in some cases killed. In Compartment 43, Alice Holt Forest, in the same county, where the minimum temperature at grass level was —7·5°C (on two consecutive nights) and —3·7°C at 4 feet, the damage to young Corsican pines was trifling, although Norway spruce and Western hemlock in an adjacent compartment were considerably damaged.

The abundant cones matured by Corsican pine stands in nearly all parts of Britain in the winter of 1961–62 were equally remarkable. The yield of home-produced seed, though restricted to accredited seed source stands, far exceeded that of any earlier year, a result which may be ascribed to the coincidence of the brilliant summer of 1959 with the attainment of physiological maturity of the extensive stands created 30 to 40 years ago. In many parts of the south grey squirrels were attracted to stands of Scots pine and (particularly) Corsican pine by the plentiful cones which, in a year when seeds of broadleaved trees were very scarce, aided them in withstanding an unusually prolonged winter.

There has been continued consultation with Mr. D. J. Read, of the Botany Department, Hull University, who is engaged in a detailed ecological investigation of die-back disease of Corsican pine in Allerston Forest in Yorkshire.

FOREST SOILS

By W. H. HINSON and D. F. FOURT

During the year, attention has been increasingly directed to the study of soil moisture and drainage as it affects crop growth, and to the development of recording instruments for this work. The appointment to the section in November of Mr. R. Kitching, whose training is primarily in physics, is intended to provide the means of bringing current techniques of instrumentation from other fields to aid in the solution of biological problems.

The analytical work on foliage samples from silvicultural experiments has continued on a large and increasing scale (see earlier reports). It is proposed to review the results regarding pole stage crops in 1963, after a detailed growth assessment in the autumn of 1962.

Soil survey carried out by members of the Working Plans Section has been supported by a modest amount of soil analysis this year; there appears to be a continuing demand for this work.

Soil Moisture Relations in Woodlands

The studies carried out in 1960 in collaboration with Dr. A. J. Rutter (*Rep. For. Res., For. Comm.* 1960) on soil moisture were continued. Measurements were carried out in four stands of Scots pine, and on a grass-covered site, in the Crowthorne section of Bramshill Forest.

Following examination of the results to date, certain parts of the observed pattern, especially the spring drying sequence, will be examined in greater detail. In May and early June of 1961, during a dry spell, the observations seemed to suggest that the soil about 12 inches down started to dry before that at the 6 inch level. This had been noted in 1960, but the effect could not be completely distinguished from the result of summer rainfall. Even later in the season woodland soils were frequently drier at depths of 1 foot to 5 feet 6 inches than in the top 6 inches. On the grass site, the drying seemed to proceed strictly from the surface, reaching near to wilting point at the surface before the heavy rains of mid-June.

In an attempt to find factors which might be correlated with (and more easily measured than) rainfall interception, a study was made of light passing through the canopy as a percentage of that outside. Using a grid of lines passing midway between the rows of trees, simultaneous readings were taken of light intensity in the stand and in an adjoining clearing. A pair of photo-cells with individually calibrated milliammeters were used. An overcast day was chosen. Four stands were examined, two being 21 years old and two 33 years old. Height ranged from 26 ft. to 43 ft., and there were considerable differences in spacing and in the degree of branch suppression. Light values in the stands, however, varied little, from 4·5 to 5·0 per cent of the intensity outside, which suggests that in unthinned young Scots pine stands there is a maximum amount of live needles which can be retained.

During the course of the weekly visits to these sites it was noticed that the branches of the lower dead crown varied in their 'attitude'. In the winter, they were typically straight and at an acute angle to the stem, but in the May 1961 dry spell these branches gradually bent, their tips curving round till pointing downwards. The winter shape was nearly restored following rain and during humid periods. Drying of tension and compression wood in the branches seems the most likely explanation.

In another part of the study, twelve vernier girth bands were placed at breast height on stems of a range of canopy classes on three of the sites. The readings were taken at approximately weekly intervals and plotted as a cumulative curve; in Figure 1.

This shows the cumulative gain on girth increment for the four largest trees (A, B, C and D) on the best plot. It is presumed that these would be less affected by competition, and hence more likely to reflect site factors.

The curves show well-marked increases and decreases in rate of increment in all the trees, presumably due to the same cause. As neither soil moisture nor temperature seem to vary in the same way, transpiration stress causing changes in the degree of stem hydration seems the most likely explanation, and this is being investigated by other methods, including measurement of the electrical resistance of tree stems as a possible means of following changes in stem hydration.

Electrical Resistance of Tree Stems

After some preliminary experiments with a Wheatstone bridge, it became clear that no serious work could be carried out until arrangements could be made to avoid local effects at the electrodes. This problem has been solved by the design of a portable transistorised four-terminal bridge for use with four electrodes; two for current feed and two for potential measurement.

Garnier Gauge Observations, 1961

As mentioned in *Rep. For. Res., For. Comm.* 1960, a pair of grass lysimeters, installed near the Alice Holt climatological station, are maintained through the season. The design is similar to that figured in Green, F. H. W. (1959) *Quart. J. Roy. Met. Soc.* 85.3.64. 152–8. The site is surrounded by scattered trees at least 50 yards away, with the main forest block 100 to 200 yards beyond. The district is a wooded plateau at about 350 feet above sea level, and drainage is usually imperfect or poor in the soils of the area.

Table 6 gives the summarised records for the Alice Holt gauges in the season of 1961.

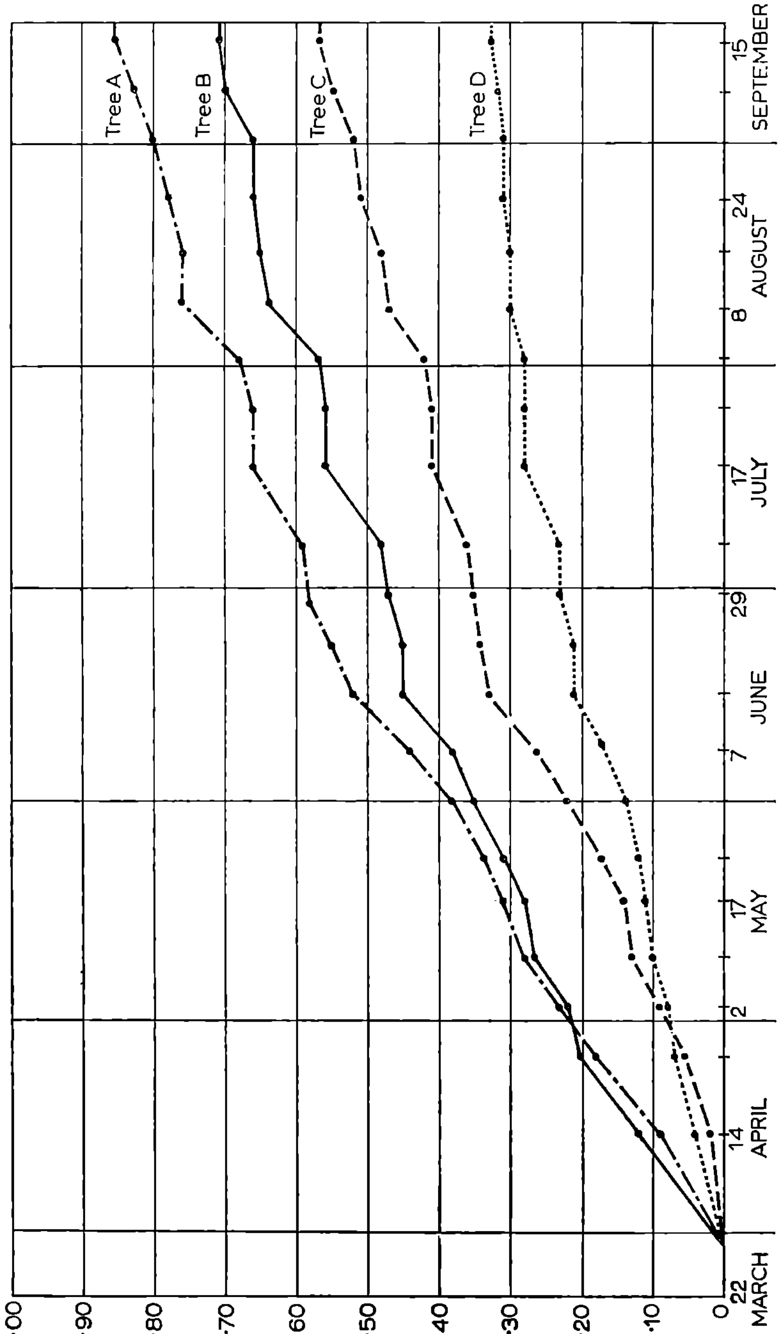

FIGURE 1. Girth Increment of four dominant Scots pine trees, A to D, at Crowthorne, Bramshill Forest, 1961.

Table 6

Garnier Gauge Records, Alice Holt 1961

Month	Potential evaporation (inches)			Rainfall inches at Alice Holt	Sunshine	
	Lysimeters		Calculated value		Daily mean hours (from Tables)	Actual hours 1961
	A	B				
January	0·165	0·125	0·25	4·80		
February	0·265	0·245	0·40	2·51		
March	0·255	0·235	1·00	0·11		
April	1·950	2·120	1·629	3·54	5·05	3·16
May	2·670	2·990	3·278	1·02	6·20	7·19
June	4·520	4·470	3·848	1·15	6·90	7·89
July	4·860	4·860	3·685	1·91	6·50	6·29
August	3·865	3·660	2·704	2·05	6·30	5·39
September	2·665	2·720	1·591	2·83	4·60	4·29
October	0·450	0·470	0·65	3·52		
November	0·535	0·495	0·20	2·58		
December	0·305	0·190	0·15	4·16		
Total	22·505	22·580	19·385	30·18		

The calculated potential evapotranspiration values in the table are derived from the estimates of irrigation need in Technical Bulletin No. 4, Ministry of Agriculture, 1954 for N.E. Hampshire; adjusted by the use of the formula P = P.av + x (n—N.av) where P.av is the average potential transpiration, x is a weighting factor and N.av is the average sunshine for the area, while n is the actual sunshine record from a Campbell Stokes sunshine recorder at Alice Holt Lodge.

Daily observations of the gauges suggest the following practical comments:

(1) The grass cover on the gauges is capable of intercepting some water during rainfall or watering, thus causing some apparent increase in consumption with the frequency of overhead watering and the number of falls of rain.

(2) In dry weather there was heavy dew present on the grass on the gauges but not on the surround. This must have come from the soil in the gauges, and will probably evaporate faster than transpired water; also increasing the apparent consumption.

(3) By the construction of the lysimeters, and the absence of any connection with the surrounding soil, there is little tension acting on the soil water in the container. Thus it was not surprising to find conditions of waterlogging with a marked 'reducing' smell, when placing and removing the porous-pot soil moisture tensiometers in May. The possibility of applying a small amount of tension to the soil in the gauges, equivalent to about 60–70 cm. of water, is under investigation to simulate field capacity more closely, and to increase sensitivity.

(4) During the months of April and May, tensiometers were in place. Tensions stayed very low, below field capacity, although little or no watering was carried out.

(5) Tensiometers were removed in late May, being difficult to maintain in good order due to damage by frost.

(6) The heavy snowfall—11 inches or so—on the last two days of the year is excluded from the calculations.

The data obtained so far are of some interest, but it seems doubtful if these gauges provide much in addition to the available estimates of evaporation, especially as the faults seem inherent in the present design. The observations will however be continued.

The chief points brought out by this year's observations are:

(i) The amounts actually measured for May fell below the estimate, probably due to a reduction in watering needs, as suggested by the very low tensiometer readings. (ii) All measurements for the other summer months substantially exceed the estimates. (iii) Although considerable variation was found between the two meters, the annual totals were surprisingly close.

Fertiliser Prescriptions in Forest Nurseries

Soil analysis carried out on material collected in December from the cultivated zone of plots at Elvetham nursery, where comparisons of compost and fertiliser dressings have been maintained since 1950, are set out in Table 7.

Table 7

Soil Analysis, Elvetham Long-term Fertility Trial 1961

(*Means from quadruplicated plots*)

Treatment	Organic matter %	Exchangeable Potassium m.e./100 g	Total Phosphorus % P
Control	3·28	0·057	0·015
Fertiliser	3·14	0·070	0·019
Compost	4·30	0·051	0·022
Compost plus fertiliser . .	4·36	0·074	0·025

The differences in organic matter content due to the compost treatment reach statistical significance, the other differences do not.

The amount of mineral nutrients remaining at the end of the growing season is very small, even before the winter leaching. There is little tendency for nutrients, even phosphate, to accumulate in this light sandy soil. It should be noted that after allowing for removal by the crop, the amount of total phosphate would be at least two or three times higher than is recorded for the treated plots, if no leaching of phosphate from the cultivated 9 inches had occurred. The organic matter of the compost decomposes at about the same rate as it is applied. These results strongly support the contention that prescription of fertiliser rates by soil analysis is quite useless on such soils. For all practical purposes, the residues are of no economic value, nor is there the smallest risk of any particular nutrient building up to a level which could conceivably result in unbalanced nutrition after a long period of standard dressings.

Chlorosis on Calcareous Soils

The severe frost on May 27th-28th badly damaged the groups of young trees at Weston Common where spraying treatments have been applied in the past two seasons. The beech were browned all over, and much of the Corsican pine young growth was discoloured or distorted.

Consequently, the work was discontinued on that site and an unfrosted area near the top of War Down, Queen Elizabeth Forest, was selected for a limited study. Twenty pairs of young beech, from 100 to 180 cm. tall, were selected, each pair being of similar degree of 'yellowing'.

In early June, one of each pair, at random, was sprayed with 200 cc. of 0·1 per cent $MnSO_4$. At the assessment in early August, seven sprayed, and seven unsprayed trees had improved their colour mark by 1 degree in 4. This is part of a general improvement in colour noted in this area.

FOREST GENETICS

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

The Survey of Seed Sources

The object of this survey is to locate suitable seed sources, so that the practising forester may know where to obtain seed of the best of the existing varieties and cultivars. The survey of seed sources was begun in 1951 and by the end of August 1961 the whole of Great Britain had been covered once. The content of the Register of Seed Sources is, however, unsatisfactory because there are shortages of suitable seed sources of such widely used species as Norway and Sitka spruce, Lodgepole pine, Western hemlock, the Silver firs, sycamore and ash. The scarcity of seed sources of ash and sycamore is due to the generally low quality of these two species throughout the country, whereas the lack of seed sources of the other species results from the relatively small acreage of stands over twenty-five or thirty years of age from which a choice could be made. Thus, a re-survey of the country ten years after the first survey began should bring more seed sources of these species to light. Another reason for continuing the survey of seed sources is that a large proportion of the older seed sources of species such as Scots pine and the larches are near or past maturity, and many of those classified as 'Normal' will be felled before long. There are now many younger plantations that can replace the older seed sources as these are felled, and provide the increased acreages necessary for the species that are poorly represented in the Register of Seed Sources. The survey work during 1961 yielded 132 classified seed sources totalling more than 1,500 acres, and details of these were incorporated in a supplement to the Register compiled in spring 1962. Table 8 summarises the state of the Register of Seed Sources on March 31st, 1962. The Register now contains 535 classified seed sources totalling 8,833 acres.

The principal species omitted from this summary are Serbian spruce, Western hemlock, sycamore and ash, for which less than 50 acres of seed sources have been classified and registered.

Nineteen sixty-one was an exceptionally good seed year for Corsican pine, *Pinus nigra* var. *calabrica*, and all the seed collected by the Commission Forest seed collection teams came from 'Plus' or 'Almost plus' registered seed sources.

Table 8

Area of Registered Seed Sources in Scotland, England and Wales (on March 31*st*, 1962)

Species	Classification	Distribution by Countries Scotland (acres)	England (acres)	Wales (acres)	Totals
Scots pine	Plus & Almost plus	1,219	424	0	1,643
	Normal	1,746	107	0	1,853
Corsican pine	Plus & Almost plus	0	1,041	0	1,041
	Normal	34	607	2	643
Lodgepole pine	Plus & Almost plus	14	0	0	14
	Normal	11	15	16	42
European larch	Plus & Almost plus	438	5	0	443
	Normal	254	28	12	294
Japanese larch	Plus & Almost plus	33	49	17	99
	Normal	26	29	3	58
Hybrid larch	Plus & Almost plus	124	0	0	124
	Normal	6	0	0	6
Norway spruce	Plus & Almost plus	0	1	0	1
	Normal	104	24	10	138
Sitka spruce	Plus & Almost plus	4	2	0	6
	Normal	47	2	6	55
Douglas fir	Plus & Almost plus	124	186	46	356
	Normal	56	194	13	263
Western red cedar	Plus & Almost plus	11	24	0	35
	Normal	17	59	5	81
Sessile oak	Plus & Almost plus	5	12	0	17
	Normal	26	18	35	79
Pedunculate oak	Plus & Almost plus	149	30	0	179
	Normal	17	1	5	23
Beech	Plus & Almost plus	4	116	0	120
	Normal	10	1,038	11	1,059

The Formation of Seed Stands

The next step in the process of improving the genetic quality of seed collected in Britain is to convert the best *seed sources* into *seed stands* or *seed production areas*, in which all the phenotypically poorer trees are removed, thus leaving isolated the crowns of the finest trees for seed collection purposes. This conversion of seed sources into seed stands was greatly accelerated in 1961, and by the end of the year 271 acres of Scots pine, 56 acres of Corsican pine, 31 acres of Lodgepole pine and 69 of other species had been wholly or partially converted into seed stands.

The Selection of Plus Trees

The selection and propagation of outstanding phenotypes (Plus trees) and other trees of more specialised interest (Special trees) were continued. The total number of Plus and Special trees of all species that have been marked and recorded is now 3,173. More than eighty trees, mainly Lodgepole pine, were selected in Northern Ireland and the Irish Republic during August 1961 and special thanks are due to the members of the two Forest Services who made the work of selection so successful. A countrywide summary of the content of the register of Plus trees is given in Table 9.

Almost two-thirds (or nearly 2,000) of the Plus and Special trees have been selected in Scotland, whilst just over one thousand have been found in England. Ninety-seven Plus trees have been selected in Wales. There are 131 foreign Plus trees in the Register and these are represented in Britain by clones of grafted plants or rooted cuttings. There has been a slight but steady loss of selected trees amounting to about two per cent of the total each year. Most losses are due to windblow, unavoidable fellings or rejection of the tree because of the appearance of disease or other faults.

Table 9

Selection, Registration and Propagation of Plus and Special Trees

Common Name	Selected and Registered	Propagated Vegetatively	Planted in Tree Banks
Scots pine	810	718	575
Corsican pine	96	64	46
Lodgepole pine	169	38	4
Other pines	35	18	1
European larch	440	318	282
Japanese larch	137	118	71
Other larches	47	17	13
Douglas fir	480	315	254
Norway spruce	68	20	18
Sitka spruce	154	28	17
Other spruces	17	3	3
Silver firs	51	—	—
Western hemlock	35	19	7
Western red cedar	61	55	25
Other conifers	110	69	20
Total conifer	2,710	1,800	1,336
Sessile and Pedunculate oak	173	29	14
Beech	124	68	44
Sycamore	15	2	—
Ash	42	24	10
Birch species	86	54	34
Other broadleaved species	23	7	—
Total broadleaved	463	184	102
Grand total	3,173	1,984	1,438

Large diameter (11 millimetre) increment cores were taken from twenty Plus trees of Sitka spruce and from five dominants growing near to each Plus tree.

These cores are being examined by the Wood Anatomy Section of the Forest Products Research Laboratory and the Plus trees will be graded on the basis of the anatomical examination, density determination and chemical analysis made at Princes Risborough. The wood characteristics of the progenies derived after free pollination from several of the Plus trees will then be examined in an attempt to establish parent-progeny relationships for these characteristics.

The 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, beech and certain other species continued during the year, and 1,438 clones have been planted in Tree Banks (see Table 9, right-hand column). The Plus and Special trees are represented in these tree banks by clones of grafted plants, or by rooted cuttings, and by this means are preserved against loss by windblow, fire or felling; moreover they 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.

Vegetative Propagation

As in previous years, grafting and the rooting of cuttings were used to raise clonal material for inclusion in Tree Banks, field tests and seed orchards. The final total of grafts attempted during the spring of 1961 was 10,942, and the number of successful grafts surviving to the spring of 1962 was 6,829, representing 390 parent trees. The overall success was sixty-two per cent. The late spring frosts of May 1961 damaged many of the newly developing grafts made outdoors on nurseries and seed orchard sites.

There is a growing interest in heteroplastic grafting, this being the term used to describe grafting of scions of one species onto rootstocks of another species of the same genus. The uses of heteroplastic grafting include the induction of flowering, and the reproduction of valuable clonal material of an exotic species. The technique may also provide an additional check on the species relationships established by morphological and cytogenetical methods.

The criteria for success in heteroplastic grafting include comparable success to that obtained in normal grafting within species and healthy growth of the scion for at least five, and preferably ten, years. On the basis of these criteria European and Japanese larch appear to be completely interchangeable as rootstock and scion in Britain; Japanese larch, *Larix leptolepis*, can be used as a rootstock for *L. occidentalis* and *L. gmelini*. Among the two-needled pines, scions of Corsican pine, *Pinus nigra* var. *calabrica*, can be grafted on rootstocks of Scots pine, Lodgepole pine, and Mountain pine, *Pinus mugo*. Lodgepole pine, *Pinus contorta*, can be grafted onto Scots pine. The incompatibility of graft unions within species is a separate problem referred to later under Seed Orchards.

Rather more than 15,000 cuttings were inserted in the propagation frames at Alice Holt, Grizedale, Bush and Kennington nurseries, and most of these were clones of X *Cupressocyparis leylandii* and Western red cedar. During the spring of 1962, 5,500 rooted cuttings of Leyland cypress and Western red cedar were distributed for planting in field tests and Tree Banks. The propagation frames at Alice Holt were overhauled during the year in preparation for more intensive work on the vegetative propagation of Sitka spruce.

Experiments continued at Grizedale nursery on the rooting of cuttings in rooting media comprising loam, sand and granulated peat in various proportions, with the addition of inorganic fertiliser. The most promising combination of treatments consists of inserting each cutting in June into a three-inch clay pot containing seven parts by volume of loam, four parts propagating sand and three parts granulated peat, to which had been added a normal quantity of 2N;1P;2K fertiliser (that is, four ounces per bushel of the rooting medium). The plants rooted in this experiment have been extended to the transplant lines to examine subsequent survival and growth.

Controlled Crossing and Progeny Testing

Controlled crosses were made on Lodgepole pine trees at Harwood Dale, Allerston Forest, in Yorkshire, and on clones of Scots pine in a seed orchard at Ledmore Forest in Perthshire. The objective at Allerston Forest was to mass-produce seed of a cultivar based on selected trees originating from the Lower Skeena river region in British Columbia, and to make the inter-provenance cross British Columbia coast × East Washington inland. Bad weather restricted this work, but just over one thousand controlled crosses were attempted.

At Ledmore, pollen was applied from one to four times at intervals of two days to the female flowers of a single Scots pine clone, to determine whether increasing the number of times pollen is applied will increase the yield of viable seed from the flowers isolated in each pollination bag. A limited series of test crosses was also made to begin the work of determining the general combining properties of the clones in the Scots pine seed orchards at Ledmore; a grand total of 1,681 controlled crosses were attempted.

Two progeny tests of larch and one of beech were sown during the spring of 1961, and routine assessments continued on the progeny tests of pines, larches, Douglas fir and beech which have been extended to forest sites. Seed from sixty controlled crosses made in a larch seed orchard at Newton Nursery, Morayshire, germinated at different rates. The majority of the Japanese x Japanese larch seedlings appeared seven or more days later than seedlings of European x European and European x Japanese larch.

The Formation and Management of Seed Orchards

Seed orchards consisting of clones of grafted plants derived from Plus trees of Scots pine, Lodgepole pine, European larch, Douglas fir, Western red cedar and beech have been formed, both to produce seed and provide a means of further improvement of these species. Seed orchards composed of clones of European larch and Japanese larch have also been planted to produce seed of the first generation Hybrid larch, *Larix* x *eurolepis*.

Small quantities of seed were harvested in 1961 from two Scots pine seed orchards in Scotland and from the Scots pine tree bank at Newton Nursery, Morayshire. A total of four pounds of seed was extracted from the cones. The work of managing the 170 acres of seed orchard in various parts of Britain continued during the year. There was some drought damage in the larch seed orchards at Newton, but more widespread damage was caused by the extensive and severe frosts during the last week in May 1961. However, most seed orchards had recovered by the end of the year, although the frost damage had obviously been a setback to growth.

The need for protection against the attacks of *Adelges cooleyi* in Douglas fir, *Chermes viridis* in European larch and *Adelges pini* on Scots pine has stimulated further trials of insecticides which will be repeated and extended in 1962. The other insect pests encountered during the year, such as *Myelophilus piniperda* and *Evetria buoliana* on Scots pine grafts, were more easily controlled by the use of standard insecticides.

The staking, pruning and mulching techniques that have been developed and applied during the past three growing seasons are now beginning to show beneficial results in the seed orchards of larch and Douglas fir, but a problem now appearing in the older seed orchards of beech and Douglas fir is delayed incompatibility of the graft unions. So far the occurrence of breakages at the graft union has affected less than five per cent of grafts, but the reasons for these breakages are being investigated.

The Technique of Tree Breeding

An improved 'pollen gun' is being developed to replace the existing model, and an electrically-driven oscillator is being tested for pollen extraction under field conditions.

Other Work

Nineteen sixty-one was International Seed Year and marked the climax of the World Seed Campaign sponsored by the Food and Agriculture Organisation of the United Nations Organisation to encourage the use of better seed by farmers and foresters everywhere. During the year illustrated lectures, demonstrations and short training courses were given by members of the Genetics Section to more than 750 people. The financial advantages of good tree seed were stressed, and people were trained in the use of seed collection equipment. In October the Forestry Commission held a five-day training course on forest genetics, tree breeding and seed production at Northerwood House in the New Forest. This was attended by ten people from Britain and nine experienced forest officers from abroad representing the Irish Republic, Germany, Malaya, Nigeria, Norway, Phillipines, Tanganyika and Uganda. The course was followed by a seven-day study tour of State and private forests in England and Wales, to give participants a comprehensive view of the present application of genetic principles in British forestry practise.

The flow of enquiries from Forestry Commission and outside sources continued. Most of these concerned vegetative propagation by grafts and cuttings, the layout and management of seed orchards and the selection and treatment of seed stands. Technical advice was given to the Scottish Forest Tree Seed Association and the Forest Tree Seed Association of England and Wales.

FOREST PATHOLOGY

By D. H. PHILLIPS

No major changes in the research programme took place in the year under review. The largest single project remained that dealing with root diseases (particularly that caused by *Fomes annosus*), but important work was carried out on *Keithia thujina* (*Didymascella thujina*) and other fungi of special importance in forest nurseries, and on many other miscellaneous diseases and disorders. Several investigations were the result of some of the numerous enquiries received from Commission forests, private estates, and the general public.

A quarantine nursery for the reception of trees imported under licence was set up in the grounds of the Glasshouse Crops Research Institute, Rustington, Littlehampton, Sussex. Thanks are due to Mr. F. W. Toovey, Director of the Institute, who made the facilities available, and to Mr. G. F. Sheard, Scientific Liaison Officer and Head of the Horticulture Section, who gave valuable assistance.

Death and Decay Caused by Fomes annosus (Fr.) Cooke

The felling and replanting of conifer plantations usually results in increased attack by *Fomes annosus* in the succeeding crop, spread of the fungus taking place mainly from infected stumps. The level of infection by *F. annosus* in British forests therefore tends to rise as more and more stands begin to reach maturity and are thinned, felled, and replaced. Hence the control of *F. annosus* is becoming increasingly important, so that the study of this fungus, and the disease and decay that it causes, has become a major investigation, including an examination of general control methods and associated problems, and the testing for disease resistance of tree species and provenances.

Initial stump infections take place by means of airborne spores, and can be kept to a minimum by the use of protective chemicals applied to the stump surface at the time of felling. For some years, creosote of a standard grade has been used for this purpose, but the testing of alternative materials has been carried out. Several chemicals have given good results, but the performance of many has been variable, and the tests are being continued. Among the materials examined were formaldehyde, sodium carbonate, polybor (as a liquid and as a dust), and diquat. Experiments to assess the long-term effects of stump protection have also been established.

Stump treatment with creosote does not prevent the underground spread of existing infection through contacts between root systems, and experiments are therefore being carried out in an attempt to reduce or eliminate existing infestations at the time of clear-felling. Eradication experiments in which chemicals were applied to infested stumps have not been successful, but two other methods have shown greater promise. In one, mechanical removal of all stumps has been carried out, and good results have been obtained, though the method cannot be used on steeply sloping ground. Stump removal costs from about £20 to £30 per acre (including the lifting of the stumps, clearing them into drifts, and raking to remove any remaining roots and to level the site for planting); it is therefore expensive, but less so than was originally anticipated. If further work confirms its value, it may prove justifiable on heavily infested sites if no cheaper alternative becomes available.

In the second method, limitation or eradication by means of biological control has been attempted. The experiments so far have been confined to pine, although the work is being extended to include other trees. At the time of clear-felling, the freshly cut pine stumps have been inoculated with spores of the fungus *Peniophora gigantea*, a saprophyte that competes with *F. annosus*. Encouraging results have been obtained, *P. gigantea* growing rapidly through the stumps and into their roots.

To investigate the behaviour of *F. annosus* on varied sites, observations have been made on artificially inoculated stumps, and trials have been made with a laboratory method designed to test the relative susceptibility to infection of roots collected from forests on different soils and with different histories.

Spore trapping to examine the *Fomes* air spora has been continued, and some work has been done on ways in which crop infection may occur other than through infested stumps. An examination of timber from trees killed by *F. annosus* showed that if the trees were felled within three years of death, deterioration in strength was slight in all except the superficial tissues. All infection could be eliminated by impregnation with creosote in the hot and cold tank, and the treated timber could be used for fencing and other purposes without risk of the spread of disease.

Honey Fungus (Armillaria mellea (Fr.) Quel.)

Trials are being carried out on the control of this fungus by chemical and girdling treatments of hardwood crops before felling and replanting, but no results are as yet available. Two small-scale experiments on soil sterilisation, using carbon disulphide, were established in plantations of cricket-bat willow (*Salix alba* var. *caerulea*) in which serious loss of trees had occurred.

Needle Blight (Keithia thujina Dur., syn. Didymascella thujina (Dur.) Maire) of Thuja

Rotation sowing of *Thuja* seed in selected nurseries isolated from other *Thuja* is now practised in England, Scotland and Wales. Needle blight occurred on *Thuja* transplants in the rotation nursery at Kirroughtree Forest in South Scotland. Although infection was light, a considerable proportion of the stock was removed as a precaution against further development of infection. The infection almost certainly originated from a small number of *Thuja* plants in the nursery within a large hedge of Lawson cypress. These *Thuja* plants had in fact been removed before the infection was observed, and Kirroughtree is to be retained in the Scottish rotation.

For the first time, a high level of chemical control of infection of *Thuja* transplants by *K. thujina* was achieved by means of cycloheximide and its derivatives. Effective control of severe infection was obtained by a single spray treatment with Actidione BR (a commercial formulation of cycloheximide used extensively in North America against White pine blister rust) and with the acetate, semicarbazone and oxime derivatives of cycloheximide. Concentrations of 50 and 150 parts per million of all these materials were effective, but although no plant poisoning symptoms were observed following the use of the derivatives, Actidione caused leaf burning and stem deformation at both concentrations. Further, more extensive, experiments have been started, using a range of new formulations of cycloheximide and the semicarbazone derivatives at different concentrations and at different times and rates of spray application.

Grey Mould (Botrytis cinerea Fr.)

Observations have been made on the early stages of infection by *Botrytis cinerea* on seedlings of various conifer species in densely sown experimental seedbeds. The fungus occurs on nursery stock that has been damaged or severely weakened by other factors, but damage directly attributable to infection by *B. cinerea* is rarely serious. Experimental work on *Botrytis* infection in forest nurseries is to be discontinued because of the low and irregular incidence of the damage caused by this fungus.

Damping-Off

Close liaison has been maintained with Rothamsted Experimental Station, Harpenden, Herts., where the critical study of seedling infection and loss through damping-off in Sitka spruce has been continued. Significant control of damping-off has been achieved, using a range of soil treatments and seed dressings. The results of this work will appear in a forthcoming *Report of the Rothamsted Experimental Station.*

Needle Cast (Lophodermium pinastri Desm.) of Pine

No active experimental work has been carried out on the biology or control of this disease, which causes irregular but often serious losses in forest nurseries in this country. Nevertheless, a provisional recommendation for chemical control of infection of nursery stock has been issued, based on results obtained by Continental workers in the control of the disease both in pine plantations and nurseries. The material recommended was zineb, applied in July, August and September as a wettable powder at a concentration of 0·3 per cent active ingredient in 100 gal. water/acre. Experiments are now being carried out to determine the most effective spraying regime to control infection by *L. pinastri* under forest nursery conditions in this country, and to compare zineb with other fungicides.

Sooty Bark Disease (Cryptostroma corticale (Ell. and Everh.) Gregory and Waller) of Sycamore

A further survey of sooty bark disease on sycamore in the Wanstead district of North-east London was carried out in 1961. This survey confirmed the fact that the intensity of infection was increasing, and was probably at its highest level since about 1954. The disease was recorded on a private estate near Kettering, nearly 100 miles north of the area of the previous records. This new record is of considerable significance because of the economic importance of sycamore in certain areas of the Midlands and North-east England, which are subject to a high level of atmospheric pollution. Very little is known about the infection biology of *C. corticale,* and work on this subject has therefore been started by Dr. B. E. J. Wheeler at the Imperial College of Science and Technology, London.

Blue Stain

In co-operation with the mycological staff of the Forest Products Research Laboratory, Princes Risborough, a large-scale experiment has been started in Thetford Chase in East Anglia to test the effectiveness of chemical treatment of logs in the control of blue stain. The treatments have been applied immediately, and soon after felling, the logs being stored at ride-side for periods of three and six months before conversion and assessment of blue stain. As yet only preliminary results are available from the first of a number of sets of logs treated and stored for three months. These results indicate that effective control of blue stain can be obtained by log-end treatment with protectants, particularly in conjunction with whole-log D.D.T. applications. Whole-log treatment with a combined fungicide/insecticide spray gave especially encouraging results.

Crumenula sororia Karst.

This fungus was found regularly associated with stem cankers on young, severely checked Corsican pine over extensive areas of Ringwood and Wareham Forests in Dorset and Hampshire. Observations indicated that the fungus was an active pathogen, but that infection had occurred as a result of the extremely low vigour of the plants, which is with little doubt partly related to a serious lack of nutrients in the soil.

In Britain *C. sororia* has been recorded only once before, again on Corsican pine, at Brechfa Forest in South Wales, where, however, the damage caused appeared to be slight. An aerial application of fertilizer was made to part of the affected area at Ringwood in April, 1962, and detailed records have been made of the growth and health of trees in line transects in blocks of Compartment 67, Ringwood Forest, so that any effects of the treatment on tree growth and infection by *C. sororia* can be assessed.

Group Dying of Conifers (Rhizina undulata Fr.)

Observations were continued at Muirburnhead on groups that followed fires lit in Sitka spruce in 1955. Activity by *Rhizina* was much less evident than in previous years. In 1960, abnormal fructifications of *R. undulata* were observed. Similar fruit bodies were found in several groups in 1961, and *R. undulata* was not then found where aberrant fructifications had been seen the previous year. Specimens of the abnormal fruit bodies were submitted to Dr. J. L. Gay, of Imperial College, London, who found evidence that they were affected by a hyper-parasite. Observations were started in two areas on damage by *R. undulata* to conifer plantings on old conifer sites that had been recently cleared and burned over.

Top Dying of Norway Spruce

As earlier work suggested that mild winters, or climatic variations occurring in them, might be important factors in this disorder, developments following the mild winter of 1960–61 were carefully watched. At Knapdale, in West Scotland, the condition of already affected trees deteriorated sharply, and many died. There was little evidence of needle discoloration or loss in previously healthy trees, but 1961 leaders generally showed reduction, which was very pronounced in some cases. Sharp reduction in leader growth is one of the symptoms of top dying, but it is not yet known whether this precedes foliage symptoms. Measurements were made of the leader growth of healthy and affected trees at The Stang Forest in North-east England, where winter temperatures are relatively low. The decline of the affected trees was much more gradual than at Knapdale, and there was some evidence that it was related to spring and early summer rainfall deficiencies.

Bacterial Canker (Pseudomonas syringae van Hall f.sp. populea Sabet and Dowson) of Poplar

An assessment was made of naturally occurring bacterial canker in all the poplar varietal trials in Great Britain. There was marked variation in the incidence of cankers, as between the various trial areas, that could in no way be related to fertility or any other readily discernible site characteristic. A few clones that appeared resistant in inoculation trials showed some susceptibility to natural infection on certain sites.

Larch Canker (Trichoscyphella willkommii (Hartig) Nannf., syn. Dasyscypha willkommii (Hartig) Rehm.)

An assessment of larch canker was made in the international and other provenance trials. The results have not yet been fully analysed, but generally they agree with previous information on the relative susceptibility of races of larch.

Elm Disease (Ceratocystis ulmi (Buism.) Moreau, syn. Ceratostomella ulmi (Schw.) Moreau)

Work on the selection, propagation and testing of resistant clones was continued in co-operation with the Silviculture Section.

Bark Necrosis

Short investigations resulting from advisory queries were made into bark necrosis of alder, sycamore, and *Abies grandis.* All three cases appeared to relate to the hot, dry summer of 1959.

Advisory Queries

Two hundred and thirty-three enquiries were dealt with during the year, 105 from Commission forests and 128 from private sources. Some queries concerned diseases clearly caused by pathogenic organisms, and these were usually relatively easily diagnosed and disposed of. In other cases, no primary pathogen was involved, and the disorder was wholly or partly cultural or climatic in origin, with any organisms present acting as weak pathogens and secondary invaders. Investigation of such cases was often difficult and lengthy, and sometimes led to a tentative diagnosis only.

FOREST ENTOMOLOGY

By D. BEVAN

Pine Looper (Bupalus piniarius): Pupal Survey

The annual winter assessment of pupal numbers has indicated low densities in all but two of the forests covered. The units included were as for 1961, though the technique of sampling was modified slightly following increased knowledge of the distribution of pupae lying in the soil. This change, involving the substitution of a transect of 10 plots each of a ¼ sq. yd. for one of 5 plots of 1 sq. yd. not only lessens the amount of work by half, but provides better representation of areas.

The two forests in which relatively high counts are reported, Cannock Chase in Staffordshire and Tentsmuir in Fife, both have a previous history of Pine looper infestation and are, therefore, of particular interest. Cannock Chase has shown a disturbingly high population over the last three surveys, as indicated by the figures for "forest mean" (i.e. the average pupal count per sq. yd. of the compartments sampled) and for the "highest mean count per sq. yd. of any compartment sampled".

Count made in winter	*Cannock Chase Forest Mean*	*Highest Compartment Mean*
1959–60	5·1	34·6
1960–61	7·1	25·4
1961–62	6·7	22·4

The Tentsmuir population has not the immediate threat of the Cannock Chase one, but is interesting for its rate of increase. Data for this forest are as follows:

Winter	*Tentsmuir Forest Mean*	*Highest Compt. Mean*
1960–61	1·8	7·6
1961–62	4·6	14·0

Culbin, in Morayshire, the only other forest in Britain in which artificial control has had to be used in the past against Pine looper, and in which a rise was reported last year, showed little change this year.

Winter	*Culbin Forest Mean*	*Highest Compt. Mean*
1959–60	1·2	2·6
1960–61	2·9	8·2
1961–62	2·7	7·2

Epidemiological Investigations

Studies continue into the epidemiology of Pine looper, *Bupalus piniarius*, in the permanent study plot at Cannock Chase, and into the Larch sawfly, *Anoplonyx destructor*, at Mortimer Forest in Shropshire. Pine looper parasitised by *Cratichneumon nigritarius* were noted throughout the twelve months of the year, and it now seems certain that the Pine looper pupa is both the main summer and winter host of this species of *Ichneumon.* The minute egg parasites of Larch sawflies, *Metasecodes* and *Cirrospilus* species, continue to be numerous, but their quantitive effect on populations have not yet been assessed.

Increment Loss Studies

Investigations continue into the losses resulting from varying degrees of defoliation of larch by the sawfly *Anoplonyx destructor* and of spruce by the aphid *Neomyzaphis abietina.* In the former, a further successful control operation was carried out by helicopter over an 18-acre area near Drumtochty Forest in North-east Scotland. Girth bands fitted on sample trees within the plot are as yet showing no significant difference from those on neighbouring untreated crops. With the latter, work continues on the thirteen permanent plots in which girths are measured and degrees of defoliation assessed. The severe needle-loss caused by this aphid during the spring and early summer of 1961 will, it is hoped, give an opportunity to estimate the economic results of such an attack over the next few years.

Trypodendron lineatum – Ambrosia Beetle

Experiments were carried out both into the chemical protection of stacks of timber against Ambrosia beetle, and into the differences in susceptibility to attack with variation in felling date. It has been found that a high degree of control can be obtained by spraying the stacks with 0·75 per cent B.H.C. emulsion in water applied at the rate of 1 gal. per 100 sq. ft. of bark surface. The earlier winter fellings (November and December) showed themselves outstandingly more susceptible than the early spring ones (February to March). It has thus become obvious that management must aim to remove material from the forest by the end of April when attack commences, giving a high clearance priority to the longer-felled logs.

It is intended now to enter a phase of 'user trials' with chemical control, and no further research work in this direction is planned. Some additional biological information, however, is required before full advice can confidently be given upon how forests are best managed in order to reduce the likelihood of attack to a minimum. In progress at the moment are investigations into the comparative susceptibility of trees (*a*) felled before and after 'sap-up', (*b*) stacked at ride sides, and (*c*) those left at stump in the forest.

Other Work

Springtail Damage in Nurseries

The Springtail, *Bourletiella hortensis*, continued on a reduced scale as a pest on certain nurseries. After failure to gain useful control of these insects artificially with both D.D.T. and B.H.C., a trial of Malathion gave a high kill and can now be recommended. Seedlings damaged during 1960 were grown-on into 1961 and the resulting plants, although growing healthily, all produced multiple leaders and would, in the normal way, have been culled. It is thought probable that Collembola damage of this kind may, in fact, be quite common and widespread. Not all seedlings survive to record the attack in this way, since those which are completely severed at or below ground level at the time of attack die, leaving little or no trace. It is possible that this damage may be a cause of an hitherto unrecognised seedling loss and apparent poor germination. It is intended to investigate the matter.

Winter Moth Attack on Spruce

An unusual infestation by the Winter Moth *Operophtera brumata* occurred in Sitka spruce at Rumster Forest, Caithness. There was severe damage to foliage of young trees growing in heather vegetation, but much less to the rather better growing plants in grass. Heavy mortality amongst the late larval stages was observed and found to have been due to a virus disease. It has yet to be confirmed, however, whether or not the organism has reduced numbers below pest proportions.

Sawflies on Larch

A survey of larch areas was carried out for sawfly population assessment purposes and to check on the distribution of the Larch bark beetle, *Ips cembrae*. The damaging Larch sawfly, *Pristiphora erichsoni*, was nowhere found to be numerous, but the less serious *Anoplonyx destructor* appeared in large numbers in several Scottish forests, and in particular at Cardrona, Glentress, Auchenroddan, Craigvinean, Drumtochty, and on the Atholl estates in Perthshire. The area in North-east Scotland previously reported as occupied by *Ips cembrae* is unchanged, but there is a first record in the main larch-growing area at Craigvinean, in Perthshire, mid-Scotland. The beetles here were, however, found breeding in logs and there is no suggestion of attack upon green trees in this area yet.

One hundred and seventy-five enquiries were dealt with during the year, of which 50 were from the public and the rest from Commission staff.

GREY SQUIRREL RESEARCH

By H. G. LLOYD, J. F. SHILLITO, J. J. ROWE, L. A. TEE and H. W. PEPPER

This project is carried out jointly by the Infestation Control Laboratory of the Ministry of Agriculture and the Research Branch of the Forestry Commission.

Analysis of the Population study made in the Straits Inclosure of Alice Holt Forest, is near completion, with a view to the publication of results.

Poisoning Experiments

Field work has continued in Scotland. The trials of warfarin in peanuts, completed in July 1961, were most encouraging. The result of these trials indicates that a high degree of squirrel control can be achieved by offering poisoned bait for a period of ten days. The number of baiting points, in relation to area of woodland, varied in density in these experiments from approximately one point per two acres to one point per four acres. Cage tests of the soluble sodium salt of warfarin in wheat have been conducted, and also tests of a mixture of warfarin and toxophene at 0·025 per cent. The mixture of anticoagulant poison showed no advantage over warfarin alone, and although the results of the cage tests showed some variation, they justified field trials in Scotland in February–March 1962. Because of the small population sizes of grey squirrel in Scotland in 1962, an accurate assessment of wheat as bait is not yet possible. Further trials of warfarin/wheat are at present under way.

Traps

Since the last report, a new make of trap, the Legg Midget, has been developed and is now on the market. It is, unfortunately, little cheaper in price than other squirrel cage traps, but it shows advantages over these in ease of setting and portability. Details are given in the Commission pamphlet *Traps for Grey Squirrels*, which was revised and re-issued in 1962.

Damage by Bark Stripping

Pilot field experiments on the bark-stripping habits of grey squirrels, and the degree of protection afforded by trapping during the damage period, are currently under way. Because of the reduced size of grey squirrel populations in 1962, it is expected that little immediate headway will be made in these studies.

Questionnaires

Replies to the annual Forestry Commission Squirrel Questionnaire have been studied at Alice Holt. The results showed an increase in population size in 1961 and an increase in the incidence and extent of damage. The Timber Growers' Organisation Grey Squirrel Questionnaire, which covered estates in England and Wales, was also analysed at Alice Holt. The results in general confirmed those obtained from the Forestry Commission Questionnaire. Comments on methods of control show that trapping methods are not well understood and underline the need for the trapping demonstrations planned during the "Grey Squirrel Year" organised by the Forestry Commission, the Timber Growers' Organisation, and the Scottish Woodland Owners' Organisation for 1962.

Other work during the year included trapping of woodland within the Straits Inclosure population study area, Alice Holt Forest. This was done in order mainly to determine the population size two years after the area had been cleared of squirrels. Squirrels obtained here and elsewhere were examined for reproductive condition – the results of which will be the subject of a report.

FOREST MANAGEMENT

By D. R. JOHNSTON, A. J. GRAYSON,
D. Y. M. ROBERTSON and R. T. BRADLEY

General

The Management Section in its present form has now been in existence for four years, during which time the four sub-sections – Working Plans, Economics, Mensuration and, to a lesser extent, Census – have, for the most part, been concentrating upon the development of their own specialised methods and techniques.

The year under review, however, has seen a change in emphasis and the Management Section as a whole is beginning to investigate some of the planning problems which are facing the Forestry Commission and which have been highlighted by the current working plans programme. As a result there has been close collaboration between Working Plans, Economics and Mensuration, and it is often difficult to say where the work of one section begins and that of another ends. The subjects so far investigated in this way include the profitabilities of various thinning grades, species and quality classes, rotation lengths, the forecasting and control of thinning production, the calculation of optimum roading intensity and the economic consequences of achieving normality.

D.R.J.

Economics and Census

Work in the economics field has been increasingly of a consultant and advisory character. In particular more help has been given to field officers in formulating economic appraisals of alternative courses of action proposed in working plans. The time absorbed by these activities and other matters of applied economics has reduced the amount of effort devoted to economics research. The need for this is at the same time growing in urgency as more problems in management are recognised. For example, the differences in prices of different species, which may reasonably be expected in the light of future market developments, have a major bearing on species selection at planting where various silvicultural possibilities occur. Similarly, the future trend in relative costs of hauling timber to roads, and of road and bridge construction, must be estimated if reasoned assessments of desirable roading intensity are to be made. In addition, the general field of risk in relation to decision-making deserves special attention. Apart from physical risk, uncertainties of future markets, technological developments, costs of forest operations, and timber prices all require evaluation.

Continued use of Census data has been made in national and various regional forecasts of future cut. On the other hand, requests for Census information from outside bodies have virtually ceased. The next Census of Woodlands is now scheduled for 1965 or 1966.

A considerable amount of work has been undertaken in connection with the work of a recently-formed study group concerned with land use. This group is revising the work of the Natural Resources (Technical) Committee (the Zuckerman Committee) on forestry and agriculture. Good progress has been made in the establishment of economic criteria which are truly comparable for the two kinds of activity.

Minor studies included: (*a*) the review of factors affecting the country's demand for sawn softwood, (*b*) the evaluation of pruning cost expressed per hoppus foot of pruned log at maturity for various pruning specifications and rates of growth, (*c*) a second mill study of the same sawmill reported on in the *Report on Forest Research* for 1960.

A.J.G.

Working Plans

During the year under review, working plan field work was carried out and completed at forests having a gross area of 183,000 acres. At the end of the year, teams were operating in forests with a total area of 144,000 acres. Field work continued to gain momentum during the year and it is expected that the area completed in the coming year should be considerably greater.

At the end of the year, two changes in administration were introduced. First, the Conservancy staff allocated to working plan teams were seconded to the staff of the territorial Director concerned. The main reason behind this change was that, while working within Conservancy boundaries, the work load was unevenly distributed between teams, but under the new administration it will be simpler to allocate teams to areas of roughly equal work load. Secondly, and at the same time, a system of checking the field work was introduced. To carry out this work, four checkers were appointed. Their duties include making spot checks in the field of the work carried out by the working plan teams. They also have the responsibility, in those regions covered for sample plot work from Alice Holt, for the control and planning of sample plot work. It is hoped that this new system will obviate many of the minor errors which have proved annoying in the past.

A soil survey of Ringwood Forest (Hants. and Dorset) was completed during the year and a pilot survey at Wareham Forest in Dorest was started. A change in staff has held up this work, but it is hoped that soil surveys will be completed over a larger acreage in the coming year.

Collaboration with the Ordnance Survey continued and was strengthened during the year. At Kielder and Kershope Forests in the Borders, the Ordnance Survey combined a revision of the one-inch sheet with a fresh survey of Forestry Commission plantations. Apart from checking, the field work for this was completed at the end of the year and an Ordnance Survey draughtsman is now employed at the Ordnance Survey centre in Southampton, by the Forestry Commission, in drawing the new maps. When sufficient of these maps are available, crop assessment and enumeration will commence in the two forests. In South Wales, advantage is being taken of a re-survey on the 25-inch-to-one-mile scale by the Ordnance Survey to save the labour of a fresh basic survey by our own teams.

Towards the end of the year the Ordnance Survey agreed to vary their programme of aerial photography in the revision of the 6-inch sheets in Scotland to fit in with the Forestry Commission's working plan priorities. Following the "flying", the Ordnance Survey will provide us with prints of the areas completed, and we shall then produce revised basic forest maps from these prints. This should save some four years on the date by which the Ordnance Survey revised maps will be published. It will necessitate the training of one or two of our staff in mapping from photographs. Investigations were being carried out at the end of the year into the possibilities of contract flying by private companies for the production of photographs for basic map revision.

While the work of the section in past years has principally aimed at the improvement of field techniques for the collection of basic working plan information, the section is becoming increasingly concerned with the use of the collected data. In the coming year, it is expected that the advisory service in plan writing and use of data will be fully engaged.

During the year, difficulties peculiar to this section were encountered in recruiting suitable men for the working plan field parties. The intake of Assistant Foresters from the Training Schools to Management Section contained no 'volunteers' and, as a result, it was difficult to keep up the standard of recruitment. In addition, the marriage rate of Assistant Foresters has been very high and there is no doubt that once married, even although willing, an Assistant Forester becomes less suitable for working plan field work.

Training. Assistant Foresters due to join the Working Plans field teams were given a month's course at Northerwood House on ground survey techniques. This was the fifth course of its kind and again we were fortunate enough to secure the services of an Ordnance Survey instructor.

D.Y.M.R.

Mensuration

The revision and extension of the general yield tables for conifers has continued, and a series of yield tables for a range of thinning patterns, types and intensities is being prepared for each species. As a result of calculations on relative profitabilities, the analysis of these tables is being used as a guide to the thinning regimes likely to be of most use as a basis for a new yield table publication. To assist in applying the new yield tables, alternative versions will be developed for use in regions where the growth pattern differs markedly from that shown in the general tables.

The application of the Sitka spruce stand tables to other species is being tested in expectation that a single general stand assortment table will be adequate for all species.

A new thinning experiment has been established in Douglas fir at Alice Holt Forest and consists of three blocks, each with five randomised treatments. One of the objects of the experiment is to determine the point at which volume increment falls off under progressively heavier thinnings, of both low and crown types. The growth of individual trees within these plots is being studied by means of vernier girth bands.

The analysis of the data from felled permanent sample plots is in progress and so far shows, amongst other things, that the assumption of the linearity of the volume/basal area regression is completely justified.

An investigation of the direct measurement of increment by borings has been started at Allerston Forest in Yorkshire, and includes an assessment of the influence of climate on radial growth.

Badan's Direct Recording Caliper

This is a machine which measures breast height girth or diameter and records it directly on to paper tape for use in electronic computors.

Attention is drawn to two errors in the *Report on Forest Research* for 1961:

(i) the description should have read "Direct Recording Caliper" *not* "Direct Reading Caliper"; (ii) the invention, design and development of the instrument should have been specifically attributed to M. René Badan, a Swiss forestry graduate working with the Section during the year in question.

The development of Badan's instrument for direct recording of girth and other measurements on to computor tape, has been undertaken by Elliott Automation, and a note on progress is given in the report of the Statistical Section, page 81.

R.T.B.

WORK STUDY

By J. W. L. ZEHETMAYR

Organisation of Work and Assignments

While nominally the organisation and staff of the section remained as described in the *Report on Forest Research* for 1961, with four teams in the field, in fact only ten team-members were available, so that throughout the year under report certain teams operated with two instead of the usual three members. In retrospect it would have been better to have reduced the number of of teams and put the fourth team leader on writing-up results.

The assignments reported on last year were completed between August, 1960 and March, 1961; all the team-members moved station and the teams were redeployed as shown in Table 10.

These assignments represent two new departures. In North Scotland the proposed pulp mill at Fort William is still regarded as a possible future development, and the work is concerned with the synthesis of the optimum working system rather than the improvement of current technique. This provides an opportunity for a more fundamental experimental approach than the section has used before.

The two assignments on forest maintenance open new fields, and a great deal of basic study is needed to establish the present position. Unlike production work, one has no economic basis of comparison. The operations studied so far include brashing (i.e. removal of lower branches from young conifer stands), drain maintenance, weeding and cleaning. Study methods have been evolved, site conditions defined, and in the case of brashing a new form of piece-rate evaluation and control have been devised.

During the year substantial aid was received from the Statistical Section in analysing problems arising from the complexity of work study data – particularly on horse extraction and on figures of yield, output and earnings from pulpwood compartments. The statistical resources available are, however, recognised as being able to cope with only a fraction of the data collected.

A much closer liaison with the Machinery Development Officer has been possible now that a trained Work Study Officer has been available for the forest testing of machinery.

The section is assisting in the development of Forest Worker Training courses and here the main gap is films of good working techniques.

Table 10

List of Work Study Assignments, 1960–1962

Conservancy	Forest	Dates	Main products or jobs studied
Production Assignments West Scotland (Cowal Districts)	Glenbranter Glenfinart Benmore Ardgartan	Completed March 1961	Logs for Cowal Ari sawmill, Strachur: tops sold at roadside for pitwood.
South Wales	Rheola	Completed Jan. 1961	Tonnage pitwood.
East England	Thetford Chase Swaffham Kings Brandon Depot	Begun Sept. 1960	Logs, pitwood, pulpwood, chipwood, stakes, etc. A new chipboard factory (Novobord) is in view.
North Scotland	North Strome South Strome Achnashellach	Begun April 1961	Until now poles have been sold at roadside; development work for a proposed new pulp mill is now under way.
Forest Maintenance Assignments North-east England (Border district)	Kielder Redesdale Wark	Begun Oct. 1960	Brashing Drain maintenance
North Wales	Mathrafal Dyfnant	Begun Jan. 1961	Brashing Weeding Cleaning

Equipment and Methods

Tool List

The section has assisted in the first substantial revision and extension of the Forestry Commission's Tool List issued, for internal circulation only, in 1959. An important feature of the revision has been the introduction of chain-saw maintenance equipment.

Tools

Development work has been carried out on pulp hooks, cant hooks, paint sprays, brashing saws and draining tools. The case-hardening of draining spades (rutters) is a promising development.

Census of Machinery and Working Methods

The lack of knowledge of methods actually in use can hamper development, and a census was taken in October, 1960. Key results on which to base future work were:

(i) *Proportions of Chain-Saw Working.* The low proportion of Forestry Commission working cut by chain-saw compared to that so done by timber merchants; partly this is due to the high proportion of small poles, on first thinnings and the scattered nature of the work.
(ii) *Horse Extraction.* The complete dependence, by both Forestry Commission and timber trade, on the horse for extraction in Scotland and Wales, of 70 to 80 per cent of the total cut; the comparative figure for England, is only 25 per cent.
(iii) *Hand Loading.* The great amount of loading by hand (70 per cent overall); the Forestry Commission is doing more loading mechanically than are the timber merchants.

Chain Saws

The use of chain saws has increased substantially in Forestry Commission fellings in the year, worker ownership becoming normal rather than exceptional. Thus at one large forest where no chain saws were in use in September, 1960, there were at least ten a year later. Much help has been given in training, both in use and maintenance, and the best method of use for various jobs has been investigated. The most difficult points have been to ensure equitable conditions for the worker-owner, *vis a vis* the worker using hand tools or a Commission-owned chain saw, and to reassure Trade Union representatives on the desirability of this development. Detailed proposals have been submitted and in general accepted.

Forest Trials of Machines

During the year the following items have been under test, either in the course of the work of the teams, or as special items of general importance. These forest trials follow mechanical development and testing carried out by the Machinery Development Officer.
(i) *Isachsen Double-drum Winch.* After teething troubles the trial outfit has been in intermittent use for nine months, and has extracted a total of 15,000 hoppus feet at a gradually reducing cost. On difficult sites the costs for thinnings are within measurable distance of horse costs, while in windblow and (by inference) clear fellings, the Isachsen is cheaper than the horse. This machine typifies the problems of the introduction of specialist equipment, needing much training, and special arrangement of felling, rack layout, roadside bays, etc. The operating experience is helping in the specification for the development of a hydraulic winch by the Machinery Development Officer.
(ii) *Isachsen Log Loader.* Though rejected for small logs as inferior to the H.I.A.B., this equipment may be valuable for large logs.
(iii) *Belt Loader for Pit Props, etc.* Rejected as unlikely to reduce costs.
(iv) *H.I.A.B. Hoists.* With a full appreciation of their capabilities it has been possible to introduce them into areas where they were not in general use.
(v) *Portable Brush Cutters.* Jo-Bu and Brielmeyer models have been tested against hand-weeding methods. They save time in short woody growth, but are unlikely to reduce costs substantially. For scrub clearance in woody growth, substantial savings are possible.
(vi) *Drain Cleaning Machines.* The prototype of the Forestry Commission flail drain-cleaner has been tested on peat, but though reasonably effective, a great deal of mechanical development work is required. First trials of the 'Melio',

a German machine, appear much more promising for this type of ground. A major need now is for a new approach to forest layout on typical Border country, to allow of access by machines for drain maintenance and extraction.

Piece Rates and Control Procedures

Piece Rates

A booklet for assisting in setting piece rates for production work in Cowal was completed, for internal use within the Commission.

Rates for brashing spruce are under test in the Borders and North Wales.

Costing of Production Operations

The procedure developed by the section has reached all the territorial Conservators. It has been used to demonstrate the marginal size of tree in Cowal, West Scotland, where it can be shown that the cash surplus on departmental workings of thinnings, for Cowal Ari logs and long pitwood sold at roadside, increases with average volume of tree approximately in the following way:

			Hoppus feet		
Average size of tree:	2	4	6	8	10
Surplus per hoppus ft.:	Nil	4d.	7d.	10d.	1/-

Work study findings on piece rates would, if anything, increase this steep gradient of profitability.

Similar calculations have been made on an extensive series of costings in Wales covering 300,000 hoppus feet of spruce for Messrs. Bowaters' paper mill at Ellesmere Port, Cheshire, and also to the economics of hardwood pulpwood supplied to Messrs. Wiggins Teape's mill at Sudbrook in Monmouthshire. The procedure is now being applied to different categories of produce at Thetford Chase in East Anglia.

Labour Control

Trials of a new recommended procedure have been made in a number of areas. Examples of results are:

(*a*) It has highlighted the low proportion of piecework in some areas, e.g. in a district of four forests, the proportion in Forest Year 1960 varied from five to twenty-five per cent of the time actually worked.

(*b*) It has shown the great value of the new records for modification of piece rates and for negotiations with Trade Unions, e.g. in one large forest area the proportion of working time on piecework was 60 to 70 per cent for Forest Year 1961, and the earnings were:

	Earnings per man-day	*No. of days on piecework*
Production	£3·0	2,450
Brashing/draining	2·7	9,575
Other jobs	2·9	2,637
	Average £2·9	Total 14,662

Training and Dissemination of Information

A great part of the effort of a Work Study Section, especially in a large and diffuse organisation, must be devoted to the putting-over of information to those not directly "work studied". Almost half the time of the head of the section is now devoted to courses, visits, and report writing, qûite apart from the activities of the Work Study teams. A steady, though smaller call, is also made on the time of other members of the Section. The year's activities in this field may be summarised:

(a) **Courses for Forest Officers and Foresters at Northerwood House, New Forest.** Four courses were held in the year, and with a further Divisional Officers' short course in October 1961, the position now is that two-thirds of the 105 Divisional and Grade I Forest Officers, half the Grade II Forest Officers, one third of the Head Foresters and one in eight of the Foresters have done the week's course. The main effort should now be turned to Foresters' courses with more emphasis on tools and working methods, and less on control procedures, costing, etc. (One difficulty here will be that Northerwood is not the best situation for this type of course, since it is far from the conditions where the bulk of the Work Study has been carried out, making field exercises difficult.)

(b) **Scottish Woodland Owners' Association Courses on "Work Rationalisation".** Assistance has been given with a series of three of these courses held at Castle Douglas, South Scotland, May to October, 1961. They served to introduce Work Study principles to all kinds of S.W.O.A. members, from Regional Chairmen to contractors.

(c) **Workers' Courses.** Assistance has been given with two courses on chain-saws organised by the Royal Scottish Forestry Society, and with two woodmen's courses organised by the Royal Forestry Society of England and Wales. The proposed new Forest Workers Training Scheme in the Commission will have its short courses based partly on the findings of the Section in various operations, particularly as regards type of tool, method of use and maintenance.

(d) **Talks.** Talks were given to Oxford and Edinburgh University Forestry Schools, one Forester Training School, and to several groups of workers either at their own or at their Trade Union representatives' request.

(e) **Shows.** An exhibit was set up at the Northern Show, Inverness.

(f) **Reports.** Over twenty reports were made from work study teams to Conservators for whom assignments were in progress. These varied in size and scope, but except for the initial survey reports, they all contained information believed to be of immediate practical value, and recommendations for improvements of organisation, etc. Four quarterly reports for internal use were made to Conservators by the head of the section; these included as Appendices several documents resulting from extensive tests of procedures, notably those on Costing of Production Operations and Labour Control.

Visit of Work Study Consultants: Future Work

Professor Steinlin of Freiburg University, Western Germany, Professor Samset of the Forest Research Institute, Oslo, Norway, and Jagmastare Helmers of M.S.A. (Sweden Central and South Sweden Forest Work Study Association), visited forests in the north and west to discuss extraction. Their most important suggestions were:

(1) To look again at the extraction methods in order to increase loads, particularly in horse work, by use of sledges, rack-ways, preloading by hand, etc.

(2) To persevere with machinery, e.g. double-drum winches, accepting alterations of forest layout, felling methods and conversion point as necessary, to get an overall saving. Long training was often necessary before new machines paid.

(3) To adopt an experimental approach rather than the *ad hoc* method used so far by the Section.

It would appear that the time has come to re-assess the future of the Section and to allocate resources to:

(*a*) Development assignments with an experimental approach, concentrating on particular operations or products.

(*b*) Assignments to improve methods in all ways relevant to a particular forest or district.

(*c*) The use of work study officers on a consultant basis to advise on specific problems and to spread the knowledge at all levels of improved methods, procedures, etc.

UTILISATION DEVELOPMENT

By B. W. HOLTAM

Properties of Home-grown Timber

The comprehensive study of the properties of home-grown timber, which began in 1959 as a joint undertaking with the Forest Products Research Laboratory, Princes Risborough, has continued.

Bagshot Scots Pine Thinning Experiment

The termination of a thinning experiment at Bagshot in South-east England, in which four plots of 74-year-old Scots pine had been subjected to different thinning regimes since 1921, enabled a study of the effects of thinning upon timber properties of the remaining trees to be made at the Laboratory. Details of the standing crop from which the logs were supplied are given in Table 11.

Table 11

Bagshot Scots Pine Thinning Experiment – Final Crop

Treatment	Site Factors		Characteristics of Final Crop						
Thinning Grade	Site Quality Class	Mean Annual Increment Hoppus feet per annum	No. of stems per acre	Mean height (feet)	Mean Quarter Girth over bark (inches)	Total Volume Hoppus feet over bark	Volume to 6 inches breast height quarter girth	% Grade 'A' logs	Volume Grade 'A' logs Hoppus feet over bark
A	IV	52	786	50½	21½	3,474	1,710	27	462
B	IV	58	551	52½	25	3,593	2,475	17	421
C	III	68	285	60½	31½	3,432	3,470	32	1,110
D	III	67	180	62½	36	2,777	2,890	42	1,215

Between 40 and 50 per cent of the trees from the A and B plots were below sawmill size (i.e. below 6 inches B.H.Q.G. over bark); to provide material suitable for sawing, the sample trees which were selected for examination from these plots were above the average girth while those from the C and D plots were quite near to the average girth for the respective plots.

The sample sawlogs from each plot were converted and the sawn timber was graded (according to *Grading Rules for Sawn British Softwoods*—F.P.R.L. Leaflet No. 49); it was observed that the lots from the D grade thinning plot gave a larger proportion of Grade I and II sawn timber than the logs from the other plots.

Other than specific gravity, (which was about 5 per cent higher in timber from plots A and B than in that form the C and D plots), there were no significant differences in timber properties between the plots. However, the total volume of the C and D plots was about 15 per cent greater than the B plot and 30 per cent more than the A plot, and the D plot produced a higher proportion of good sawlogs than the other plots.

Work on the Larches

Sample logs of Japanese larch and of European larch from eight randomly selected sites in Great Britain have been sent to the Forest Products Research Laboratory for examination of the timber properties of Japanese larch, and to compare its timber properties with those of European larch which has been grown under similar conditions. A consignment of Hybrid larch from one of the eight sites is being examined at the same time.

Lodgepole Pine Provenances

A preliminary examination of the timber properties of Lodgepole pine from fifteen different provenances from Allerston Forest, Yorkshire, has almost been completed. The material was of small size and was provided from provenance plots of 23-year-old trees which were being thinned. This work, together with that done in the previous year on similar material from provenance plots at Beddgelert and Clocaenog Forests in North Wales, is expected to provide information on the differences in timber properties which might be attributable to the effects of provenance.

Preservative Treatment of Small Transmission Poles

Work is proceeding on the preservative treatment of round timber of the size and type used for small transmission poles in an attempt to find means of improving the permeability of certain species which are difficult to impregnate. There is evidence to indicate that immersion in water for some weeks prior to preservative treatment improves the permeability of the sapwood of certain species considerably.

Thetford Winter Seasoning Experiment

The experiment in winter seasoning of round wood billets of pine which was outlined in last year's Report (*Rep. For. Res. For. Comm.*, 1961) has been completed.

Fence Post Trials

Field assessments of the trials, which were set up in Scotland in 1957 and in England and Wales in 1958, were made during the year and will continue to be made in future. An interim report on the results is given on page 133 in Part III of this report. A noteworthy result has been the comparatively short service life of some of the untreated oak posts, but it must be remembered here that round oak posts of the sizes tested – up to four inches diameter – consist largely of sapwood.

Wood Chips for Litter

A developing shortage of straw for cattle bedding, and an apparent shortage of wood shavings for use as deep litter in the broiler poultry industry, has aroused considerable interest in the possibility of producing wood chips which might be suitable for these purposes.

The guidance of the Ministry of Agriculture, Fisheries and Food, and of other interested organisations, has been sought in an attempt to determine the size and properties of wood chips that are most suitable for use as bedding both for cattle and for deep litter poultry. It appears that a curly flake about $\frac{3}{4}$ to 1 inch long and not more than, say, 1 millimetre thick, is probably more suitable than other types of chip for use as poultry litter. For cattle litter a similar type of chip would be suitable, although a greater degree of coarseness would be tolerated. For both purposes the chip should be reasonably dry.

No readily transportable machine which would produce a suitable chip economically has been encountered, and work is now proceeding in collaboration with the Forest Products Research Laboratory on the design of a machine to produce this type of chip.

Mechanical Handling of Agricultural Produce

There is an increasing interest in the use of wooden pallets and box pallets for handling agricultural crops. Discussions have taken place with the National Institute of Agricultural Engineering, the Timber Development Association and the Ditton Laboratory of the Agricultural Research Council to ascertain the possible role of home-grown timber in the manufacture of box pallets for the harvesting and storage of potatoes.

Timber Shuttering for Textural Concrete

In response to requests from architects and from the cement industry, trials were undertaken at the Forest Products Research Laboratory to determine which home-grown timber, and which sawing and machine techniques, would produce softwood shuttering which would give a figured surface to concrete. Such textured surfaces not only have aesthetic appeal, but reduce the visual effect of blemishes and changes in the density of the concrete. Home-grown Douglas fir boards which had been machine planed with dull cutters gave the best results, although good results were also given by similarly machined boards of Japanese larch.

Home-grown Thinnings Bungalow

The section of the bungalow constructed out of home-grown timber which was exhibited at the Royal Highland Show at Ingliston, Edinburgh, in 1960, has been re-erected as an office for the Research Forester at Tulliallan Nursery, Kincardine-on-Forth. The office is open for demonstration to visitors and a descriptive leaflet has been prepared.

MACHINERY RESEARCH

By R. G. SHAW

The outstanding event of the year has been the progress made in the development of hydrualic power transmission. The advantages are the absence of the need for friction clutches and brakes, the provision of infinitely variable speeds, and the ease with which power can be transmitted to points remote from a power unit. Hydraulic transmission is already playing a leading part in the progress being made in directions which, until now, have presented great difficulties. Some of the following projects under development employ this transmission in various forms.

Tractors

The first tractor with hydraulic transmission arrives for trial as the year under review comes to an end. This is a Fordson Super Major using Lucas hydraulic equipment.

Transport

The Alice Holt Logger has completed trials. It provides a means of transporting single logs or bundles of thinnings up to a weight of one ton. This project has been extended to enable heavier logs weighing up to four tons to be picked up at stump and carried away. A standard wheeled tractor is used with a high-frame two-wheeled trailer, which is placed astride the load; the load is then lifted by winch and carried underslung.

Contact has been maintained with hovercraft development, and a simple experimental hover trailer to be hauled by a tractor is being built at Alice Holt. Owing to the rough ground that forestry trailers are required to negotiate, this trailer is being designed to work in a state of semi-hover, the weight being partially supported on skids which will contact the high points on the ground. The object is to produce a trailer which will operate on ground too soft to support the weight of a normal trailer.

Loading

The increasing output from the Commission's forests stresses the importance of efficient loading. Apart from the self-loading underslung trailer mentioned above, trials are taking place of the latest conventional loading equipment. A new lorry-mounted H.I.A.B. hydraulic loader has been imported for trial from Sweden. This loader provides a very long reach, and incorporates a rotatable grab, which allows bundles of timber to be placed on the lorry in exactly the right position.

Ploughing

Experiments have been undertaken with the Glenamoy plough designed in Eire to dig a drain deep below ground level, extruding the spoil through a duct to the surface. The object is to provide deep draining without depositing large quantities of spoil on the surface as is done in open draining. This is a long-term project which will not give conclusive results until some time has elapsed.

Drain Cleaning

It is now widely thought that a depth of 18 inches is not sufficient for even minor drainage systems. Consequently, the continuous-acting flail machine which was developed over the last three years is no longer a probable solution. A large number of hydraulic diggers is available to dig or clean drains to a substantially greater depth, but the cost works out at around 20/- per chain. The whole subject of drain digging and cleaning is under examination in the light of the latest draining specifications.

Winches

Modern winch development is another project which shows the advantages that are being obtained from hydraulic transmission. The elimination of clutch and brake, combined with the finger-tip control that is now possible, make winching a comparatively simple operation. This is well illustrated in the twin drum hydraulic winch being developed in conjunction with T. T. Boughton & Sons. This project is still in the development stage.

Bark Peeling

The investigation into the peeling of crooked logs showed that chemical treatment in the early summer loosens the bark sufficiently for it to be removed by a subsequent drum barking operation. This project is in abeyance pending proof of a commercial requirement.

Weeding in Young Plantations

An experiment showing promise is the modification of a 40-inch Wilder Rainthorpe Chopper to enable it to straddle a row of young trees. The machine is a mounted model, which is necessary to make it manoeuverable in confined spaces. The centre tines on the rotor have been removed, and a tunnel made to ensure that the plants pass down this protected path as the tines are cutting the weed growth on each side.

DESIGN AND ANALYSIS OF EXPERIMENTS

By J. N. R. JEFFERS

With the general increase in the staff of the Research Branch, the demand for advice on the design and analysis of experiments and surveys, and for the analysis and interpretation of numerical data, has also increased. The Statistics Section has continued to provide these services, and to carry out research into the application of methods of statistical analysis and electronic computing to problems of forest research and management. There have been no increases in staff during the year, and the necessary increase in the amount of work to be done has been achieved through increases in working efficiency, made possible only by the use of electronic computers for all computing and analysis.

Electronic digital computers have therefore continued to play an essential part in all of the work of the Section. Two computers have again been used for the bulk of the computing, the Ferranti Pegasus computer at the nearby Royal Aircraft Establishment, Farnborough, and the Ferranti Sirius computer at the London Computer Centre.

Advisory work on the design and analysis of forest experiments has again been undertaken for a number of Oversea Forest Departments, and for other organisations and research stations interested in forest problems, particularly for the Forest Products Research Laboratory, Princes Risborough.

The Statistician attended the Congress of the International Union of Forest Research Organisations at Vienna in September, 1961, and took an active part in the setting up of the Advisory Group of Forest Statisticians of Section 25 of the Union. This Group is concerned with the application of statistical methods to problems of forest research, and each member of the Group is responsible for the setting up of a regional sub-group of statisticians interested in forestry applications of statistical methods. The subject of electronic computers and their application to forest research and management also received particular attention at the Congress, and the collection of information on electronic computers and their programming, with particular reference to forestry, was made the responsibility of the British regional group, under the Statistician.

Perhaps the most important need in the field of application of methods of statistical analysis and electronic computing lies in the communication of the methods that are available to the people who have the problems. Not only is there a big discrepancy between the methods available and methods actually used by foresters, but this discrepancy is rapidly increasing. New methods are being evolved at a very fast rate, but are not generally published in a form, or a place, in which they are likely to be appreciated, or even seen, by foresters. Such methods, nevertheless, represent a vast potential development of forest research and management, and deserve wider publicity than they at present receive. The Statistics Section has therefore started a series of short notes, entitled *Sigma*, on promising techniques, in order to bring them to the notice of research foresters; enquiries regarding these notes may be directed to the Statistician. A series of *Statistics Section Papers* has also been started, giving more detailed descriptions of actual applications of statistical and computing techniques to forestry problems; these also will be available from the Statistician in due course.

Design of Experiments and Surveys

Advice on the design and analysis of experiments and surveys remains as an important function of the Section, and designs have been provided for more than 120 investigations throughout the year. No very marked change in the type of investigations for which designs were required has been observed this year, most of the work taking the form of the consolidation of the many new types of experiments and designs introduced in previous years.

Demand for one type of experiment, however, deserves particular mention, i.e. that of the so-called clinal plot. These experiments are basically a return to the use of systematic arrangements of experimental treatments which can be regarded as a 'cline' of levels of intensity, e.g. of thinning intensity. The whole subject has been re-opened by a recent suggestion that such experiments are more economical of area, because of the virtual elimination of edge effects between treatments, and that they are easier to interpret. In fact, the designs which are suggested are statistically invalid, and should be avoided wherever possible. In particular they should not be confused with the very different fan-designs proposed by Nelder for investigation of spacing in vegetable crops. A fuller discussion of this work is given in a paper by J. F. Scott entitled "Statistical Objections to Clinal Points" in the *Empire Forest Review*, No. 41 (1), 1962, pp. 17–18.

Compilation of data for the *Handbook of Research Planning-Factor Data* of the United States Department of Agriculture has continued throughout the year, and a great deal of benefit has come from the use of this handbook as a preliminary source of information in the design and analysis of experimental investigations.

Analysis of Experiments and Surveys

The demand for the analysis and interpretation of numerical data has con-continued to increase, and more than 10,000 separate analyses were completed in the year under review. About one third of these analyses were routine ones of intermediate assessments of long-term experiments, the remainder being special analyses of important immediate problems.

The examination of the relationship between the compressive strength of home-grown pitprops and the size, moisture content, rate of growth, and degree of bow, of the props, occupied an important part of the work of the year. This investigation, one of the largest ever carried out on timber properties, involved the use of complex multiple regression and multivariate techniques, and enabled tables predicting the strength of props to be constructed for a number of important species and for a variety of conditions of moisture content, rate of growth, and degree of bow. It is interesting to note that, with the possible exception of Japanese larch, props of all species of timber regularly used for mining timber in this country are sufficiently strong for work in the mines, provided that they are properly prepared and seasoned, and that beliefs in the inherent weakness of home-grown props, because of fast rates of growth, are unfounded.

Applications of multivariate analysis have continued to play a large part in the work of the Section. Some of the more important of these applications have included the work on pitprops, a study of the variability of Lodgepole pine, investigation of the taxonomy of the collective birch species "*Betula alba*", and examination of the relationships between the timber properties of Sitka spruce. Publications describing these applications have been prepared and will appear in print shortly. The work carried out so far confirms that this is one of the most profitable fields of application of statistical methods, the types of problems that are capable of being tackled often being incapable of efficient analysis by other means.

Working plan enumerations have also continued to occupy a large part of the computing service, although no new techniques have been introduced in the past year. The general programme for working plan surveys, written two years ago, has continued to provide all the essential information required for this important field of activity of the Management Section. A great deal of work has, nevertheless, gone into the construction of the conifer stand tables, i.e. tables giving the proportions of timber above certain diameters, for stands of given top height and girth, and these tables are now practically complete.

Computer Programming

Work has continued on two different computers, the Ferranti Pegasus and Sirius computers, and compatible programming systems have been set up for the work which has been undertaken by the Section. More detailed descriptions of the use of these machines and the programmes which are currently available to them are given in the paper by J. N. R. Jeffers on page 166 of this report.

International Union of Forest Research Organisations

The report of the Working Party of Section 25 of the International Union of Forest Research Organisations, on the "standardisation of measurements" and the "collection and compilation of information on instruments used in forestry", in the preparation of which the Section took an active part, was presented at the Vienna Congress and accepted. This Working Party has now, therefore, been disbanded.

As has been mentioned earlier, the Section has taken an active part in the work of the Advisory Group of Forest Statisticians, and has the special responsibility of collecting and distributing information on electronic computers and their application to problems of forest research and management. The work on this has been started, and it is hoped to produce the first major reports in time for the conference to be held at Alice Holt in 1963.

LIBRARY AND DOCUMENTATION

By R. M. G. SEMPLE

General

The extension and reorganisation of the library has been virtually completed during the year. The additional space and more systematic arrangement of the material, both in the library and its ancillaries, is already saving the staff a great deal of time, and for the next five years at least should allow literature to be stored in a fitting and easily available manner. There is good indication that the better presentation of literature is appreciated by the users of the library, and is encouraging a steadily increasing consultation of reference works, by readers who now need seldom consult the library staff to 'track down' the greater proportion of the items required. The new reading room has proved a distinct asset and is in steady and, we hope, increasing use by both visiting and resident officers.

A clerical assistant was added to the library staff during the period of reorganisation and has been retained on a part-time basis thereafter. Trained in general library duties and, in particular in the more routine aspects of documentation work, she has proved exceedingly useful.

Library

The number of books in the library was increased by 140 to a total of 3,806; 91 of these books were purchased, the remainder being received as gifts or by exchange. Nine hundred and seven books are now on permanent loan to Section libraries. Other (short-term) loans increased from 1,032 to 1,238; this figure includes books, periodicals and other publications, and is an extremely gratifying increase. In addition 347 publications were borrowed from outside libraries for Forestry Commission staff – again a significant increase on last year's figure of 222. Forty-three volumes of periodicals were bound, bringing the total to

1,511. The above rather dry statistics reflect but do not really convey the appreciable increase in the use of the library already referred to – as a source of information and reference and a place to study.

Documentation and Information

Assessed on the same basis as last year, the card catalogue now holds some 96,000 cards. This represents the addition of about 5,000 cards, or some 1,400 references. This is a distinct advance, and has been made possible by the employment of additional staff and more efficient techniques on the routine side of the work. It is, however, not nearly good enough and a serious back-log still remains to be tackled. The additional work involved in reorganisation is in part responsible for these arrears. But the fact remains that the volume of forestry literature is increasing every year and even if, as we have done, we set limits to the field we cover, a figure of 2,000 references per year would be in no way unreasonable if we are to keep abreast of the significant literature affecting British Forestry. Sixty per cent of these might be drawn direct from the Commonwealth Forestry Bureau, the remainder from other sources. Further streamlining of routine technique is still possible, but it remains to be seen if this target can be reached without calling, for short periods at a time, perhaps, on additional staff with technical background and experience.

Requests for information have continued to come in at a steadily increasing rate, continuing last year's trend. Again, enquiries from field staff and Forester Training Schools have formed a large part of the total, and there has been a definite increase in the proportion from 'outside' sources. Many of the queries have been met by the preparation of special bibliographies; others have required specific information on technical points, and these have been dealt with direct or in consultation with the appropriate section of the Research Branch.

There has been a considerable increase in requests for translations – mainly from German, Dutch and the Scandinavian languages. The major (Forestry Commission) translations completed now number 140, and a number of shorter and more specialised items have also been translated for members of the Research staff, copies being held in the information files.

PHOTOGRAPHY

By I. A. ANDERSON

Photographic Collection

Fourteen thousand nine hundred and ninety-five slides and 1,555 prints were loaned for various purposes. As many of the lectures for which slides are used are of a general nature, it is proposed to compile standard sets, duplicated from originals in the Photographic Collection, which can be retained in Directorate and Conservancy offices to cover recurring local needs. It is also suggested that, to assist those who cannot conveniently visit Alice Holt, a guide to the photographs contained in the Collection be produced. This, together with the duplication of slide sets, will be put in hand as soon as it is practical to do so.

Films

No films were produced during the year, but a brief synopsis of two future films was prepared. These will deal with the National Forest Parks, and with the work of the Forestry Commission.

Two hundred and sixty-eight loans of films were made.

General

During the year a start was made on a planned programme of re-equipment to extend the available facilities. When completed, it will enable the section not only to function more efficiently, but to give a better service, over a wider field of activity, to the Commission as a whole. Particularly, this year has seen the introduction of a general service providing, from opaque originals, dimensionally stable masters for dyeline printing. Undoubtedly, the demand for document and plan copying will increase, and it is reasonable that the Section be prepared to meet it.

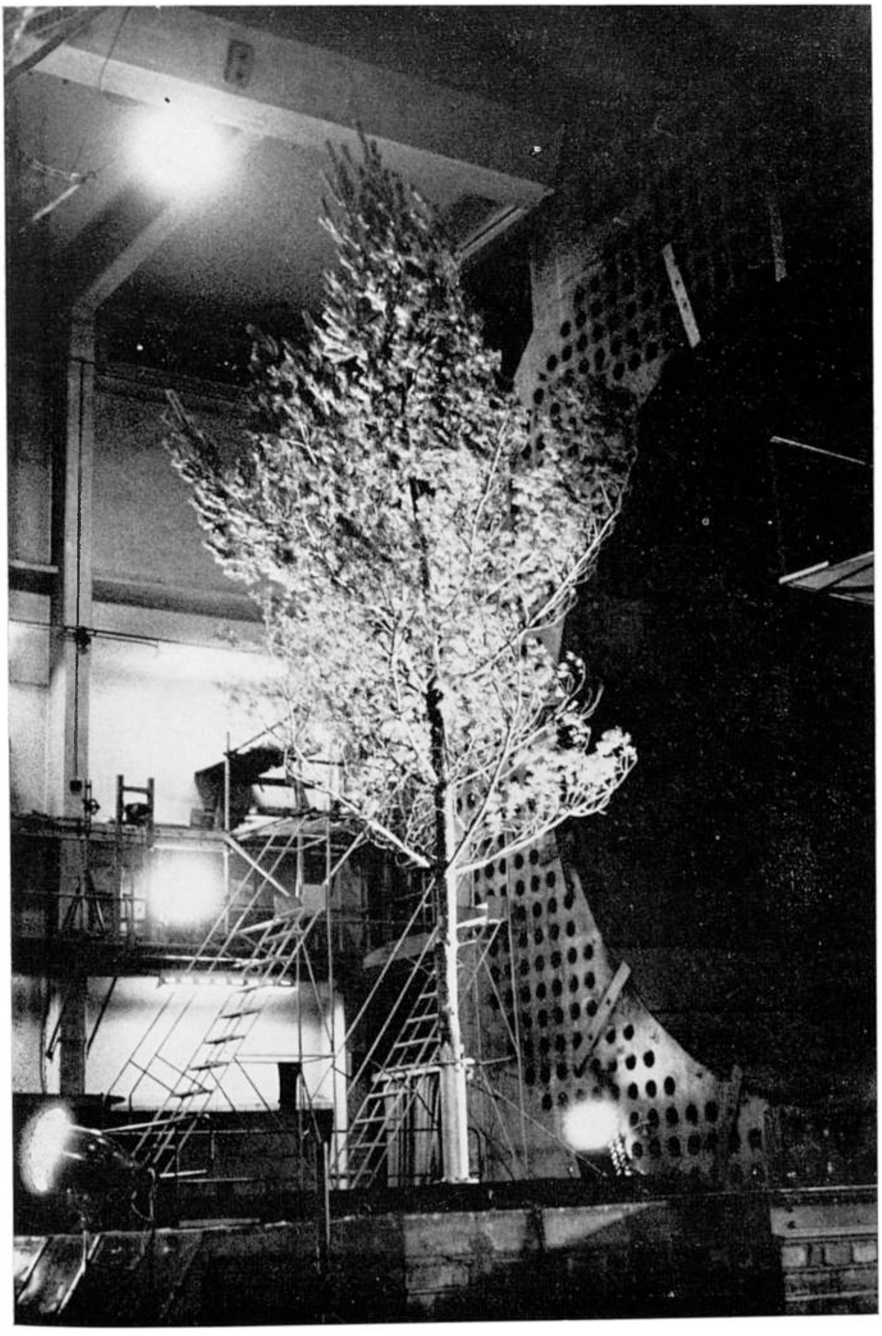

PLATE 1. Fraser: Wind Tunnel Studies.
A tree mounted in a wind tunnel at the Royal Aircraft Establishment, Farnborough, Hants., for studies of the relationship between wind velocity and forces acting on a tree.

PLATE 2. Fraser: Wind Tunnel Studies. Douglas fir at rest.

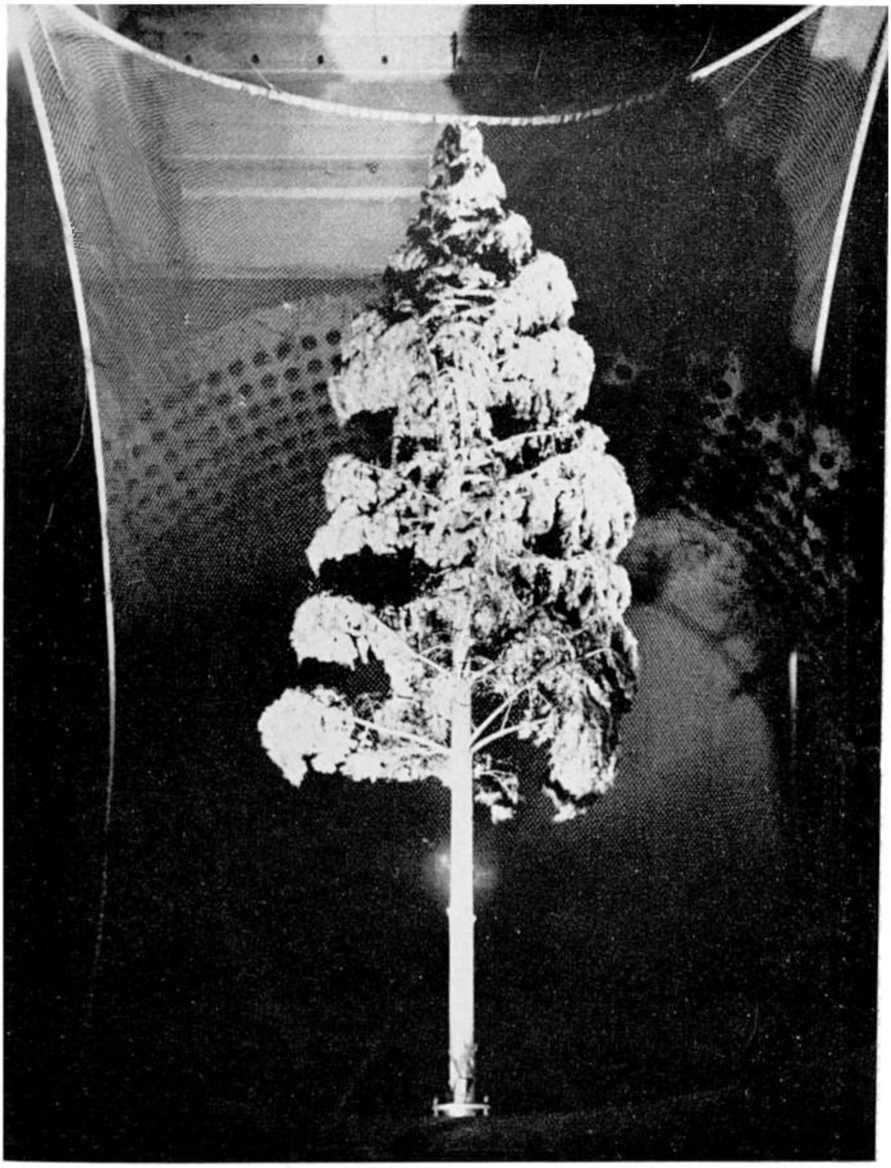

PLATE 3. Fraser: Wind Tunnel Studies.
The Douglas fir, shown in Plate 2, when subjected to a maximum wind velocity of 50·5 knots (58·1 miles per hour).

PLATE 4. Holmes: Removal of Epicormic Shoots by 2,4,5-T.
Balsam poplar, close-up of epicormic shoots severed level with main stem in 1960, two years after treatment with 0·2 per cent 2,4,5-T (acid).

Note: (*a*) Sharp constriction at junction of living and dead tissue. (*b*) The basal $\frac{1}{4}$–$\frac{1}{2}$ in. of each shoot is alive, and has produced fresh sprouts in the year following treatment.

PLATE 5. Holmes: Removal of Epicormic Shoots by 2,4,5-T.
General view of 59-year-old oak in July 1961, one year after treatment of epicormic shoots. *Note:* Hand-pruned tree (05) on left; tree (44) sprayed 0·4 per cent 2,4,5-T (acid) also on left; untreated tree with heavy crop of epicormics on far right.

PLATE 6. Holmes: Removal of Epicormic Shoots by 2,4,5-T.
View of a hand-pruned oak stem July 1961, one year after pruning.

PLATE 7. Holmes: Removal of Epicormic Shoots by 2,4,5-T.
View of an oak stem treated with 0·2 per cent 2,4,5-T (acid), taken in July 1961, one year after treatment.
Note extensive death of epicormics, though no shoots have fallen.

PLATE 8. Brown: Forest Ecology.
Die-back of Corsican pine at Brendon Forest, Somerset. Note healthy Lodgepole pine on right.

PLATE 9. Matthews and others: Genetics.
The hybrid Leyland cypress, x *Cupressocyparis leylandii* growing at Alice Holt Forest, Hampshire.

PLATE 10. Matthews and others: Genetics.
A young Scots pine Seed Orchard, at Drumtochty Forest, Kincardineshire.

PLATE 11. Aldhous and Atterson: Nursery Investigations.
Trials of the herbicide simazine in transplant lines of Douglas fir. *Left foreground*, treated, 4 lb. per acre; *right foreground*, control unweeded.

PLATE 12. Aaron: Fence post Trials.
Assessing the condition of a post by a 50-lb. pull.

PART II

Research Undertaken for the Forestry Commission by Workers at Universities or other Institutions

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RESEARCH ON SCOTTISH FOREST AND NURSERY SOILS

By W. O. BINNS and J. KEAY

The Macaulay Institute for Soil Research, Aberdeen

From 1947 to 1958 much of the work of the Forest Soils Section was devoted to a study of the physical and chemical changes in the soil resulting from afforestation of sand dunes and deep peat. Since 1954, however, fertiliser trials, initiated both by the Institute and by the Forestry Commission, have assumed increasing importance, and in addition some greenhouse studies on seedling nutrition have been started in the last two years.

Fertility Investigations on Sand Dunes

During the year several new investigations were started in Culbin Forest, Morayshire, as described below.

Greenhouse trials in which Corsican pine seedlings were grown in sand from Culbin showed that nitrogen, phosphorus, potassium and sulphur were deficient for these plants. It was already known that ten-year old Corsican pine would respond to nitrogen, phosphorus and potassium on the Culbin sand dunes (*Rep. For. Res. For. Comm. Lond.* 1960), but a response to sulphur had not been sought. The plots in the nutrient demonstration (*Rep. For. Res. For. Comm.*, 1961) which did *not* receive sulphur showed slight yellowing of the current needles early in the growing season, although this later disappeared. In order to test for a deficiency of sulphur, a field trial consisting of two levels of nitrogen and four of sulphur was laid down in July 1961, and the treatments re-applied in spring, 1962.

Corsican pine transplants grown in "Culbin" sand *without* added boron developed a slight mottling of the needles. In October analysis of needles from the field nutrient demonstration showed that, in the foliage from plants stimulated with major nutrient fertilisers, the boron levels had fallen to as low as 11–12 parts per million. A field trial testing boron at three levels, and copper at two levels, was laid down in August, but the foliage levels in October were not affected by the treatments; these treatments were re-applied in the spring of 1962.

The Research Branch of the Forestry Commission had previously tried to establish a lupin crop at Culbin, with the object of improving the nitrogen status. The lupins had failed to develop satisfactorily and a greenhouse pot experiment was undertaken to try to determine which nutrients might be deficient. When any one of the elements nitrogen, phosphorus, potassium, calcium, magnesium, sulphur was omitted, less than 50 per cent dry matter was produced compared with a control. When any one of the elements boron, manganese, copper, zinc, iron, molybdenum was omitted, less than 80 per cent dry matter was produced compared with a control. Clearly it is unlikely that a healthy crop of lupins can be grown at Culbin without compound fertilisation. These results are being tested in less detail in a field trial.

Tree Growth on Deep Peat

At the Lon Mor Experimental area of Inchnacardoch Forest, Inverness-shire the frosts of May, 1961, severely damaged and checked young Sitka spruce, including trees which had been treated with nitrogen, phosphorus and potassium in 1960; these experiments may have to be abandoned.

Fifteen-year-old Lodgepole pine which had been treated with magnesium sulphate in spray form in the spring, showed no appreciable uptake of magnesium by the autumn.

Trials on older Lodgepole pine suggest that 150 lb. potassium per acre will raise the foliage potassium content of deficient trees to a satisfactory level, and produce a growth response, whereas 75 lb. per acre will not.

Survey of Deep Peat Areas for Afforestation

Sampling and analysis have now been completed for twelve sites, ranging from Cumberland to Caithness, and the results of the study described by Binns (1962). The conclusions previously reported (*Rep. For. Res. For. Comm. Lond.* 1961) have been confirmed, and for those sites where there are experiments, there is a good correlation between the total phosphorus content of the top six inches of the peat and the response of trees to phosphate manuring.

This study is to be followed up by a survey, in collaboration with the Department of Agriculture and Fisheries for Scotland (Peat Section) of three trial forests on deep peat in Caithness and Sutherland.

Nitrogen Mineralisation

The experiment at Glentrool (*Rep. For. Res. For. Comm., Lond.* 1961) continues, and the results to date are being analysed statistically. When the analysis is complete, future work on the nitrogen cycle in Scottish forests will be considered on a wider scale.

Forest Nurseries

Regular analyses for the four Long-Term Fertility Experiments in Scottish nurseries (*Rep. For. Res. For. Comm., Lond.* 1957) have continued. In the experiment at Teindland woodland nursery, after 11 years the organic treatment, which adds about 23 tons of raw hopwaste per acre per annum, has maintained the soil organic matter content at its original level of about 18 per cent. By contrast in the plots *without* hopwaste the soil organic matter content has fallen to about 9 per cent. The hopwaste treatment has raised the acetic-soluble phosphorus and magnesium contents considerably, and the potassium contents slightly.

In the experiment on agricultural soil at Newton, samples taken at the end of the second four-year rotation (2½ years after any manures had been applied) showed that plots treated with hopwaste had slightly but significantly higher acetic-soluble phosphorus contents than other plots. Samples taken 18 months later, shortly after a further addition of hopwaste, showed a five-fold increase in acetic-soluble phosphorus contents in the treated plots, while in untreated plots the contents were unchanged.

At the end of the second rotation there was significantly more total phosphorus in the hopwaste plots than in the others. The difference between them was about half the increase in acetic-soluble phosphorus noted above, while the increase in total phosphorus in the hopwaste plots during the rotation was half this again. This suggests that threequarters of the phosphorus added in hopwaste (not allowing for phosphorus added in mineral fertilisers) cannot be found at the end of the rotation. As plant analysis shows that a relatively small amount of phosphate is removed by the crops, and as added phosphate is normally fixed in the soil rather than leached away, there is an appreciable discrepancy. Analysis at the end of the present rotation may help to explain this.

REFERENCE

BINNS, W. O. 1962. Some aspects of peat as a substrate for tree growth. *Irish Forestry*, 19(1), 32–55.

A STUDY OF THE EFFECTS OF DISEASE CONTROL MEASURES ON THE SOIL MICROFLORA OF SITKA SPRUCE (PICEA SITCHENSIS) IN FOREST NURSERIES

By M. A. RAM REDDY

Rothamsted Experimental Station, Harpenden, Herts.

The following brief abstract is taken from an unpublished thesis presented to the University of London for the degree of Doctor of Philosophy. Mr. Ram Reddy's studies were carried out under the general supervision of Dr. F. T. Last:

The series of experiments, the results of which are briefly reported below, was undertaken to throw further light on the mode of operation of partial soil sterilisation in forest nurseries. The experiments were carried out at five Forestry Commission Research nurseries of differing histories and soil types.

Sitka spruce seedlings (*Picea sitchensis*) did not affect the balance of micro-organisms in the soil away from the rhizosphere. The numbers of micro-organisms *in the soil* remained roughly constant throughout the season; but *in the rhizosphere*, bacterial numbers reached a peak in May, and fungi progressively increased as the season advanced.

The pattern of disease differs at Kennington Old and Ringwood nurseries, in each of which Sitka spruce seedlings grow poorly in unsterilised ground. At Kennington Old, pathogens are more active during May/June than at other times, whereas at Ringwood damping-off is less important, and shows no seasonal variation.

Although the fungi isolated from soil differed at the two nurseries, those isolated from root surfaces were similar—*Cylindrocarpon radicicola* was the most frequent, followed by *Pythium* species and *Fusarium* species.

Field experiments at five Forestry Commission nurseries in the south of England tested the effects of chemical and cultural treatments (a) on the growth of Sitka seedlings and (b) the soil microflora. Two groups of chemical soil sterilants with differing biological properties were compared. Formalin, chloropicrin and metham-sodium, (which are phyto-toxic and so were applied at least two months before seed was sown), always increased the height of seedlings but rarely affected seedling numbers. In contrast, Maneb and PCNB applied at sowing time, increased seedling numbers but rarely affected height. The growth and survival of direct-sown seeds and transplanted seedlings were affected similarly by formalin, so the control of pre-emergence and immediate post-emergent diseases is unlikely to be the cause of the increased growth.

Formalin and chloropicrin always increased numbers of soil bacteria and usually significantly decreased numbers of fungi. At Ringwood, however, plots treated twice or more with formalin always contained more fungi than untreated soils.

Trichoderma viride was everywhere the main fungus colonizing soils treated with chloropicrin. The colonizers of formalin-treated soils differed at different sites. *Penicillium canescens* and *Phoma* species were numerous at Kennington Old and *Penicillium canescens* and *Trichoderma viride* at Ringwood.

Although soil treatments often greatly affected the numbers of micro-organisms in soil, numbers in the rhizospheres were usually unaffected.

Treating seed with fungicides often increased the numbers of seedlings emerging and surviving, but rarely affected their height. They had more effect in unsterilised soils, and those treated with formalin or metham-sodium, than in soils treated with PCNB or Maneb.

PROTEIN-FIXING CONSTITUENTS OF PLANTS: PART III

By B. R. BROWN and C. W. LOVE
Dyson Perrins Laboratory, Oxford University
and W. R. C. HANDLEY
Department of Forestry, Oxford University

In Parts I and II of this series the isolation and partial characterisation of the leaf constituent of heather, *Calluna vulgaris*, which is considered (Handley, For. Comm. Bull. No. 23 *Mull and Mor Formation in Relation to Forest Soils*, 1954) to be an important factor in the decomposition of residual leaf proteins in litter, and the formation of raw humus by this species, have been described. The results indicate that the leaf constituent concerned is probably a condensed tannin, and that leucocyanidin forms at least part of the tannin molecule.

Protein-fixing constituents have been observed in extracts of the fresh leaves of a variety of plant species, including those which are not associated with the formation of raw humus as well as those which are, and therefore a comparative study has been started. Acetone-water extracts of the leaves of a number of species have been prepared and the protein-fixing constituents isolated and examined in the same manner as for *Calluna vulgaris*. The results are given in Table 12.

Table 12

Species Survey of Leaf Protein-fixing Constituent

Species	Paper chromatography Streak ($FeCl_3$ spray)		Action of conc. HCl Anthocyanidin			Tannin type
	2% Acetic acid	BAW*	Colour	Cy†	De[x]	
Heather *Calluna vulgaris*	+	—	Red	++	—	Condensed
Douglas fir *Pseudotsuga taxifolia*	+	+	Red	++	+	Condensed + Hydrolysable
Norway spruce *Picea abies*	+	+	Red	++	+	Condensed + Hydrolysable
Yew *Taxus baccata*	+	+	Red	++	+	Condensed + Hydrolysable
European larch *Larix decidua*	+	+	Red	+	++	Condensed + Hydrolysable
Birch *Betula* spp.	+	+	Red	+	+	Condensed + Hydrolysable
Beech *Fagus sylvatica*	+	+	Red	++	—	Condensed + Hydrolysable
Bracken *Pteridium aquilinum*	+	+	Red	++	—	Condensed + Hydrolysable
Sycamore *Acer pseudoplatanus*	+	+	Red	++	—	Condensed + Hydrolysable
Maple *Acer* sp.	+	+	Red	++	—	Condensed + Hydrolysable
Oak *Quercus* spp.	+	+	Red	++	—	Condensed + Hydrolysable
Hazel *Corylus avellana*	+	+	Red	—	++	Condensed + Hydrolysable
Circaea lutetiana	+	+	—	—	—	Hydrolysable
Chestnut *Castanea sativa*	+	+	—	—	—	Hydrolysable
Chamaenerion angustifolium	+	—	—	—	—	Hydrolysable
Ash *Fraxinus excelsiar*	—	+	—	—	—	Hydrolysable
Bamboo	—	+	—	—	—	Hydrolysable
Mercurialis perennis	—	—	—	—	—	None present
Brachypodium silvaticum	—	—	—	—	—	None present
Deschampsia caespitosa	—	—	—	—	—	None present
Nettle *Urtica dioica*	—	—	—	—	—	None present
Elderberry *Sambucus nigra*	—	—	—	—	—	None present
Wych elm *Ulmus glabra*	—	—	—	—	—	None present

*BAW = n-Butanol-Acetic acid-Water (4:1:5 v/v)

†Cy = Cyanidin, x De = Delphinidin.

The plant species investigated fall into four sharply differentiated groups as far as protein-fixing constituents are concerned:

(a) Those in which protein-fixing constituents have not been detected.
(b) Those in which the protein-fixing constituents have the characteristics of hydrolysable tannins.
(c) Those in which the protein-fixing constituents appear to be a mixture of condensed and hydrolysable tannins.
(d) Those in which the protein-fixing constituents appear to be condensed tannins.

The litter of the species of group (a) does not give rise to raw humus and is readily accepted by members of the soil fauna, especially earthworms; this could be due to the residual leaf proteins being more readily available apart from any consideration of palatability.

In the case of the species of group (b) the litter of these species is also not associated with the formation of raw humus and, as suggested elsewhere (Handley, *Plant and Soil* 15, 37–73 1961), the residual nitrogen of the litter of at least some of these species is likely to be more readily available than that of the raw humus-forming species *Calluna vulgaris*. Experiments with model protein-leaf extract complexes show differences in availability of nitrogen (Handley, *Plant and Soil* 15, 37–73, 1961) which could be due to differences in the hydrolysable tannins involved in the different species, but this requires further investigation.

The species of group (c), although all appearing to be characterised by having leaves containing both condensed tannins and hydrolysable tannins, comprise species whose litter can give rise to raw humus and others whose litter is usually regarded as potentially mull-forming. It is clear that at least three different types of condensed tannin are involved:

(1) Tannin containing both leucocyanidin and leucodelphinidin moieties.
(2) Tannin containing leucocyanidin but no leucodelphinidin.
(3) Tannin containing leucodelphinidin but no leucocyanidin.

No one of these groups is characteristic of the raw humus forming species. The situation is further complicated by an investigation in which extracts of the fresh leaves of a single oak tree were examined at various times during two growing seasons. The results are given in Table 13 and indicate that, whilst the young leaves contain only hydrolysable tannins, the older leaves contain both hydrolysable and condensed tannins.

Table 13

Seasonal Changes in the Tannins Extractable from Oak Leaves

Date of Collection	Tannin
Late April	Hydrolysable
May	Hydrolysable
July	Hydrolysable and Condensed
August	Hydrolysable and Condensed

So far only one species, *Calluna vulgaris*, has been found whose leaves contain only condensed tannins (group d) and this is essentially a species associated with the formation of raw humus.

It is clear that a great deal of chemical work remains to be done especially in the case of the condensed tannins. For example, the leucoanthocyanidin moieties have so far been shown to account for at most 10 per cent of the tannin. The greater part of the tannin which remains may or may not be composed of leucoanthocyanidins, and variations in the chemical nature of these as-yet-unidentified parts of the tannin could well be the source of marked differences in, for example, the digestibility characteristics of the complexes they form with residual leaf protein, since it is well known that even quite small modifications in molecular structure can result in large differences in biological properties.

Unfortunately, the chemical methods at present available for the degradation of substances such as condensed tannins have either proved ineffective or are too drastic, with the result that the fragments obtained do not give the necessary information.

THE ACTION OF ENZYMES ON PLANT POLYPHENOLS: PART I

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Since it seems unlikely at present that progress can be made with characterisation of the condensed tannins of the leaves of various species by the use of purely chemical methods, work began in October 1961 to attempt to use enzymes to break up the complex condensed tannin molecules and protein-tannin complexes. It is hoped that any resulting fragments will throw light on the structure of the condensed tannins and thereby elucidate the differences between the condensed tannins of the leaves of different plant species.

It has been known for a considerable time that the so-called white rot fungi produce enzymes capable of oxidizing phenols, and since these organisms are well known for their activity in decomposing the more complex constituents of wood and dead leaves, it seemed probable that they might be a source of enzymes able to break down tannins and tannin-protein complexes.

It is also known that organisms such as *Penicillium solitum* and *Aspergillus niger* are able to decompose substances such as (+)-catechin so completely that no aromatic nuclei remain (Bokadia, Brown, Cobern, Roberts and Somerfield, *J. Chem. Soc.*, 1962, 1658). In addition it was shown by paper chromatography that the isomer (+)-epicatechin, resulting from epimerisation of the (+)-catechin during sterilization by heat, is not changed by the activity of these organisms.

Since there is a very close constitutional connection between catechin and the condensed tannins and (+)-catechin is readily available, it seemed important to study the enzyme system which can bring about changes in catechin as a preliminary to the study of the possibility of the stepwise degradation of condensed tannins by enzymes.

The effect of various wood rotting fungi and *Aspergillus niger* and *Penicillium solitum* on (+)-catechin when grown on both solid and liquid media was examined and the results shown in Table 14 were obtained.

Table 14

*Growth of Fungi on solid medium containing (+)-Catechin**

Organism	Production of yellow compound	Growth
Polyporus versicolor	+++	Good
Polyporus sanguineus	+++	None
Polyporus hirsutus	+++	Poor
Polyporus abietinus	++	Poor
Stereum hirsutum	++	Poor
Marasmius scorodonius	+++	None
Trametes gibbosa	+++	None
Collybia butyracea	+	Poor
Hypholoma fasciculare	+	None
Aspergillus niger	—	Poor
Penicillium solitum	—	Poor

* 0·1% (+)-catechin
0·15% KH_2PO_4
0·06% NH_4NO_3
0·05% $CaCl_2\,6H_2O$
0·05% $Mg\,SO_47H_2O$
0·05% $Na_2B_4O_7$
Trace of $Zn\,SO_4$, $Fe\,Cl_3$, $CuSO_4$ and $Mn\,Cl_2$

When grown on solid media containing (+)-catechin, the organisms produced a yellow outer zone around the inoculum and a darker brownish inner zone. Since the enzyme appeared to be extracellular, an attempt was made to isolate the enzyme. *Polyporus versicolor* was grown in 3 per cent aqueous malt extract solution and the enzyme subsequently extracted from the culture medium by precipitation with $(NH_4)_2SO_4$ and then partially purified by dialysis. Boiling for 5 minutes destroyed the activity of the enzyme, which was found to be inhibited by sodium azide. It was also observed that the products of the action of the enzyme on (+)-catechin differed according to the hydrogen ion concentration at which the action occurred. At pH 5·0 a yellow compound was obtained with an λ max. at 390 mμ whilst at pH 7·0 a dark orange compound with a λ max. at 460 mμ was obtained. When the action of the enzyme was prolonged for 48 hours or more the orange coloured substance appeared to be precipitated in the form of a complex polymer.

It seemed clear that this was an example of the well known phenoloxidase activity as used in the Bavendam test. Little is known of the chemical changes involved, although chemical oxidation of ∝-naphthol gives rise to a purple quinonoid polymer which is probably also produced by the action of *Polyporus versicolor* on ∝-naphthol (Fåhraeus, G. *Kungl. Lantbr.-Högsk. Ann. Uppsala.* 1949, 16,618).

The action of a cell-free extracellular enzyme preparation, obtained from cultures of *Polyporus versicolor* grown on aqueous malt extract medium, on a variety of phenolic substrates was investigated (Bocks, Brown and Todd, *Proc. Chem. Soc.* 1962, 117). The results obtained indicated that the enzyme preparation could bring about several different types of change:

(1) Inter- or intra-molecular coupling to yield coloured extended quinones.
(2) Inter- or intra-molecular coupling to yield colourless products.
(3) Polymerisation to yield complex structures and often complex mixtures of coloured substances.
(4) Pyrogallol is changed to the benztropolone structure purpurogallin, which is itself susceptible to further change.

The absence of effect of the enzyme preparation on tyrosine differentiates it from tyrosinase and the changes produced by the action of the enzyme preparation on p-cresol and resorcinol differentiate it from laccase as obtained from the lac tree.

It seems clear that since this particular enzyme preparation produces polymeric products from simpler phenols, it is unlikely to be of assistance in the stepwise degradation of condensed tannins.

Non-oxidative changes produced in (+)-catechin by ***Aspergillus niger*** **and** ***Penicillium solitum.***

Attention was therefore turned to the enzymes of *Aspergillus niger* and *Penicillium solitum* which do not produce phenoloxidases but are none the less able to decompose (+)-catechin.

When these organisms were grown in a liquid medium containing (+)-catechin as the sole source of carbon, it was observed that after several days no phenolic compounds could be detected, apart from some polymer which did not account for the whole of the (+)-catechin initially added, and coloured compounds were not produced.

The catechin isomers can be differentiated chromatographically and when *Aspergillus niger* and *Penicillium solitum* were grown in the presence of these substances (+)-catechin and (—)-epicatechin were attacked whereas (+)-epicatechin and (—)-catechin remained unchanged. Their structure is indicated in Figure 2 on page 96.

It is clear that the isomers which are attacked have the opposite stereochemistry at position 2 compared with the isomers which remain unchanged. The apparent influence of such small differences in molecular configuration on enzyme activity could, as suggested earlier, have important consequences for the decomposition of more complex polyphenolic substances, e.g. condensed tannins, which are to be found in different plant species.

Preliminary experiments have shown that when *Aspergillus niger* is grown as a stationary culture on aqueous malt extract solution for 72 hours, and the culture medium is then replaced with a *mineral salt medium* (see below) containing

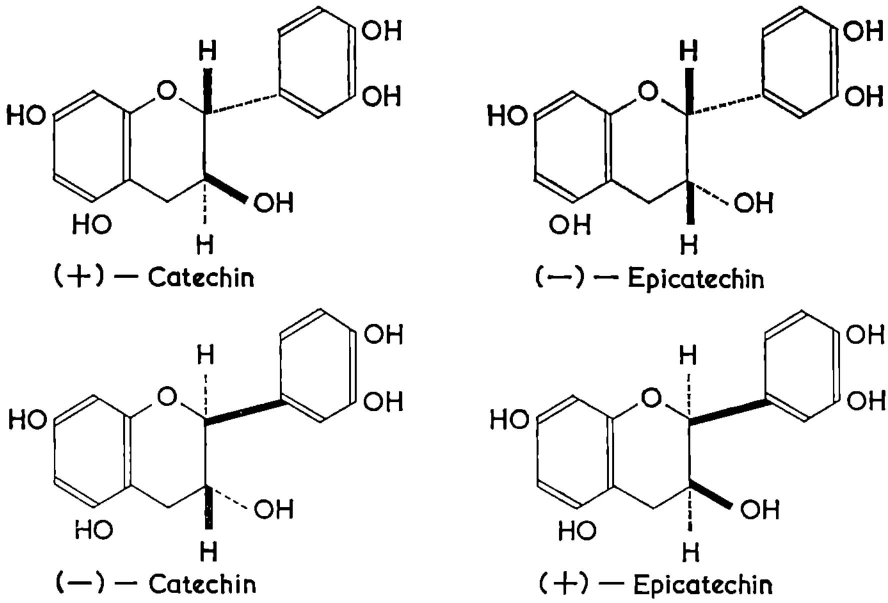

FIGURE 2. Diagrams of structures of isomers of catechin and epicatechin.

0·5 per cent (+)-catechin, a phenolic intermediate can be identified in the medium after 24 hours. The intermediate does not appear to be produced by *Penicillium solitum* under the same experimental conditions.

The intermediate appears to be stable to heat, can be extracted from the aqueous solution by ethyl acetate and has an R f value of 0·61 on paper chromatograms run with 2 per cent acetic acid.

The enzyme system involved appears to be intracellular as no activity could be detected in the culture fluid.

It is intended to study this enzyme and the intermediate products from catechin further and then to investigate the action, if any, of this enzyme on condensed tannins.

Note: The mineral salt medium mentioned above has the following composition:

0·5% (+)-catechin
0·3% $(NH_4)_2H\ PO_4$
0·1% $K\ H_2\ PO_4$
0·8% $(NH_4)_2\ SO_4$
A trace of $Zn\ SO_4$, $Fe\ Cl_3$, $Cu\ SO_4$ and $Mn\ Cl_2$

BIOLOGY OF FOREST SOILS

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Sampling of leaf discs in the experiments described in last year's report (*Rep. For. Res. For. Comm., Lond.* 1961) continued until leaf fall in 1961. The additional information collected since the last report has confirmed that skeletonisation and fragmentation of leaf discs occurs almost exclusively in the lower layer of litter, which is in contact with the soil.

On the experimental sites, the animals most important in removing and fragmenting leaf discs appear to be earthworms, and although both sites have similar earthworm population, leaf discs disappear from the oak-dominant woodland more quickly than they do from the beech woodland. The rate at which leaf discs disappear shows distinct seasonal fluctuations, being at its highest in February and March, slowing down in April and continuing only sporadically until the end of August. After this, the rate of disappearance of oak discs increases until it reaches about half its peak value of the early spring. The rate of disappearance of beech discs did not show this marked increase in the autumn. An interesting feature of the sporadic fluctuations in rate of disappearance during the summer, and the increase in rate of oak leaf disc disappearance in the autumn, was that these changes were markedly correlated with moisture conditions in the litter. The periods when no fresh disappearance took place coincided with dry conditions, and the periods of renewed disc disappearance followed almost immediately upon the wetting of the litter by rain.

Changes in rate of disc disappearance have also shown interesting relationships with the percentage of hydrolysable carbohydrates, as found in further samples of leaf discs taken at the same time as the determinations were made of rate of disc disappearance. With oak discs, percentage hydrolysable carbohydrates in those discs showing most fragmentation, and therefore, assumed to form a suitable food substrate for the fauna, remained at a steady level of approximately 100 milligrams of hydrolysable carbohydrates per gram of leaf litter until mid April; thereafter the amount of hydrolysable carbohydrate rose until it was about 300 milligrams per gram leaf litter by the beginning of August. A subsequent drop to 200 milligrams per gram coincided with the renewal of disc disappearance. It should be emphasised that the percentage of hydrolysable carbohydrate is determined on the remaining parts of leaf discs showing signs of fragmentation, and is only indirectly a reflection of what is eaten; but the marked rise in hydrolysable carbohydrate during the period of least feeding activity (presumably because of the dry conditions of the litter during that time) is most interesting. Beech leaf discs showed a similar percentage of hydrolysable carbohydrates for the first six months of the experiment i.e. until mid April, but so far no rise in percentage like that found with oak has been detected. This finding would appear to agree with the observation of slower disappearance of litter in the beech woodland.

In collaboration with Dr. Edwards, the rate of disappearance of oak and beech leaf discs in the soil is being studied. The experimental site, which has had a number of soil insecticide treatments, has the useful feature of possessing plots which have different components of the soil fauna dominant. The leaf discs have been enclosed in nylon mesh bags of different size, designed to exclude different sections of the fauna. The experiment has shown the overall importance of earthworms in fragmenting leaf material, but where earthworms are excluded by fine mesh nylon, enchytraeid worms and Collembola are eventually able to break it down completely.

It has been found in these experiments that different types of beech leaves show great difference in the rate at which they are attacked by soil animals. Thus the thicker 'sun' leaves, which are dark brown at the time of leaf fall, are left untouched, whilst the thinner 'shade' leaves, light brown at the time of leaf fall, are quite readily eaten.

SOIL FAUNA RESEARCH

By D. R. GIFFORD

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The period April–November 1961 was employed in completing the first stage of the study on the fauna developing below Sitka spruce planted on a *Molinia* moor at Ae Forest, Dumfries. This work has been written up, submitted and accepted as a thesis for the Doctor of Philosophy degree at Edinburgh University. The results may be summarized as follows.

Two experiments are reported on here, the first a preliminary review of the fauna of two sites, one *Molinia* grass moorland, the other a 30-year-old Sitka spruce plantation, which had been established on *Molinia* moorland. One hundred and eight species of *Acarina* were collected in these sites; 33 species of rather constant occurrence were studied quantitatively for a period of twelve months, to observe their status in the upper 3·8 cm. of each profile, as well as the effect of seasonal change and variation between sites upon it.

Analyses of variance due to season and site, and the interaction of these, for some *Mesostigmata*, are typified by the figures for three species of *Veigaia* shown in Table 15.

Table 15

Occurrence of Veigaia Species

Species	Source of variance	Degree of freedom	Sum of squares	Mean square	Variance ratio	Probability
Veigaia nemorensis	Season	11	879·09	79·92	9·02	0·001
	Site	1	460·21	460·21	53·19	0·001
	Interaction	11	234·29	21·30	2·45	0·01
	Intrasample	96	848·40	8·84	—	—
V. transisalae	Season	11	345·90	31·44	5·01	0·001
	Site	1	0·53	0·53	0·10	—
	Interaction	11	161·04	14·64	2·33	0·02
	Intrasample	96	602·00	6·27	—	—
V. cervus	Season	11	302·82	27·53	5·45	0·001
	Site	1	110·21	110·21	21·81	0·001
	Interaction	11	29·89	2·72	0·54	—
	Intrasample	96	485·20	5·05	—	—

It is clear that each of these three closely related and abundant species has specialized environmental optima of some kind, and that study of the predaceous population as a whole is unlikely to produce results of significance.

The *Oribatei* were similarly highly variable between species and the examples shown in Table 16 among the primitive *Oribatei* illustrate this.

The figures for *E. sellnicki* show such high variation between samples that this masks other sources of variance to some extent. The figures for *P. peltifer* were treated logarithmically, but such transformations are not justified in face of the coarseness of the variation.

At the time that these experimental data were obtained it was considered that a Poisson distribution was shown in the results, but it is clear that further

Table 16

Occurrence of Oribatei

Species	Source of variance	Degree of freedom	Sum of squares	Mean square	Variance ratio	Probability
Nanhemannia nanus	Season	11	1326·67	120·61	5·95	0·001
	Site	1	1552·20	1552·20	75·05	0·001
	Interaction	11	826·20	75·10	3·70	0·001
	Intrasample	96	1946·80	20·28	—	
Eobrachychthonius sellnicki	Season	11	873·9	79·4	3·24	0·01
	Site	1	6·5	6·5	0·27	0·2
	Interaction	11	539·7	49·1	2·00	0·05
	Intrasample	96	2355·2	24·53	—	
Platynothrus peltifer	Season	11	1·6901	0·1532	5·4042	0·001
	Site	1	1·1032	1·1032	38·990	0·001
	Interaction	11	0·9805	0·0891	3·142	0·01
	Intrasample	96	2·7223	0·0283	—	

analysis to test the figures for contagious or negative binomial distribution is required.

It is clear that seasonal factors and site variation play an important part in determining the status of the *Acarina* in the soil at Ae. It has been shown that the effect of seasonal change was marked in all the species dealt with in detail. In *E. sellnicki* this factor is significant only at 1 per cent, but in all the *Veigaia* spp., *N. nanus* and *P. peltifer*, P values of 0·1 per cent were shown for this factor.

Site variation, that is the comparison between the surface beneath Sitka spruce and that below *Molinia* grass, is less universally important. In *V. transisalae* no significant effect could be detected, but in *V. cervus* and *V. nemorensis* this factor was highly significant, *cervus* toward *Molinia*, *nemorensis* toward Sitka spruce. Among the *Oribatei*, *E. sellnicki* was equally common in samples from both sites, and no significant difference could be shown. In contrast, *N. nanus* and *P. peltifer* were both strongly affected by site, both being so much commoner in *Molinietum* that analysis was scarcely more than a formality.

Analysis of the interaction of site and seasonal factors on numbers is instructive in showing that seasonal influences are often considerably disturbed by site, but that in some species, e.g. *V. cervus*, this disturbance does not influence population. It is deduced from this that unequal effect of seasonal variation in the two types of vegetation is a function of the latter; this is, of coures, to be expected, but it is of interest to detect its penetration into the soil. The factor for Interaction in the analyses presented provides some measure of the extent of this interference.

The second experiment now reported consisted of a similar series of extractions, but at three depths, each unit being 3·8 cm. in depth, and detailed analysis was confined to nine species. Mean depths for the occurrence of each species were calculated for Sitka spruce plantation and for *Molinia* moorland, on the basis of the numbers collected in each of the vertically superimposed units of each sample. It was possible to compare these sets of figures, and to demonstrate as highly significant difference between them, on an overall, as well as a seasonal, basis. But the quotation of specific means for each species is not practicable on the basis of observations so far completed, since the stratification of the sample is too coarse to define with accuracy the true mean depth, which lies within the upper crust, at least for *Molinia* moorland.

The mean sample population depth in Sitka spruce is determined as 4·15 cm. This lies precisely on the lower face of the F horizon as measured in a series of samples from the experimental area, but without observations of the other species of *Acarina* present it would be unwise to draw conclusions from this relationship.

The upper part of the Litter horizon is frequently matted with fungous mycelia, widely recognised as being antagonistic to many *Acarina*. In the earlier experiment the dominance of *Collembola* in this upper layer was a feature which supports other workers' views and observations concerning the abundance of these animals in sites of dense hyphal growth.

The structure of the organic soil at the mean population depth is open, with some lumpiness, the material strongly comminuted, and mixed with many arthropod faeces, which appears to support the observation on depth. It is, however, important to remember that only nine species were dealt with in this study, among a spectrum of 108 recorded species.

The mean sample population depth in *Molinia* moor was determined at 2·75 cm. The L and F horizons do not, on average, have a depth of as much as 1 cm.; it is not clear how the arthropods are distributed in the upper unit of each sample. The structure of the raw humus allows movement along the joints of the blockiness ascribed to wetting and drying; also there are many root channels.

It is perhaps unreasonable to use a system of sampling and analysis which does not permit the establishment of a mean population depth of less than 1·9 cm., the mean for the upper unit, particularly since the upper strata of *Molinia* raw humus are so evanescent. If the established means for depth in respect of both parts of the population are treated by subtraction of this half-unit, the *Molinia* fauna is seen to have a hypothetical mean depth of 0·85 cm.; which lies at about the observed base of such F horizon as is present, while in Sitka spruce the mean would lie just above the base of the litter, as distinct from the F layer. It is idle speculation to consider this aspect without sampling based on more detailed vertical stratification of the sample. But subsidiary studies on the fauna of the unincorporated *Molinia* litter were made, revealing a fauna rich in species and of large size, in that material.

A comparison between *Oppia* species confirms Evans' (1952) observation concerning their specialised vertical distribution. *Oppia ornata* lives in sites significantly shallower than *O. neerlandica* in both *Molinia* and spruce sites. It is not purely a matter of soil structure or animal size which determines this difference, since the L and F layers of spruce provide adequate pore space for the movement of these mites.

The general conclusions reached in these two studies can be outlined as follows: subsidiary sampling in seminatural forest conditions is referred to briefly in the discussion.

The derivation of the *Acarina* fauna of 30-year-old Sitka spruce plantation has been shown to be from the original population of the *Molinia* moorland, at least with respect to all the species of quantitative importance. While there is no marked difference between this relict *Molinia* fauna and that of older woodland, it is clear that in true forest conditions a richer species composition will appear. Thus the fauna of the spruce plantation is likely to continue development, particularly round sources of a fauna more typical of true forest conditions.

The general structure of the population conforms with the observations of other workers. In the spruce litter, where there is abundant fungous mycelia, and primary breakdown is occurring, there is a dominance of *Collembola*, although the *Oribatei* are particularly abundant just below this level. In the *Molinietum* there is rapid disintegration of the grass litter, which is disposed of without delay. The *Acarina* appear to play the dominant role here numerically with the fauna extending, in suitable climatic conditions, high into the loose detritus characteristic of the moorland. The part played by fungous attack in the breakdown of the *Molinia* litter differs from that observed in spruce litter. The appearance of mycelia on and in the blades of the dead grass is, of course, inevitable, but there is rarely any matted litter bound together in the way described in spruce. It was also seen that the *Collembola* were less abundant in these circumstances, although common always. Comparison of the relative status of *Collembola* and *Oribatei*, from spruce and *Molinia* respectively, showed this clearly.

The influence of tree planting on the fauna is obscure. The microarthropods appear to have no difficulty in adjusting their feeding habits to conform with the new conditions; observation of the structure of the F layer of both sites indicates that a high proportion of the comminution of material is the work of microarthropods, and it has been shown that the species of quantitative importance are the same in both situations.

The development of a new structure in the upper strata of the organic profile is of the greatest importance to the mesofauna. In the changed circumstances of spruce litter, the pore spaces allow free access for even large species into the upper H horizon. There has been a significant response from the population, which is most abundant in the second unit of depth in Sitka spruce litter, but remains closely confined to the near surface in *Molinietum*. This is partly attributed to the structural differences between the two soils. It has already been shown that feeding habits appear to have little to do with the problem, in an overall sense. But in the spruce profile the narrow horizontal stratification of the *Acarina* round the Fermentation zone suggests that they are best able to obtain a food supply, and to effect comminution of the litter, at that level. It is likely that the conditioning effect of fungous and bacterial decay is at its optimum there for those species which make secondary attack on the spruce needles. The primary attackers so graphically described by other workers, such as the *Phthiracaroid* species, with their burrowing juvenile stages, were not much in evidence in the spruce profile. They appear to be common enough in the twig litter, but made little contribution to the needle break-down as observed. Mycologists have commented on the ephemeral nature of the attack of the first wave of zymogenous fungi in such circumstances. It is not unlikely that their suppression in the succession of breakdown leads to conditions which are highly suitable for the *Oribatei*, and the observations made in spruce litter at Ae support the view that early colonisation by microflora encourages a large *Collembolan* population, with associated predators, while beneath this stratum lies a 'comminution' layer, abundantly populated by the *Oribatei*, though the other groups are well represented also. On the open moor this process is one involving a hemiedaphic fauna, although the species structure, as well as the quantitative features of the population, do not deviate considerably from the characteristic fauna in spruce.

The influence of tree planting on site factors appears to have been very great. Apart from the effect on soil profile, disturbance of the relationship between seasonal change and the fluctuations of population level of various mite species was observed. The evaluation of the effect, climatically, and on water relations, of the tree development on the moorland site was beyond the scope of the present enquiry, but the information acquired, particularly that of the first experiment, suggests that this influence will have increasing importance, rather than the reverse. The design of the experiments in the current investigation was aimed at obtaining basic facts concerning the development of the microarthropod population in the changing surroundings, but it is clear that further investigation on a more advanced plane, of climatic conditions and fluctuations in the upper soil, should be applied to the study of the microarthropods. The observations made on three closely related species of *Veigaia* are of considerable interest in this context. Although these mites have the predatory habit, appearing in the upper strata quite abundantly, they have all exhibited specialisation in their habitat requirements, which places them in a fairly wide series of optimum vertical stratification, while the effect of climatic conditions on their distribution and abundance, although uniformly significant, is very differently affected by the development of interaction between climate and the tree crop. In fact, no straightforward relationship could be discerned between the optimum depth and the likelihood of disturbance by this interaction. It was most significant in the species (*V. nemorensis*) which has the least optimum depth, but it was more significant in the species (*V. transisalae*) with the greatest optimum depth than in *V. cervus*, which was not affected. It may be significant that the last-named is most abundant in *Molinietum*. It is possible to conclude that micro-environmental studies will become of increasing importance in the investigation of soil microarthropods.

It seems possible that the lack of observed vertical migration related to seasonal change, observed by other workers elsewhere, may be due to two factors. In the *Molinietum*, the fauna tends to the hemi-edaphic status, which presupposes suitable climatic conditions. Combined with the fine, greasy structure of the raw humus such a situation would tend to make vertical movement important only in the litter, while measurement was confined to the raw humus. In the spruce plantation, conditions might well be sufficiently stable at the comminution layer for climatic effects to be little disturbed by seasonal change. It is necessary to remember, however, that seasonal fluctuations in numbers are highly significant in many species. Haarlov (1960) suggested that reproduction was carried on at any time when conditions were suitable, but a review of reproductive cycles related to the other factors examined during this work appears to be required.

It was concluded that the effect of structural alteration in the upper soil profile, as well as the disturbance of climatic effects at litter level due to tree planting, are factors of high importance to microarthropods at Ae. The downward displacement of a food supply in the most suitable stage of the breakdown succession is held to be the primary cause of the redistribution, vertically, of the population.

The current work programme has been based on the refining of techniques for environmental studies on *Acarina*, in preparation for the incorporation of investigations of the microflora into this study. The appointment of a worker in this field will take place in October 1962, and should permit the reorientation of the study toward an investigation of the process of litter destruction and the role of various organisms in bringing this about.

During the year under review discussions with the other recipients of grants for study of soil biology from the Forestry Commission were held, which helped considerably in deciding on a programme for the immediate future.

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STUDIES IN SOIL MYCOLOGY: PART VI, MYCOSTASIS IN SOILS

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Soil Extracts

During the past year the work has been concentrated on an attempt to obtain evidence as to the nature of the inhibiting substances responsible for the phenomenon of mycostasis. Since the first need here is to separate these diffusible substances from the soil micro-organisms which produce them, this has mainly involved the preparation of sterile water-extracts of soils by filtration under nitrogen, as described in the *Reports on Forest Research* for 1960 and 1961.

This work has continued to present difficulties owing to the variable nature of the biological materials used. Controls, consisting of washed-agar discs inoculated with spores of *Mucor ramannianus* in distilled water, sometimes showed variations in germination as great as 20 per cent. This is of the same order as the depression in germination obtainable with extracts of forest soils which give a complete inhibition with the Cellophane film test.

Improved methods, including the use of conductivity-water instead of distilled water for the controls, reduced this variation to less than 10 per cent; but the difficulty remains that the methods of testing and extraction used must result in some dilution of the inhibitor.

In testing the effect of the extract on germination, a drop of it containing the test spores is placed upon a washed agar disc, and the inhibitor may therefore be diluted by the water contained in the agar jelly. An attempt was made to remedy this by drying down the discs before use and allowing them to take up soil extract by inhibition. The drawback to this is that it delays the testing of the unstable inhibitor; and although there was some indication of an increased effect, this was not definite or consistent enough to justify the delay.

The method of extraction now used has been found by trial and error to give the most inhibitory extracts. It involves diluting the soil solution by moistening the soil to field capacity and Seltz-filtering through a Membrane-filter which, though superior in this respect to the Ford Sterimats or fine filter papers previously used, probably absorbs some of the inhibitor. Loss of the inhibitor through aeration is reduced as much as possible by incubating, filtering, and testing under nitrogen.

The variable results accord with the supposition that these conditions favour the growth and activity of a complex of soil micro-organisms which produce an inhibitor or inhibitors sensitive to heat and to aeration, the activity of the extract also being modified by the amount of free carbohydrate nutrients present. Thus, some extracts have strongly stimulated germination, as compared with water controls, others have shown no difference or an inconclusive, or doubtfully significant, reduction, others a definite reduction, varying from a germination of 2 per cent to about 60 per cent, with water controls at 80 per cent upwards.

The trouble has been that many of these active extracts have not been repeatable, and hence have not provided a basis for further experimentation. However, after extensive work on the methods, reasonably consistent results began to be obtained early in 1962.

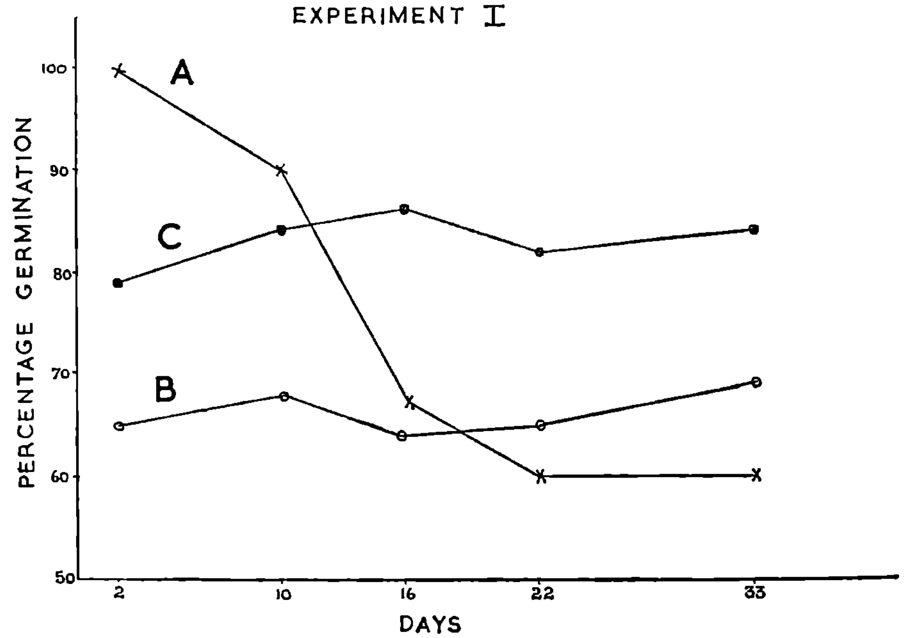

FIGURE 3. Experiment I.

A — Germination of test spores in extract of a forest soil 'fed' with one large initial dose of spores of the test fungus (*Mucor ramannianus*).

B — Germination in extract of untreated sample of the same soil.

C — Control; germination in conductivity-water.

Spore-feeding Experiments

Figures 3–5 show the results obtained with a forest soil, mineral layer under spruce, Marian y Winllan, North Wales, which had shown the most consistent record of mycostatic effect during the germination survey (1957–60). For each experiment one collection of the soil was sieved, air-dried, and kept for three weeks to attain equilibrium before the first extract was made, after which it was kept moist with conductivity water in air until subsequent extracts were made by the standard method described earlier. For each experiment the graph B represents the percentage germination of test spores of *Mucor ramannianus* inoculated in the sterile filtered soil extract on to a washed agar disc. The graph C represents the control germination of spores inoculated in conductivity water. In experi-

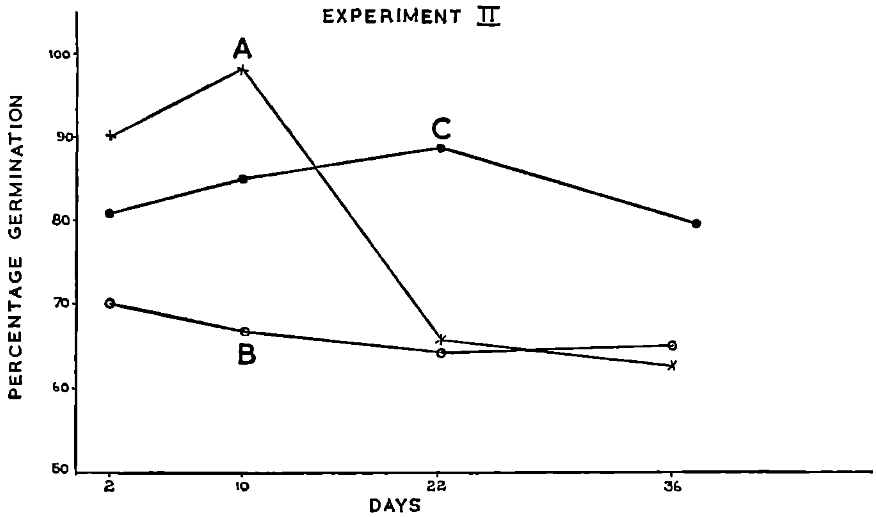

FIGURE 4. Experiment II.
A, B, and C as in Experiment I, except that in A the spore-dose was one-third the size.

ment I (Fig. 3) for instance, the average germination for the extract was 66 per cent as compared with 84 per cent for the controls. The results from later collections of the same soil, as seen in Figures 4 and 5, were closely similar, with a range of variation for all three experiments of only 64 to 70 per cent germination. The controls showed a somewhat greater variation (79–89 per cent).

In all three experiments the difference between B and C was significant; in experiments I and II at the 1 per cent level, in experiment III at the 5 per cent level, approaching the 1 per cent level.

The graph A, in each Figure, represents the effect upon the germination of test spores of extracts from the same soil 'fed' with spores of *Mucor ramannianus*. In Experiment I (Fig. 3) the soil sample was given a single massive initial dose consisting of the spores collected from eight 10 cm. petri dish cultures, in suspension in conductivity water. The graph shows a strong initial stimulus to germination, followed by a falling-off which reaches a minimum significantly below the level for untreated soil extract on the 22nd day, and remains at the same level on the 33rd day. The difference between the last two A values, tested against all five B values in experiment I, was significant at the 5 per cent level.

In Experiment II (Fig. 4) the initial dose of spores was about one-third the size of that in Experiment I, the maximum stimulus was not reached until the second test on the 10th day, and the final minimum on and after the 22nd day is not significantly different from that for the untreated soil extract. The spores in these two experiments were collected from the surface of malt agar cultures without subsequent washing, and the early stimulus to germination can be attributed mainly to nutrients added to the soil with the suspension.

In Experiment III a different procedure was adopted. The spores used were twice washed by centrifuging down in conductivity water, to remove superficial nutrients, and were then fed into the soil sample at three-day intervals, starting with the second day, and in very much smaller doses, each amounting to less than one-twelfth of the initial dose given in Experiment II. The results are seen in Fig. 5, graph A, and show a consistently lower level of germination than that

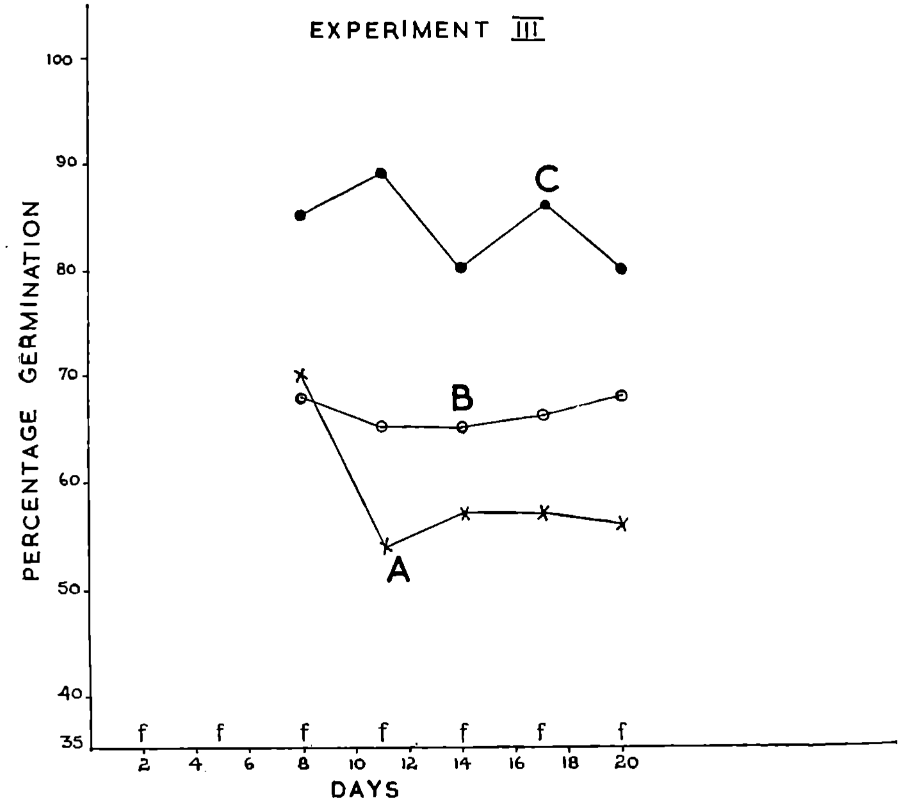

FIGURE 5. Experiment III.
A, B, and C as in Experiment I, except that in A the spores were washed, the spore-dose was very small, and was repeated at three-day intervals on the days marked 'f'.

given by the untreated soil extract from the eleventh day onwards. This difference was significant at the 1 per cent level. Even at the conclusion of the Experiment the soil had received less than half the spore-dose given in Experiment II. The background and interpretation of these experiments will be discussed in the next section. Thanks are due to Mr. Duncan H. Stewart, of the Forestry Commission Research Branch Statistics Section, for the tests of significance referred to above.

The Nature of the Widespread Soil Mycostasis

Evidence for Microbial Origin

As with all other methods of soil study, it is impossible to carry out any investigation without some disturbance of the soil, so that the evidence provided by such experiments as to what occurs in the natural soil, is necessarily circumstantial. In particular, it should be made clear that no suggestion has ever been made that these laboratory tests with soluble substances diffusing from incubated soils through Cellophane or other filter-membranes provide evidence that the inhibitor was present to the same extent in the undisturbed soil at the time of collection.

At the time of our original announcement of the discovery of "A Widespread Fungistasis in Soils" (Dobbs and Hinson 1953) there were already several indications suggesting that the phenomenon was of microbial origin: notably, its absence from deep, sterile subsoils, its destruction by lethal temperatures and chemicals, and its non-removal by leaching. Since, however, its exact nature was uncertain, and almost certainly complex, the phenomenon was described in deliberately cautious and general terms, designed to cover all possibilities: "The indications of the work at Bangor are that there exists in the soil a widespread fungistatic factor."

This cautious wording was justified by later work (*Report on Forest Research* for 1958) which distinguished a permanent, thermostable inhibition present in certain calcareous soils from the generally distributed, unstable inhibition; but unfortunately it seems to have been interpreted by certain authors, notably by Lingappa and Lockwood (1961), as implying a widespread, permanent reserve of inhibitory substance in the soil, an untenable hypothesis which they proceeded to disprove in their paper on "The Nature of the Widespread Soil Fungistasis".

As soon as the unstable nature of the inhibitory substances concerned became clear, it was realised that there could be no such reserve of these in the soil solution, but that they must be currently produced by soil organisms. To quote W. H. Hinson (1954):

> "The inhibitor is soluble in water though unstable in solution, but soil leached with water still inhibits spores in film tests; this suggests continuous production, and contra-indicates a stable organic residue."

After discussing and eliminating fungal activity as a probable source he continued:

> "It might be speculated that the inhibitor is more likely to be of bacterial (or actinomycete) than fungal origin."

These early speculations have been borne out by subsequent work at Bangor and elsewhere. In the *Report* for 1958 mention was made of the difficulty of separating the inhibitor from bacterial infection, and in a paper read the same year at the International Symposium on the Ecology of Soil Fungi at Liverpool (Dobbs, Hinson and Bywater, 1960) it was stated that:

> "The inhibitory effect has been shown to travel up filter paper from wet soil, in company with bacteria from which it has not been found possible to separate it, except by the unsatisfactory method of Seitz filtering."

Also observed was a patchy inhibition of test spores on a Cellophane film floating upon water covering soil, associated with an accumulation of bacteria on the underside of the film. Subsequently, in 1958, Dr. Bywater observed a restoration of mycostasis in sterile washed sand exposed to atmospheric infection, and induced a similar restoration by mixing it with 1 per cent (v/v) of untreated soil or sand, the effect being accelerated by the addition of a trace of very weak bacterial nutrient to the sand. Dr. Alun Griffiths later isolated 7 strains of bacteria from such re-infected sand, of which only three, which were all Gram-negative rods, produced inhibitory effects on test spores when grown on agar (see *Report* for 1959).

The work of Park (1956) also showed that a bacterium (*Bacillus macerans*) isolated from soil could induce inhibitory effects on fungal spores, and that of Stevenson (1956) and Lockwood (1959) that similar effects could be produced by actinomycetes. Keer (1961) has shown that a number of strains of *Pseudomonas* and *Streptomyces* spp. isolated from tomato root-surfaces could produce inhibitory zones in the growth of *Verticillium albo-atrum*.

Lingappa and Lockwood (1961) noticed the proliferation of bacteria and actinomycetes on the surfaces of materials such as Cellophane and agar used in tests for soil mycostasis, and further confirmed the conclusion that these organisms were responsible for the inhibitory effect, by showing that the amount of soil present was immaterial, that agar discs incubated on soil at a temperature (1°C), too low for most microbial growth, did not become mycostatic, and that the mycostasis could be reduced by high concentrations of antibacterial antibiotics. At the same time these workers made a number of soil extracts by extracting with various organic solvents, but found none of them to be inhibitory, except for an extract from lignin-like material.

Fungal Spores as Micro-substrates

Lingappa and Lockwood correctly draw the conclusion in their paper that indirect methods of testing with agar or Cellophane do not directly demonstrate the presence of mycostatic substances in natural soil, but only the presence of such substances in the assay materials which provide a substrate for the growth of micro-organisms. They describe these substances as 'antibiotics', but make no reference to the considerable discussion which has taken place on the question (e.g. at the Liverpool Symposium on the Ecology of Soil Fungi in 1958) or to the instability characteristic of such substances when obtained in water extracts. They dismiss as "usually inconclusive" all other reports of mycostatic soil extracts and diffusates except for their own extraction from lignin-like material. On the other hand, they have further confirmed, by their own observations on the failure of spores to germinate in soils, the reality of the phenomenon of soil mycostasis, and suggest that the mode of action of indirect assay methods may provide some insight into its mechanism. Their most valuable contribution is the speculation, supported by some preliminary work with alcohol-extracts of spores of the maize smut (*Ustilago zeae*), that the spores themselves may act as microsubstrates in the soil, liberating sufficient nutrient to stimulate the growth of inhibitory micro-organisms around them.

The results of our spore-feeding experiments, described above, and especially of Experiment III, though far from conclusive, provide some more direct evidence in favour of this suggestion. A possible alternative explanation could be that the spores themselves, which can be observed to exert some mutual inhibition when collected together in masses, might be responsible for the increased inhibition exhibited by the soil extracts in Experiments I and III; but this seems improbable in view of the fact that by far the strongest effect was obtained with the smallest spore-dose in Experiment III, in which the spores were fed in at intervals—a technique regularly used to stimulate the growth of antagonists. Moreover, some unpublished observations at Bangor by Mr. M. J. Gash, have shown no inhibitory effects when uninfected spores of *Mucor ramannianus* are placed in sterile washed sand.

The most tenable explanation would therefore seem to be that, under these conditions in which the growth of inhibitor-producing organisms is already sufficient to render the extract inhibitory, the periodic addition of spores of the test species is capable of stimulating it further.

The extent to which the individual spore in the soil develops its own 'sporosphere' of inhibitory organisms is unknown, and could be determined only by direct microscopic examination. The observations of Hinson (Dobbs and Hinson, 1960) and of Miss M. G. Hay (now Mrs. D. J. Anderson) at Bangor in 1960 (unpublished) show that most soil-spores when precipitated from suspension are obscured by mineral or organic matter. Culture-spores after being buried in soil and recovered, after being subjected to soil mycostasis, do not, in general, exhibit any noticeable zone of bacterial or other microbial infection or growth. Even empty and decomposing conidia of *Penicillium frequentans* and two other fungi when placed directly on soil, did not reveal any detectable growth of micro-organisms to Lingappa and Lockwood (1961), while their alcohol-washings of smut spores, when evaporated down and assayed against soil organisms, exhibited a zone of inhibition within the zone of stimulated growth.

In general, therefore, there is so far no evidence that soil mycostasis is occasioned, to any large degree, by the proliferation of inhibitory organisms on the actual spore surface, but there is some evidence to suggest that fresh spores may stimulate the growth of such organisms in their vicinity, with the production of diffusible inhibitors in the soil solution. That micro-organisms can exert chemical influences in the soil, at distances which are enormous, relative to their size, has been pointed out by Burges (1960).

That diffusible inhibitors, probably produced mainly by soil bacteria and actinomycetes, are present in the soil solution whenever other conditions would permit the germination of fungal spores, seems to be an inescapable conclusion, not only from the failure of spores to germinate in soil, but from their germination in condensed water within the general soil environment when they have been removed by animals from contact with the soil mass and the soil solution, and deposited in a glass slide-trap (Dobbs and Hinson, 1960). While many of the colonies on the glass could be traced to naked spores, others arose from small soil particles (Hinson, 1954). It is not therefore the presence of soil-material and micro-organisms which causes mycostasis when these are removed from the soil-solution. It has also been noticed (Dobbs, 1960) that there is a minimum size to soil-masses which can exert mycostasis, and that small soil-crumbs projecting from a mycostatic mass lack this property (Dobbs, Hinson and Bywater, 1960).

Cellophane as a Test Material

Lingappa and Lockwood have performed a service in drawing critical attention to the important changes introduced with the use of assay materials, which may induce a selective growth of micro-organisms, but most of their work was done with water agar, a material which we discarded at the outset for soil-testing as being too stimulatory to growth (Dobbs, Hinson and Bywater, 1960).

As regards Cellophane, their only evidence consists of observations, with a photograph, of bacteria proliferating against its surface, without proof that the Cellophane had become mycostatic in the absence of test spores, or that if so it was by exerting a selective stimulation on the bacteria which produce fungal inhibitors. One reason why we have preferred to use Cellophane for soil-tests has been that, as a nutrient, it can supply only pure carbohydrate which, so far as we know, will reduce rather than exaggerate the mycostatic effect, though it is possible that this is not true of the minute quantities required by bacteria. On occasions when the sweet plasticising dressing (which is understood to be glycol) has been incompletely removed from the Cellophane, the result has been a massive proliferation of bacteria, accompanied by a breakdown of mycostasis. Furthermore, the extensive observations of Tribe (1957), on the colonizers of Cellophane buried in soils, have shown that fungi nearly always precede bacteria. He states that (Tribe, 1960): "Bacteria which directly decompose cellulose contribute little to its breakdown during the early stages before fungal action."

During the two-day period of the mycostasis test we have not detected signs of etching or attack upon Cellophane surface.

At the same time, it is well known that surfaces encourage bacterial proliferation, and cellulose film undoubtedly does this. So also must many surfaces in the soil, both mineral and organic. Mycostasis has been demonstrated with pipe clay and sintered glass (Hinson, 1954) as well as with Cellophane and agar, but it is impossible to do so with any assay material unless the soil is wet enough for the soil solution to reach the spores, just as it is impossible to demonstrate mycostasis in the soil-mass unless this is moist enough to support germination. Wetting the soil and covering it with a membrane may have some differential effect on the organisms which develop, by reducing the aeration at the surface to something more comparable to that within the moist soil mass; but unless the assay material exerts a strong selective nutrient or other chemical effect, there is no reason to suppose that the organisms which grow upon its surface in the presence of the test spores are substantially different from those which would grow in the natural soil. It may be that water agar has some such distorting effect, due both to its bulk and its nutrient properties. That well-washed and autoclaved precipitated cellulose film exerts some nutrient effect can be seen after four or five days on the soil when the first signs of attack appear. Before that time it is always possible that some trace of nutrient becomes available, but the physical properties of the surface would account for some bacterial proliferation, while if nutrient stimulus is immediately obvious, this is more likely to be due to the imperfect removal of plasticisers.

This question of the nutrient properties of Cellophane and other possible assay materials was carefully gone into in 1957 by Dr. Joan Bywater (Mrs. Daniels), before we standardised our germination tests with the use of British Cellophane Ltd.'s PT 300 film as the most useful material. Until some better method is devised, the cellulose film test provides the most convenient means of assessing certain properties of soils in relation to the germination of fungal spores when limitations of temperature and moisture have been removed. It places the spores as nearly in contact with the soil and its micro-organisms as is feasible if the results are to be fully observed, and interposes as slight a barrier as is possible to interactions between them. If in fact spore-nutrients do influence the microbial population in the soil, so also are they likely to diffuse through the 20 mμ thickness of the Cellophane film from the massive spore smear on its upper surface and influence the microbial population on its lower surface. If mycostatic organisms have already been selected, additional nutrient from the cellulose, or from the culture medium if unwashed spores are used, would only accentuate the effect. If they have not, the stimulation of a mixed soil population ought not to have any differential effect.

Conclusion

The cellulose film test demonstrates a phenomenon which is confirmed by other, less convenient, methods, including direct observation of buried and recovered spores and soil-spores. As with all experimental methods it is open to the criticism that the evidence it provides concerning natural events is circumstantial; but until there is evidence to the contrary it seems reasonable to assume that the agencies which inhibit spore germination on a sterile washed cellulose film freshly placed on or in the soil are not substantially different from those which produce the same effect in the soil in the absence of such a film.

The method has marked limitations but has been useful in a number of ways. It has been used to demonstrate the universality of mycostasis in surface soils and its absence or reduction in sub-soils, its sensitiveness to heat and toxins and its biological origin, its reaction to sugars and seasonal variation and differences in different sites and soil-layers, and the existence of more stable types of non-biological inhibition in certain soils.

Its use has also drawn attention to the existence and important biological effects of free-reducing sugars in forest soils, as reported in our third, fourth and fifth Studies, published in *Reports on Forest Research* for 1959, 1960 and 1961, respectively. It is of interest that B. R. Nagar (1962) has now found monosaccharides in four widely different soils in America.

The far more tricky and laborious method of making sterile filtered water extracts of the unstable inhibitor has nevertheless yielded some limited provisional information concerning its properties: its sensitiveness to heat and to oxygen, as distinct from that of the organisms which produce it. Since the word 'inhibitor' may cover a complex of substances, a massive repetition of this work is required to confirm and extend these results, but this is at present beyond our resources. The work of Stover (1958) however provides additional evidence of the heat sensitivity and bacterial origin of the inhibitor and of its masking by dextrose and other organic nutrients.

We also know that it has a relatively small molecule-size, since the inhibition has been shown to pass a Membrane-filter of pore-size 5 mμ. According to the makers, the pore-size of wet Cellophane is usually quoted as about 20 Å (=2mμ). But this aspect of the work, as well as the urgent development of the study of soil sugars, would be more effectively carried on by trained biochemists rather than forest botanists.

A bacteriological study is even more necessary now that we know that some mycostasis, at any rate, can be attributed to soil bacteria and probably actinomycetes. While the antibiotic effects of fungi upon bacteria have received vast attention owing to their medical importance, the effects of bacteria upon fungi have been largely neglected. One effect of the discovery and study given to soil mycostasis has been to direct attention to these reciprocal relationships and to their ecological importance in the soil. From a forestry point of view there is a particular need for studies of the influence of these mycostatic organisms upon litter decomposers, rhizosphere organisms including mycorrhiza-formers, and root pathogens such as *Fomes annosus* and *Rhizina undulata.*

It has long been certain that this kind of unstable, microbially-produced inhibitor (or, probably, complex of inhibitors) can be present in the soil only under conditions which permit of microbial activity. It can become the limiting factor in preventing fungal germination and growth only under conditions of temperature, moisture and aeration which would otherwise permit of such growth, and in the absence of sufficient sugars (or certain other organic nutrients) to mask the inhibition.

In moist temperate climates these conditions probably exist in most soils over the greater part of the year, in drier or colder climates for a smaller part; but whatever the soil or climate these micro-organisms, which appear to be universally present in surface soils, might be expected to become active before fungal germination could start. In this way they may be an important factor in limiting fungal growth to suitable nutrient substrates which will provide for sporing and reproduction. Susceptibility to the inhibition is likely to be of survival value to soil inhabitants, and may possibly be a factor in determining competitive saprophytic ability.

It is obvious that a great deal more work is needed on this complex phenomenon, and that no investigation of the growth of fungi in the soil environment can ignore its existence.

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HYDROLOGICAL RELATIONS OF FOREST STANDS

By L. LEYTON and E. R. C. REYNOLDS
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Investigations continue into the different phases of the hydrological cycle in a pole-stage plantation of Norway spruce, namely, precipitation incident on the canopy, interception and throughfall (including stem flow), soil moisture status, evaporation from the forest floor and transpiration of the trees.

Records have been kept of the catches of different types of rain gauge mounted above and at canopy level, and in a nearby open space; six of the above canopy gauges were fitted with Alter shields and two with 60 degree complete Nipher shields. Evidence of short term differences between the precipitation over the stand, and that in the nearby open space, confirms the need for measurements over the canopy itself. An attempt has been made to identify the most promising type of gauge for these measurements by analysing the relative catches of the various types in terms of those factors which might be expected to contribute to the observed differences in catch, e.g. wind speed and direction, air temperature, humidity etc. Regression analyses have confirmed that a proportion of the observed variation could be significantly related to some of these factors, implying that differences in catch can be attributed, at least partially, to particular gauge characteristics, and not entirely to random factors, e.g. siting. The results obtained so far suggest that the Nipher shielded gauges are preferable to the other designs tested; further comparisons are now being made with 45 degree and 60 degree Billwiller-type Nipher gauges kindly loaned by Mr. F. Law of the Fylde Water Board. However, in the absence of an absolute measurement of precipitation over the stand, it would appear that this comparative approach, though providing useful guidance on relative gauge performance, is limited, and that more research may be necessary on gauge behaviour under controlled conditions before the problem can be satisfactorily solved.

Substantial progress has been made in the development of a technique for the routine measurement of the transpiration of trees by determining the flux of sap in the stem, using a modified thermoelectric method. A narrow section of the stem is heated for a few seconds by radio-frequency power from a transmitter (conventional Diathermy equipment), through electrodes mounted around the stem. A short distance above the electrodes, a large number of copper-Eureka thermocouples (40–50) are inserted around the stem, just below the bark; the couples are connected in series with alternate junctions separated vertically by a few centimetres of stem. Temperature differences between the two rows of junctions, which result from the passage of heated sap up the stem, are followed with a recording microvoltmeter, and a function of the sap flux determined from the nature of the recorder trace. Apparatus has been constructed which allows six trees in the field to be measured automatically in rapid succession at set intervals during the day and night. Preliminary experiments have begun on calibrating the method in terms of absolute water loss, by enclosing the entire crown in a polythene bag and determining the gain in moisture of air blown through the bag.

With the arrival of Mr. K. F. Wells, a post-graduate student from Australia, plans have now been put in hand to investigate, in some detail, the fate of precipitation intercepted by the foliage and branches of trees, and the effect of this on the water-balance of the forest. Other new investigations which have been initiated during the year include a study of the factors responsible for the large differences in stem flow observed between different trees of the same species and between trees of different species—Norway spruce, larch and beech. The results will be published in due course.

In all the work carried out during the year, the assistance of Mr. A. E. Ogden is acknowledged.

SHELTERBELT RESEARCH

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Introduction

The third three-year phase of the research project on shelterbelts, due to expire in September 1961, was extended by a further three months to enable Mr. R. Baltaxe to complete the analysis of his work. This report therefore covers the period April to December 1961.

As stated in earlier reports, this phase of the research programme was intended to investigate the seasonal variation in the shelter afforded by belts of deciduous, or mixed deciduous and coniferous, trees. Subsequently, and as a direct result of studying the implications of such seasonal change, it was evident that a knowledge of the variation in shelter effect due to changing wind conditions was of fundamental importance to this approach. In the past it has been generally accepted that, in practice, the main features of the shelter pattern and, hence, air flow characteristics, remain the same for winds between 5 and 25 miles per hour. The nature of turbulence and its presumed effect on the shelter afforded by windbreaks had, however, been pointed out by Bodrov (1936). More recently, various studies have pointed to the profound changes wrought in shelter patterns by variations in atmospheric stability; these have been summarised by Baltaxe (1961). In view of the fact that such variations clearly prejudice the value of short-term observations of wind conditions, as commonly used to assess windbreak behaviour, it was decided to investigate the question of turbulence in the vicinity of model windbreaks in the wind-tunnel and near barriers under field conditions.

A brief report of the wind-tunnel investigations was incorporated in last year's Report (*Rep. For. Res. For. Comm.*, Lond. 1961) and pointed to the fact that, when shelter effect is being considered, measurements of the mean horizontal velocities alone may be seriously misleading.

It was also pointed out in the last *Report* that investigations of the air flow pattern in the vicinity of windbreaks in the field are a necessary complement to wind tunnel experiments, owing to the difficulty of reproducing turbulent conditions in the air stream similar to those obtaining outdoors. Because of the difficulty of locating suitable shelterbelts in the field for this purpose, it was decided to construct small-scale windbreaks of living material for these investigations, the advantage being that this allowed maximum control of the many variables involved, whilst being more representative of actual shelterbelts than is possible using the artificial screens favoured by many other workers for windbreak studies.

In addition to further developments in instrumentation during this period, the investigations undertaken with these model shelterbelts formed the major part of the research since April 1961.

Instrumentation

In order to overcome the problem created by shortage of assistance in the field, and to reduce the error involved in reading a control anemometer set some distance away from other instruments, the control instrument was converted to continuous automatic recording. This conversion of a counter-reading Sensitive Type IV Anemometer (Casella) made a contact every ten units and moved a paper ribbon 0·8 mm. each time; it was coupled with a stop-watch modified to activate a pen every minute. A second pen was connected with a bell-push button, remotely controlled so as to mark the beginning and end of the desired measuring period. This instrument was found to facilitate wind studies considerably.

Normal counter-reading anemometers were employed for the study of wind conditions near the model shelterbelts mentioned above. These were mounted in vertical banks of three, to record the wind at three heights above the ground. Changes in wind direction were observed by means of a specially designed vane at the control position. When this registered a deviation from the normal of more than 30 degrees, velocity measurements could be discarded. Since deviations of more than 90 degrees were of no interest in this context, construction of the recorder was greatly simplified.

A bi-directional vane was also made to observe the relative magnitude of vertical and horizontal fluctuations of the wind and was used in the later stages of the investigations. This gave a continuous record but, quantitatively, the records from the two vanes were not comparable since the instrument had not been calibrated.

Velocities were measured at 22, 44 and 66 in. above the ground, and at 1, 2, 3 4, 5, 7, 10 and 15 'heights' (that is: distances equal to the height of the barrier) to leeward of the barriers. When circumstances allowed, measurements were also made at 1, 2 and 3 'heights' on the windward side, in addition to the control station at 20 'heights' windward. The length of the observation run was 10 or 15 minutes, which had been found to be satisfactory.

Field Experiments

Experiments with artificial shelterbelts were conducted at Turnhouse Airport, near Edinburgh, where a site was made available for three months. The belts constructed were 112 ft. in length, 77 in. in height with a maximum width of 18 to 24 in. The material consisted of fresh Scots pine tops, which were replaced at monthly intervals, supported between several lengths of rope fixed to posts, which in turn were guyed to give a firm barrier. Four different densities were involved, from open to very dense.

The results showed that the leeward velocity curves of the windbreaks varied at least as much with changing atmospheric stability as with the permeability of the windbreaks. It was found that in the lee of a windbreak of constant permeability, variations in the velocity curve were systematically related to changes in the vertical velocity gradient of the incident wind. The vertical velocity gradients were themselves systematically related to the thermal stratification of the air, in the manner described by Deacon (1953). Over the same surface, changes in the vertical velocity gradient reflected net changes in atmospheric turbulence due to the interaction between the buoyancy and speed of the wind.

The Turnhouse results give some indication of the systematic nature of these changes for a range of stabilities, and show that these may be directly related to a parameter calculated from the ratio between velocity differences at 66 and 44 in. and those at 44 and 22 in. The windward velocities clearly show that in stable conditions the deflection of the incident wind due to the shelterbelt is less than in near-neutral conditions. Changes in the leeward velocity curves show that with increasing instability and turbulence the relative velocities are higher and the minimum of the curves moves further downstream. It appears, therefore, that increasing turbulence reduces the effect of a shelterbelt. This follows from the mixing action of turbulence.

The effect of changing stability was found to be greater with open than with dense barriers, which confirmed the wind-tunnel suggestions that the air flow behind a dense barrier is determined by the barrier itself to a much greater extent than is the case with an open barrier. The records also showed that fluctuations of velocity in the lee of a shelterbelt are at many points considerably higher than those encountered in the open. How accurate an indication of potential shelter effect is obtained from cup anemometers, therefore, still remains to be determined.

It can be concluded from the results that the turbulence of the incident wind is of paramount importance in determining the leeward shelter pattern. The anomalous results concerning the effect of shelterbelts on wind speed reduction, especially in relation to variations in the incident wind speed, which abound in the literature (Baltaxe, 1961), are probably largely explicable by neglect of the effects of changing atmospheric stability in the investigations concerned. The level of turbulence is clearly important in determining the similarity of experimental conditions in shelter studies and this total turbulence can be readily assessed by measuring the velocity profile of the free wind at three heights above ground; over a short grass cover these heights may be as low as 22, 44 and 66 in.

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RESEARCH ON FOREST FIRES

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Since fire spreads as a result of the burning fuel heating other neighbouring fuel to ignition, it is important to be able to estimate the total heat transfer ahead of a fire, i.e. the sum of radiative and convective transfer from the flames and hot gases above the fuel, and radiative and convective transfer through the interstices between fuel elements.

Flame Length

It is clear that the radiative and convective transfer from flames will depend on the size, shape, orientation and intensity of the flames. In the *Report on Forest Research*, 1961, experiments were described to measure the length and maximum height of flames from stationary fires, representing instantaneously the moving burning zone in a fire spreading on a wide front. The equation given then may be conveniently rewritten as:

$$L\left(\frac{g\rho_0^2}{m^2}\right)^{\frac{1}{3}}=70\left(\frac{u\rho_0^{\frac{1}{3}}}{m^{\frac{1}{3}}g^{\frac{1}{3}}}\right)^{-0\cdot21}\left(\frac{m^2}{g\rho_0^2D^3}\right)^{0\cdot06} \quad \ldots\ldots\ldots (1)$$

where ρ_0 has been taken as $1\cdot3 \times 10^{-3}$ g/cc,
g is gravitational acceleration,
D is the length of the burning zone in the direction of fire spread,
u is the wind speed,
and m is the rate of burning, i.e. the rate of mass loss per unit length of fire front.

The index of the factor involving D on the right-hand side of equation (1) is significant, so that the flame length L is a function of D as well as of m. However, if $L\left(\frac{g\rho_0^2}{m^2}\right)^{\frac{1}{3}}$ is denoted by L' and $\left(\frac{u\rho_0^{\frac{1}{3}}}{m^{\frac{1}{3}}g^{\frac{1}{3}}}\right)$ by u', it is possible to plot $L'u'^{0\cdot21}$ against D^3/m^2 linearly and to extrapolate to a value of $L'u'^{0\cdot21}$ corresponding to zero value of D, i.e. a line fire. This limiting value of $L'u'^{0\cdot21}$ is given by

$L'u'^{0 \cdot 21}=55\pm5$, and can be used to predict the flame length with little loss of accuracy provided the value of D does not exceed $20m^{\frac{2}{3}}$ (where m is in lb. ft.$^{-1}$ sec^{-1} and D is in feet). For these conditions the value of L′ (dimensionless) obtained in this way for a line source has been plotted in Figure 6, together with the limiting value of L′ for still air. This approximation for L′, and hence L, in terms of m, is important in that m is given by the product of the mass of fuel (less residue) per unit area of ground and the speed of spread, and so long as D is small it need not be known.

Flame Height

Measurements of the maximum height of flames above the level of the fuel bed have also been made and the results found to correlate approximately as

$$H\left(\frac{g\rho_0^2}{m^2}\right)^{\frac{1}{3}}=38\left(\frac{u\rho_0^{\frac{1}{3}}}{m^{\frac{1}{3}}g^{\frac{1}{3}}}\right)^{-0 \cdot 69} \qquad \ldots\ldots\ldots\ldots\ldots(2)$$

If $H\left(\frac{g\rho_0^2}{m^2}\right)^{\frac{1}{3}}$ is expressed by H′ (as in the case of the flame length L) H′ may be plotted as a function of u′ and this has been done in Figure 6.

During the year an analysis has been made of the results of Yokoi (1960), Hunter Rouse, Yih and Humphreys (1952), who performed experiments on convective heat sources in still air, and of those of Rankine (1950) for experiments with a wind. Yokoi used his own data to estimate flame length by regarding the distance to the point at which the temperature had fallen to 500°C as the flame length, and a similar procedure with these other data gave values approximating to the direct measurements referred to above. Rankine's data underestimate the flame height, but it is thought that they may be used to evaluate the convective heating downwind.

Heat Transfer through Fuel Bed

Heat transfer through the fuel bed is in some cases highly important, and is presumed to have been significant in preliminary experiments on the spread of fire through gorse and other bushes. Radiative transfer through the fuel obeys the same laws as the transmission of light, and optical experiments are in hand to relate this transmission to the fuel bed parameters.

Fire-Spread

A theoretical analysis has been made to relate the rate of spread of fire to the various components of heat transfer to fuel ahead of the fire. One of the simplest situations in which this theory might be tested is the spread of flames up a hanging fabric: some data are already available and are being supplemented by a short programme of work to measure the actual size of the burning zone by flash photography, as well as the flame length and the rate of spread.

Future Work

Also in progress are some experiments to study the effect of moisture on the length and height of flame and on the burning rate of wood, and further laboratory experiments are being planned to investigate the effect of moisture and other fuel parameters on the rate of fire spread, and to provide further tests of the theory.

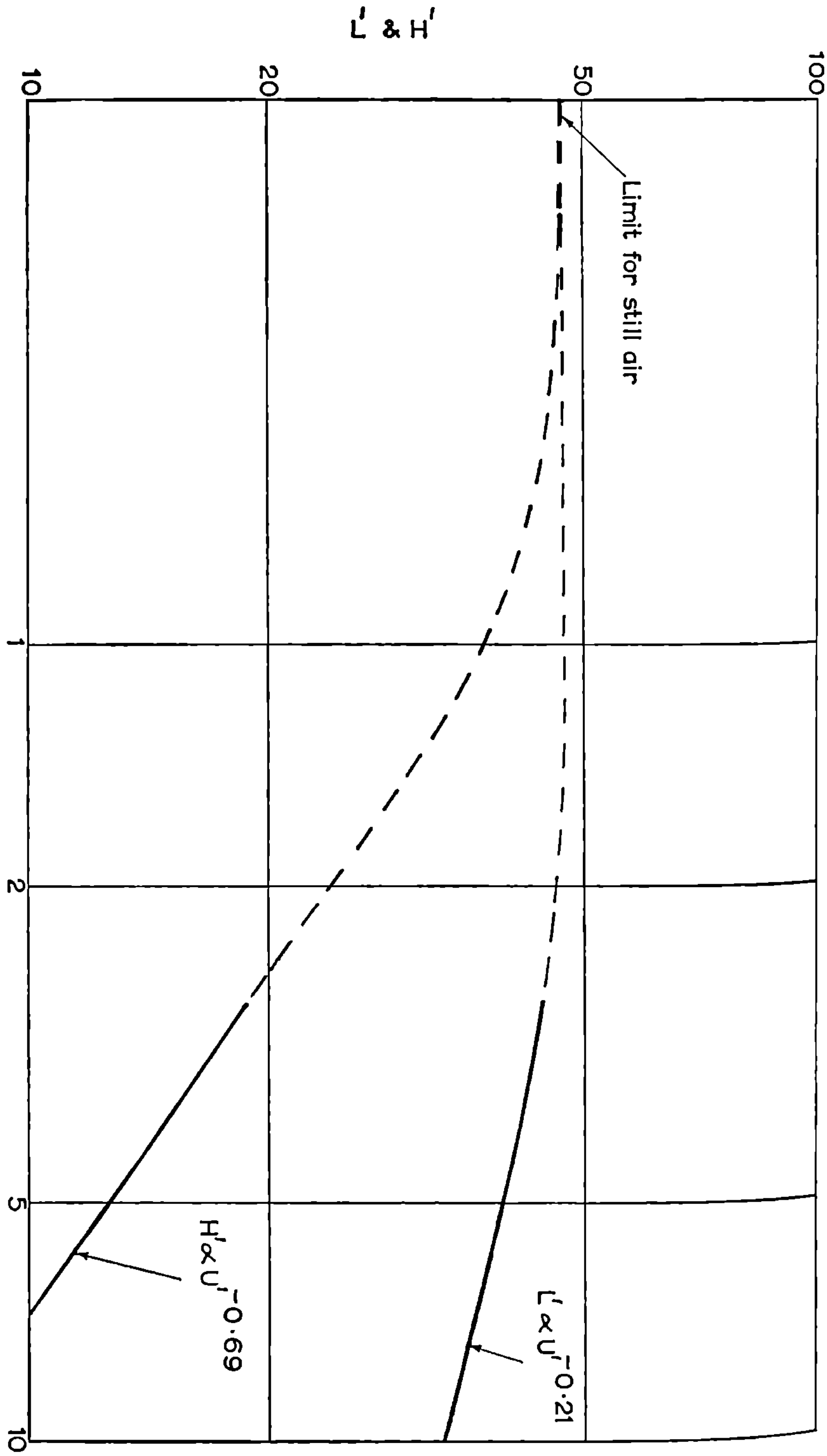

FIGURE 6. The effect of wind on the length and height of flames from a long narrow fire front.

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OAK POPULATION STUDIES IN SCOTLAND: PART II, DISTRIBUTION OF QUERCUS PETRAEA (MATT.) LIEBL. AND Q. ROBUR, L.

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Work on the variation in certain diagnostic characters of Pedunculate oak, *Quercus robur*, and Sessile oak, *Quercus petraea*, in Scotland continued with emphasis on variation within populations. This year's collections in the North-East, the Trossachs-Loch Lomond area, and the old Jed and Ettrick Forests, completed a well-dispersed pilot survey of Scottish semi-natural oakwoods. (See also *Rep. For. Res.* 1961).

Seven hundred and eighty specimens from 51 woods were added to the collections during the year (details in Table 17). The main effort was directed to woods of reputed *robur* affinity, but the results in terms of fertile *robur* specimens acquired were very disappointing. Flowering was not as general as in the exceptional years of 1959 and 1960. An impression was gained that a relatively small proportion of the types of *robur* affinity were fertile as compared with 50 to 70 per cent recorded as fertile among a number of collections of *petraea* affinity. A late frost occurred generally over Scotland in early June, and many peduncles and unripened shoots were killed.

Of the total of 1,420 Scottish collections, 940 fertile specimens were pressed, mounted, measured and recorded by the end of the year; priority was given to the population samples including *robur* forms which were needed to redress the imbalance in favour of *petraea* existing a year earlier. Sterile collections number well over 300 and the remaining unrecorded specimens are of *petraea* affinity.

Analysis of the data from the 940 fertile specimens revealed massive gene exchange among Scottish oaks, most clearly demonstrated by pictorialized scatter diagrams. Only 4 out of 54 population samples were without evidence of gene exchange; these were all of *Q. petraea* and they form the basis of the tentative definition of *Q. petraea* in Scotland in terms of the characters studied here. Twenty per cent of all fertile collections are diagnosed as *probable* good *petraea* and about 5 per cent as *possible* good *robur*. The remainder are of hybrid origin or show introgression in varying degrees. (See Cousens, *Scottish Forestry*, Vol. 16. No. 3, p. 170, 1962, for representative scatter diagrams.)

These data do not constitute a random sample of Scottish oaks: *Q. robur* forms are over-represented for 'semi-natural' woodland (defined by suitability of the site for oak and the absence of obvious evidence of planting) and possibly under-represented if the aggregate includes all plantations, hedgerow trees, etc.

The minimal sample size required to show the complete normal range of variation is about 20 fertile specimens for reasonably homogeneous woods, rising to over 50 for very heterogeneous woods. A systematic sample of 10 fertile specimens is adequate to demonstrate heterogeneity.

The implications of the botanical studies to date lend support to the hypothesis that *Q. petraea* may have been the sole indigenous oak, thus initially the survey will be confined to the location and description of mainly homogeneous *petraea* populations. These appear most likely to occur among woods of coppice origin but which have not been worked intensively. After standardising the descriptive technique with the known homogeneous populations a pilot survey of a suitable region will be carried out before extending the survey further.

Work on the species diagnosis problem will continue with collections in reputedly 'good' *Q. petraea* and *Q. robur* areas outside Scotland and more intensive study of the homogeneous populations discovered in Scotland.

Before theories as to how the present position has arisen can be confidently advanced, much more information is required on the fertility of the various forms of hybrid origin. The reciprocal interspecific cross needs repeating in Scotland and an assessment of the fertility of the F_1 hybrid and its backcrosses to both parents is required. Because of the irregularity of general fruiting of oaks, an investigation of this kind would have to be a long-term one.

PHYSIOLOGICAL STUDIES ON THE ROOTING OF CUTTINGS

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It is well-known that cuttings of many woody plants show a characteristic periodicity in their rooting ability, actively-growing ('softwood') cuttings frequently showing optimum rooting-ability in mid-summer, whereas dormant ('hardwood') cuttings are best taken in the autumn. Although there is a large body of empirical data on this subject, very little work has been carried out to determine the physiological basis of periodicity in rooting-ability. This periodicity might be due to either (a) seasonal changes in *environmental conditions* viz. light-intensity, daylength, temperature, etc., or (b) *endogenous changes* within the parent plant viz. whether the shoots are actively-growing or dormant, the state of dormancy of the buds, etc. It is well-known that growth hormones play an important role in root-initiation in cuttings, but very little attempt has been made to relate seasonal variations in rooting-ability to changes in endogenous hormone levels in the plant. A programme of work has therefore been undertaken to study the rooting ability of poplar cuttings throughout the year, in relation to various external and endogenous factors. The experiments have been carried out primarily with *Populus robusta*. Root primordia are present in the stem in the basal region of the current year's shoot and in older shoots of this species, but they are absent from tip cuttings, which were used in the experiments reported here.

Effect of Temperature and Disbudding During Rooting Period

An experiment was carried out with tip cuttings of *Populus robusta* to ascertain the effect of non-dormant buds on rooting-ability, at different temperatures.

Summarized Records of Scottish Oak Collections, 1961

O.S. Grid Square	Locality	No. of Specimens		Diagnosis Affinity	Hybrid Index*	Collections		Notes
		Tot.	Fertile			Month	By‡	
NH 2502	Loch Garry	20	16	petraea	1·6	Oct.	C	N. shore oakwood—rather open with birch
3710	Inchnacardoch	12	5	NR		,,	C	Remnant of old wood derived from coppice
3230	Kerrow Farm	15	—	robur	NR	,,	C	Riverside plantation—badly frosted—few normal leaves
4140	Erchless Estate	18	12	robur	2·1	,,	C	Planted policy wood
5240	Belladrum Estate	19	3	petraea	—	,,	C	Planted policy wood—seed stand—the best stems of *petraea* affinity.—an aff. *robur* margin
5522†	Errogie	5	3	NR		Sept.	M	Remnant of old wood—? planted
NJ 8263	Tore of Troup	17	13	mixed	p 1·2 r 1·6	Sept.	M	Remnant of old wood—mixed, planted
1963	Elgin	15	9	petraea	0·8	,,	M	? Coppice origin
6962	Montcoffer	9	3	mixed	—	,,	M	Remnant of a planted wood
1738	Scootmore	14	6	petraea	NR	Oct.	C	Remnant of a planted wood
6619	Tilliefourie	14	4	robur	—	,,	C	A planted wood
4918	Saplings of Logie	19	—	petraea	—	,,	C	High level coppice—over 1000 ft. a.s.l.
NN 9557	Black Spout	16	16	hybrid	2·9	June	C	Amenity wood of coppice origin
8359	Borenich	10	10	petraea	2·6	,,	C	? a planted wood—N. shore of Loch Tummel
7857	Kinardochy	3	3	petraea	—	,,	C	High level remnants with birch
9252	Grandtully	20	20	robur	2·6	,,	C	A planted wood—wide spacing
9751	Balnamuir	12	11	mixed	—	,,	C	? Coppice origin with stocking completed by planting
3402	Ptarmigan	50	30	petraea	1·7	July	MC	Old worked coppice, now singled and *c.*100 yrs. old
4410	Loch Katrine	18	16	hybrid	3·7	,,	MC	Old worked coppice, with some planting below, singled and over 100 yrs. old
3408†	Inversnaid	5	5	petraea	—	,,	MC	Wood derived from old coppice on steep slopes
3908†	Loch Arklet	1	1	petraea	—	,,	MC	Remnant tree among birch
4201	Stronmacnair	12	12	petraea	2·0	,,	MC	Remnant patch of oak (from coppice) L. Ard
5101†	Craigmore	10	10	petraea	—	,,	M	Selected aberrant forms in a petraea coppice wood
0909†	Inveraray	6	2	NR		Sept.	M	Planted policy wood
0811	Balantyre Wood	31	14	petraea	NR	,,	M	Coppice origin—specimens from windfall branches

Table 17—*continued*

Summarized Records of Scottish Oak Collections, 1961

O.S. Grid Square	Locality	No. of Specimens		Diagnosis Affinity	Hybrid Index*	Collections		Notes
		Tot.	Fertile			Month	By‡	
NO 0044†	Dunkeld	3	3	mixed	—	June	C	Ornamental boundary trees
0545	Cardney Estate	20	20	mixed	p 1·3 r 1·9	,,	C	? partly planted or all planted with mixed stock
1242	Goudie Wood	10	10	robur	2·0	,,	C	? planted—a policy wood near Goodie Ho.
4694†	Glen Tanar	2	1	petraea	—	Oct.	C	Self-sown oak in the Pine wood
4456†	Inchewan House	5	5	robur	—	,,	C	Ornamental trees near the house
4698	Dinnet	21	11	NR		,,	C	A planted wood with well developed ground flora
NS 4093	Strathcashell Pt.	18	18	hybrid	3·6	July	MC	A planted wood
3895	Salochie	25	12	petraea	3·2	,,	M	Coppice with standards origin. Standards sampled
3994†	Ardyle	4	4	NR		,,	MC	Miscellaneous collections
3695	Ross Wood	19	10	petraea	1·2	,,	MC	? a planted wood
4094	Cashell Burn Ravine	21	16	mixed	p 2·0 r 1·9	,,	MC	Self established oak
4699	Loch Ard For. (Viaduct)	17	12	petraea	1·9	,,	MC	Remnant patch of oak (coppice origin) near viaduct
4599	Loch Ard For. (Blairvaich)	19	18	petraea	2·1	,,	M	Coppice origin
4398	Loch Ard For. (Outliers)	8	7	hybrid	3·1	,,	M	Remnant individuals—some artificial origin?
5398†	Gartmore House	3	3	robur	—	,,	MC	Ornamental planted trees
NT 8240	Hirsel Estate	21	21	robur	2·0	July	C	Ornamental strip plantation
6911	Edgerstone Est.	36	31	petraea	0·7	,,	C	Reputed remnant of old Jedforest—derived from coppice
6426	Monteviot Estate A	15	13	robur	2·2	,,	C	A planted wood
6525†	Monteviot Estate B	5	4	robur	—	,,	C	A planted wood
3925	Fauldshope	15	11	petraea	1·0	,,	C	Reputed remnant old Ettrick For. on Bowhill Est. developed from coppice
4228	Bowhill Estate	10	10	robur	2·0	,,	C	A planted wood
6519†	Jedburgh	1	1	petraea	—	,,	C	Reputed remnant of Jed forest—the Capon Oak

Table 17—*continued.*

Summarized Records of Scottish Oak Collections, 1961

O.S. Grid Square	Locality	No. of Specimens		Diagnosis Affinity	Hybrid Index*	Collections		Notes
		Tot.	Fertile			Month	By‡	
NY 2474	Springkell Estate A	34	20	robur	2·8	Sept.	C	A planted wood
2574	Springkell Estate B	10	3	NR		,,	C	A planted wood including Plus tree Oaks
1275	Kirkwood Estate	45	15	hybrid	3·9	,,	C	A planted wood between House and River Annan
1589	Dryfie Birn	22	21	hybrid	3·1	,,	C	A planted wood now open and grazed

Note 1: * Total number of degrees of difference from theoretical *petraea* or *robur* in the sample, divided by the no. of specimens. A population dominated by hybrids should have an index between 3·0 and 4·0.

‡ C=Cousens M=Malcolm.

NR Specimens not yet recorded.

† Not taken as a population sample—others may not qualify because of inadequate fertile specimens etc.

Note 2: As a guide to the location of the areas investigated, the Ordnance Survey (O.S.) National Grid Squares referred to above, involve the following geographical districts:

NH Easter Ross; North East Inverness-shire, and Nairn.
NJ Moray; Banff, and Northern Aberdeenshire.
NN South East Inverness-shire; North East Argyll; and Western Perthshire.
NO Southern Aberdeenshire; Eastern Perthshire; Kincardine; Angus; North East Fife; and Kinross.
NS South East Argyll; Dunbarton; Clackmannan; Stirling; Renfrew; Lanark; Ayr and Bute.
NT South West Fife; The Lothians; Peebles; Selkirk; Berwick and Roxburgh.
NY Dumfries.

It was designed to study whether the presence of buds has a stimulatory effect on rooting, even at temperatures which do not permit bud-growth. The cuttings were taken at the end of February from stooled plants which had received natural winter-chilling, so that the dormancy of the buds had been terminated. The cuttings were divided into four equal series, which were planted in a mixture of peat and sand (1:1), and maintained at temperatures of 5°, 10°, 15° and 20°C. Half the cuttings at each temperature were disbudded and the remainder were allowed to remain intact. It was found that very little rooting occurred in the disbudded series at any of the temperatures. The buds of the intact cuttings maintained at 10°, 15° and 20°C expanded, and abundant roots were formed at these temperatures, the optimum being at 15°C. At 5°C the buds remained dormant and there was no rooting. These results indicate that the presence of expanding buds has a marked stimulatory effect on root-initiation, whereas in the absence of buds, or at temperatures which do not permit bud-growth, rooting is greatly reduced.

Effect of Pre-treatment at Different Temperatures and Bud Dormancy on Rooting

A further experiment with hardwood cuttings, involving different temperature regimes, was carried out with *Populus robusta* in the winter of 1961–62. The objects of the experiment were to determine (1) the effects of chilling temperatures, to remove bud dormancy, and (2) the effect of different temperature regimes before the chilling periods. The cuttings, 11 in. in length, were taken in October 1961, and divided into 3 series, which were planted and subjected to one of three different temperatures viz. 3·5°, 8° and 15°C for the first phase, which lasted 9 weeks. After this initial treatment, each of the three main series was subdivided into two equal groups, which were subjected to either 3·5° or 12°C for 8 weeks, respectively. At the end of this period the groups maintained at 3·5°C were exposed to warm conditions for a further period of 8 weeks, to encourage rooting. At the end of these treatments the rooting response was determined and the results are summarised in Table 18. Each group included cuttings from the terminal, sub-terminal and basal regions of the original shoots, and rooting was recorded separately for each type of cutting.

Table 18

Rooting Behaviour of Poplar Tip Cuttings

Temperature during phase I	3·5°C		8°C		15°C	
Temperature during phase II	3·5°	12°	3·5°	12°	3·5°	12°
Mean number of roots (from rooted cuttings only)	11·8	8·1	12·5	6·9	11·1	3·1
Mean number of active buds	3·5	4·9	2·7	3·8	2·9	0·7

Very little rooting was found to have occurred in any series at the end of Phase I.

The following main conclusions may be drawn from these results:

(1) Chilling at 3·5°C markedly stimulated the subsequent growth of the buds and the rooting response. Cuttings which received no such chilling showed a poor rooting response, although cuttings which were maintained at 8°C during Phase I, followed by storage at 12°C during Phase II, showed moderate rooting. It is evident that storage at 8°C has considerable effect on the removal of bud dormancy, though it is not as effective as storage at 3·5°C.

(2) Pre-treatment at 8°C during phase I, followed by chilling at 3·5°C, resulted in a slightly greater rooting response than did storage at 3·5°C during both phases, but pre-treatment at 15°C was not as effective as 8°C.

(3) It was observed that better rooting was given by terminal and sub-terminal than by basal cuttings. Evidence was obtained that the greater rooting response of terminal cuttings can be related to the greater amount of bud tissue which they bear.

Effect of Taking Hardwood Cuttings at Different Dates

The experiment was carried out to determine whether the date at which the cutting is taken is important, even before there has been any chilling treatment. On 21st October, 1961, one-year plants of *Populus robusta* (grown from cuttings) were lifted, planted in pots and stored at 12°C in a constant temperature room. At the same time, a number of cuttings were taken from similar plants growing in the field, placed in peat and sand and stored at the same temperature as the potted plants. After 6 weeks, further cuttings were taken from the potted plants, and both series of cuttings were then chilled for 10 weeks. After this period, they were transferred to a temperature of 15°C to promote rooting. The mean number of roots formed on cuttings taken on 21st October was found to be twice as great as that found on the cuttings taken 6 weeks later.

Thus, even though the shoots are stored under the same temperature conditions prior to chilling, it is evident that severance from the mother plant early in the autumn in some way creates more favourable conditions for subsequent rooting than attachment to the plant.

Rooting of Populus canescens

A small experiment was carried out with the Grey poplar, *P. canescens* (Clone S.A.), which is stated to be difficult to root from cuttings. Twelve basal cuttings were maintained at 15°C for 10 weeks and then subjected to chilling at 3·5°C for 6 weeks; a second batch of 12 cuttings was subjected to chilling at 3·5°C for 16 weeks from 1st November, 1961. Both groups were then maintained for 6 weeks at 15°C. The former series produced no roots, whereas the series chilled for 16 weeks produced 10 well-rooted cuttings. It would seem that this clone has a high chilling requirement, which may not be fully met under normal winter conditions, but additional chilling in a refrigerator would seem to offer a practical solution to this problem.

JUVENILITY PROBLEMS IN WOODY PLANTS

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The importance of the 'size factor' in the attainment of the flowering condition by seedling trees has been stressed in previous Reports (*Rep. For. Res. For. Comm.* 1957, 1960) in which it was shown that very early flowering of seedling birch can be obtained by growing the seedlings continuously under long days in a warm greenhouse, so that they attain the minimum size for flowering as rapidly as possible. A similar technique has now been shown to be successful with Japanese larch. Seed was sown in August 1957 and the seedlings were grown continuously in pots in a warm greenhouse under long-day conditions. By June, 1960 the seedlings had attained a height of 9 to 10 ft. and were then too tall to continue in the greenhouse. They were therefore transferred to boxes out of doors. Since it has been shown that flower-initiation in larch is markedly affected by the position of the shoot in relation to gravity (see *Rep. For. Res. For. Comm.*, 1958), 9 of the seedlings were planted horizontally in the boxes, and 12 were grown vertically as controls. The seedlings produced no 'flowers' (apart from a single male 'flower' on one vertical tree) in 1961, but in the spring of 1962 six of the horizontally-trained trees flowered, producing a total of 1,244 male and 259 female flowers; the vertical trees remained entirely vegetative. Since the flowers which appeared in 1962 had actually been initiated in the buds in the summer of 1961, it is evident that the horizontal seedlings had in fact attained the reproductive condition within four years from sowing. Since the juvenile period for Japanese larch is normally 10 to 15 years, it is evident that the method used in this experiment resulted in considerable hastening of flowering.

Considering the results which have now been obtained with birch, blackcurrant, and larch, it would seem that from the practical point of view the most effective method of reducing the juvenile period in woody plants is to grow the seedlings to a certain minimum size as rapidly as possible, and then apply conditions which are favourable to flowering; these latter conditions will vary according to the species e.g. long days in birch, short days in blackcurrant and training horizontally in larch. It would seem likely that in other species, other methods of inducing flowering will be effective e.g. bark-ringing, strangulation, root-pruning, grafting on to dwarfing stocks etc.

The results of a further series of experiments have tended to confirm the foregoing conclusions. In 1960, scions from juvenile and 'near-mature' seedlings (i.e. seedling trees approaching the normal minimal size and age for flowering) of European and Japanese larch, birch and ivy were grafted on to adult, flowering trees of larch, precocious-flowering clones of birch, and adult vines of ivy respectively. There was little flowering of any of the scions in 1961, but in 1962 certain scions of the larch produced flowers. Of 30 'near-mature' scions of European larch, 7 produced flowers, whereas none (out of 15) of the juvenile scions produced any. In Japanese larch, 11 out of 34 near-mature scions produced flowers, whereas only one out of 56 juvenile scions flowered. These results would seem to indicate that scions from larger (non-flowering) seedling trees are more readily induced to flower when grafted on to adult stocks, than are scions from smaller seedlings. This conclusion is in accordance with that formulated above, namely that it is advisable to grow seedlings to a certain minimum size before applying flower-inducing treatments.

The grafting of seedling birch on to precocious-flowering stocks has so far not resulted in flowering of the scions; similarly, juvenile scions of ivy grafted on to adult vines have retained their juvenile character. Attempts have been made to confirm an earlier report that when juvenile and adult ivy cuttings are grown together in the same culture solution, reversion of the adult cuttings to the juvenile condition occurs. Although some reversion was found to occur, this was not significantly different from that occurring when adult cuttings were grown alone, i.e. in the absence of juvenile cuttings.

Tissue cultures of juvenile and adult ivy from stem calluses have been established, to ascertain whether such cultures show morphological or physiological differences, but no such differences between the juvenile and adult tissues have yet been observed. An investigation of the content of ribonucleic acid, of juvenile and of adult ivy, has so far revealed no detectable difference between the two types of tissue.

THE EFFECTS OF STUMP TREATMENTS ON FUNGAL COLONISATION OF CONIFER STUMPS

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Further observations have been made on the effects of certain chemical treatments which proved interesting in laboratory screening and pilot field trials. Some ten substances have been tested on stumps of Scots and Corsican pines in November and in April. The frequency and abundance of fungi in the top 4 cm. of stumps were recorded six months after treatment, using the method described by Rishbeth (*Ann. Appl. Biol.*, 1959, *47*, 529). Despite attempts to select uniform trees for experimental purposes, considerable variation was encountered within treatments. Seasonal variation in the spore content of the air, as shown by untreated controls, followed the pattern found by Meredith (*Ann. Bot.*, N.S., 1959, *23*, 455), but was often obscured by the effects of the treatments. In future experiments it may be possible to overcome this problem of seasonal variation by inoculating with the more important fungal species.

The majority of substances tested caused some lowering of both frequency and abundance of the basidiomycetes, although total colonisation was markedly reduced by creosote alone. Basidiomycetes were practically absent from stumps treated with sodium nitrite, sodium dichromate, and nickel sulphate, but were only slightly affected by potassium permanganate. Complementary increases in colonisation by 'blue-stain' fungi (mostly *Ceratocystis* spp). were noted after sodium nitrite and sodium dichromate, and by *Trichoderma viride* after sodium dichromate and nickel sulphate treatment. The only substances which appear to have any selective activity against *Fomes annosus* as compared with other basidiomycetes are resorcinol and, to a lesser extent, thiourea. Although *Peniophora gigantea* is also partially inhibited by resorcinol, *F. annosus* has not been recorded from any stump so treated. Thiourea, on the other hand, though less active against *F. annosus* on stumps at the concentration used, supported at least as much growth of *P. gigantea* as the controls. *Stereum sanguinolentum*, rather infrequent even on stumps which had been inoculated with it, showed a preference for those treated with potassium permanganate. Malachite Green and to some extent the reducing agents, sodium nitrite and sodium metabisulphite, caused an increase in the abundance of the 'blue-stain' species.

Killing of tissues, as evidenced by the extent of bark-loosening and root killing in treated stumps, has been assessed. It has also been possible to estimate the rate of penetration of the woody tissues by some solutions. While rate of penetration appears to be correlated with bark-loosening, the same is not consistently true for root killing. Bark-loosening has been more extensive in the majority of treated stumps than in the controls, whereas root killing has only been so in a few cases.

Roots of stumps have been inoculated with *F. annosus* by means of infected beech-wood plugs soon after surface treatment; these roots have been sampled twelve months later. Those substances which suppress growth of the primary stump invaders, particularly the basidiomycetes, and prolong the life of the stump, such as creosote and Malachite Green, seem to be particularly favourable to the spread of *F. annosus* from an infected root into the stump body and other roots; no treatment has consistently restricted such growth by direct action. Investigation of the stump body suggests that colonisation of roots by other fungi proceeds mainly from the cut surface.

In view of the large number of factors operating in the field, the influence of chemicals on growth of the primary invaders in pure culture has been studied. Three separate isolates of each fungus were grown on 2·5 per cent malt agar containing successive ten-fold dilutions of chemicals. Approximate toxic and inhibitory concentrations agreed with those obtained by other methods; basidiomycetes were found to be sensitive to lower concentrations of most treatments than ascomycetes or hyphomycetes. Correspondence between the different isolates was high which suggests that much of the variation within treatments in the field stems from physiological differences in the substrate rather than the fungi themselves.

CHEMICAL CHANGES IN FOREST LITTER

By J. TINSLEY and R. J. HANCE

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Introduction

Manurial experiments with nitrogen, phosphorus, potassium, calcium and magnesium treatments begun by the Forestry Commission on pole stage Scots pine trees in 1958 at three sites in England, and on other species in 1959 at ten sites in England, Wales and Scotland, have revealed marked differences in their effects on the forest litter though, as yet, no significant effect on the growth of the trees has been reported.

Application of nitrogen fertilisers, particularly in combination with liming, has greatly intensified the rate of humification and markedly changed the physical character of the organic matter overlying the mineral soil at some sites. This effect appears to result from the stimulation of the microflora and it seems desirable to assess the consequent changes in the composition and properties of the organic matter, and particularly to study their effects on the adsorption, retention and release of nitrogen compounds in relation to the long-term nutrition of the forest trees.

Previous work by Hinson and Reynolds (1958), has demonstrated the difference in behaviour of compounds which provide free ammonia in the soil such as ammonia solutions, ammonium carbonate and urea on the one hand, and on the other hand of ammonium salts such as ammonium sulphate, ammonium phosphate and ammonium nitrate (as Nitrochalk). The nitrogen of the former group appears to be retained by the soil more firmly, less of it is lost by leaching, and release for plant use is slower, but extends over a longer period.

Aims of the Study

The initial aims of the present study, started in October 1961, were as follows:

1. To establish field manurial plots using different forms and rates of nitrogen fertiliser, with and without lime, on a site, preferably under Scots pine, where the pole stage trees are uniformly grown in close canopy with little or no ground vegetation, and where the forest litter is evenly deposited on a free-draining uniform podsolic soil.
2. To sample the field plots in spring and autumn of each year in order to trace the changes in composition of the organic matter resulting from the various nitrogen treatments.
3. To instal micro-lysimeters at the field site adjacent to the tree plots in order to collect drainage water samples from cores of the surface organic horizons treated in the same way as the plots, and so determine the fate of the applied nitrogen compounds.
4. To set up a series of experimental columns in the laboratory, corresponding to the micro-lysimeters in the field, where the transformations in the organic matter and the applied nitrogen compounds could be studied more closely.

Field Work

In the period October to December 1961 a survey was made of forests, chiefly Scots pine, situated within 60 to 70 miles of Aberdeen, on both Forestry Commission and private land.

On the site of the Durris Manurial Experiment 5/59/(GA) the soil was unpodsolised, having previously been agricultural land, and the small amount of spruce litter showed no obvious differences due to the nitrogen treatment applied in 1959.

No other site was found where Scots pine was sufficiently uniform and close without ground vegetation, so finally, after discussions between Mr. Holmes, Dr. Hinson and Dr. Hance at Alice Holt in January 1962, it was decided to establish the field experiment at Bramshill Forest, South of Reading, where the original studies of Dr. Hinson were begun.

After making various analytical studies on samples collected from the site, the field plots were laid out on March 26th to 29th, with the assistance of Forestry Commission staff, according to the Experiment Plan, Bramshill No. 25, 1962, described by G. D. Holmes, dated February 1962, with addendum dated 28th March, giving the revised treatments as follows:

Nitrogen Fertilisers:	A Urea	46 %N
	B Ammonium Sulphate	21 %N
	C Diammonium Phosphate	16·3%N
Rates of Application:	N_0	
	N_1 50 lb. N/acre	
	N_2 100 lb. N/acre	
	N_3 200 lb. N/acre	
Liming:	Ground Chalk 30 cwt/acre	

Supplementary Phosphorus alone, treatment: 137 lbs. P/acre as triple superphosphate

Duplicate sets of 21 micro-lysimeters were installed under the trees, and the liming material and fertilisers were applied at the same time. Each lysimeter was constructed with a ring of aluminium alloy 6 inches in diameter and 3 inches deep to hold the core of the humus horizons, supported on a perforated grid, mounted in a funnel placed on a collecting bottle, within a metal can sunk into the soil Inspection of the drainage water from each treatment on April 13th showed that much humus material had been leached from the soil receiving urea, little or none from the ammonium sulphate, and an intermediate quantity from the diammonium phosphate treatments.

Laboratory Work

Preliminary studies on the adsorption of nitrogen compounds by litter from the L,F, and H layers of a podsolic soil from Countesswells, near Aberdeen, broadly confirmed Hinson's findings that a higher proportion of the ammonia from ammonium hydroxide solution was absorbed than from ammonium sulphate or nitrate; but we found ammonium phosphate was intermediate in its retention as the following data show:

Dry Litter 10g.	*Solution* 100ml.		*Percentage of Ammonium Absorbed* NH_4OH	$(NH_4)_2HPO_4$	$(NH_4)_2SO_4$	NH_4NO_3
L Layer	5m.eq.	NH_4+	51·7	29·5	14·4	13·4
	1m.eq.	NH_4+	35·3	25·0	16·3	16·9
F Layer	5m.eq.	NH_4+	82·5	46·2	18·8	18·0
	1m.eq.	NH_4+	70·7	47·7	28·7	26·5
H Layer	5m.eq.	NH_4+	85·5	50·2	21·5	20·8
	1m.eq.	NH_4+	75·4	52·6	33·2	31·7

A further test demonstrated that urea was readily transformed to ammonium form, and virtually behaved like ammonium hydroxide after one day in contact with litter, so it was on the basis of these results that the decision was made to use urea, ammonium sulphate and diammonium phosphate for the field experiments and, although the last is rather unorthodox as a fertiliser, to exclude Nitrochalk (ammonium nitrate+calcium carbonate) because the nitrate is likely to be readily leached from the organic horizons.

One objective of the laboratory studies is to reproduce some features of the field experiment under more closely controlled conditions. To this end, a series of artificial columns have been prepared with litter from the site at Bramshill Forest in Hampshire; this has been treated with fertilisers at a rate equivalent to 200 lb. N per acre in order to check with results obtained from the lysimeters in the field. In addition to analyses of the eluates, it is hoped to obtain a measure of the CO_2 and NH_3 evolution. It is also intended to compost litter samples which have been treated with fertiliser, and to compare the chemical changes which occur with those that take place in the field.

The remainder of the laboratory work to date has been concerned with the investigation of methods for the chemical anaysis of litter samples. Suitable methods have been found or developed for the determination of carbon, total nitrogen, amino-nitrogen, acid insoluble nitrogen, carbohydrate, hexoses and carboxyl groups. Work is in progress on methods for the determination of methoxyl groups, hydroxyl groups—both phenolic and alcoholic, and carbonyl groups. In addition a study is being made of the protein component of litter with special reference to Handley's theory that the leaf proteins of coniferous species undergo a tanning reaction after leaf fall.

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DIE-BACK DISEASE OF CORSICAN PINE

By D. J. READ
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A preliminary study of factors influencing disease of Corsican pine in Allerston Forest in Yorkshire has been made in the first year of research. A survey of distribution of disease was carried out initially in an attempt to correlate its incidence with soil type, soil structure, topography or micro-climate.

Analyses of shoots of Corsican pine from healthy and diseased shoots failed to reveal any mineral nutrient deficiencies in the diseased shoots. The fact that disease is equally serious on acid soils derived from the Lower Calcareous Grits, and on the relatively calcareous soils derived from the Hambleton Oolites, again suggests that chemical nutrient factors may not be primarily involved in this problem.

Surveys of distribution of disease in relation to soil structure showed that compaction and stoniness were not significantly different in either healthy or diseased stands, so that these factors are unlikely to be important except in a few individual cases.

Particularly outstanding appeared to be the correlation of disease with topography. North-facing slopes and valley bottoms were uniformly badly affected by disease, deaths approaching 100 per cent in many such sites, while adjacent stands on South-facing slopes on exactly similar soils were healthy and vigorous.

Three meteorological stations have compared, through one winter, the temperature and humidity conditions in healthy and diseased stands. Extremes of cold are greatest in the diseased stands, and relatively stable high humidity conditions also prevail there.

Apparatus was designed to test the hypothesis that frost could, in these topographically suitable areas, be causing disease. It was shown that temperatures required to kill buds of Corsican pine in winter (—18 to —20°C) were never recorded in the field. The disease was none the less widespread and symptoms were recorded early in December. The latter observations also suggested that spring frosts were not likely to be of primary importance; indeed in the late May frosts of 1961 Corsican and Scots pines were the only two species observed not to be affected.

It was found that the fungus *Brunchorstia destruens* could be isolated from buds at the earliest stage of disease when only one or two cells show browning of their walls. Re-inoculations of conidial suspensions of this fungus into buds of Corsican pine ranging from five to forty years of age induced typical disease symptoms. Success of inoculations was dependent on humidity conditions subsequent to inoculations. These conditions were charted by the hygrographs of the meteorological stations. Inoculations carried out in Summer 1961 gave symptoms in the following October. In the intervening period the fungus could be isolated from the scales only.

Resistance to invasion seems to weaken after onset of dormancy. Studies have begun in an attempt to elucidate the effect of the physiological processes involved in winter hardening, on the virulence of the pathogen. Qualitative and quantitative analyses of sugars revealed a higher content of reducing sugars (glucose and fructose) per unit weight in Corsican than in Scots pine, but similar differences reproduced in synthetic media did not appreciably affect growth of the fungus.

A study of a disease of pines in northern Sweden was made in the summer of

1961, and similar symptoms were noted. Here the disease, caused by what is believed to be the same fungus, has recently assumed serious proportions in young natural Scots pine stands. Sites in which disease is most prominent are similar to those noted for Britain.

Isolations from the Swedish material show the fungus to possess the same mycelial and conidial characters as does British material. The perfect stage, *Scleroderris lagerbergii*, was obtained from the Swedish material, but to date searches for the same stage in this country have proved unsuccessful.

Laboratory observations have shown that the optimal growth in culture of the fungus is obtained at a temperature of 10°C. This is a very low figure for a fungus and may at least help to explain the association of disease with cold pockets. Other observations have tended to support the view that this is a low-temperature fungus. Conidial germination rates and conidial viability, for example, are increased after exposure to zero and sub-zero temperatures (centigrade scale).

What must now be ascertained is whether, in disease-prone sites, climatic factors actually reduce resistance of the host to invasion or whether increase in pathogenicity of the fungus, induced by such factors, is alone responsible for advent of disease.

Work is proceeding in the laboratory in an attempt to elucidate the effect of some varying environmental conditions on resistance of young trees to invasion by *Brunchorstia*, and attempts are being made to extract the fungal enzymes involved in the pathogenicity of the fungus.

PART III
Results of Individual Investigations

AN INTERIM REPORT ON FIELD TRIALS OF TREATED AND UNTREATED ROUND FENCING TIMBER

By J. R. AARON

The report describes an investigation into the service life of fence posts at twenty sites in various parts of Britain. The trials were arranged in collaboration with the Ministry of Agriculture, Fisheries and Food, and the Department of Agriculture and Fisheries for Scotland.

Earlier Work on the Durability of Wood Posts

The first extensive investigations into the durability of timber in contact with the ground in Britain were carried out by the Forest Products Research Laboratory of the Department of Scientific and Industrial Research. Two separate experiments were undertaken, one to assess the natural durability (i.e. the resistance to decay) of a number of species of timber, and the other to compare the efficiency of different wood preservatives. The method adopted was the so-called 'graveyard test', in which pieces of sawn timber 2 in. x 2 in. and 2 ft. long were set vertically into the ground to a depth of 15 inches. These experiments were repeated at three sites with widely contrasted conditions of soil and climate. Subsequent assessments were made by tapping the test specimens with a light mallet at intervals of between six and twenty-four months, and noting when breakage occurred. The results of these tests have been fully reported in the Laboratory's publications (Smith 1954, 1959).

From the experiments in which the natural durabilities of different timber species were studied, a system of classification according to the anticipated life of the timber when in contact with the ground has been devised. It is briefly summarised in Table 19.

Table 19

The Durability of Home-grown Timbers: Heartwood

Life in Contact with Ground in Years	Less than 5	5–10	10–15	15–25	Over 25
Classification:	Perishable	Non-durable	Moderately durable	Durable	Very durable
Heartwood of of Common Home-grown Timbers falling into this Category: *Note:* All sapwood is perishable or non-durable.	Ash Beech Birch Lime Poplar Sycamore	Scots pine Norway spruce Sitka spruce Elm	European larch Japanese larch	Oak Sweet chestnut Yew	None

These determinations have been of considerable value in the selection of timber species for outdoor purposes, but because the work was confined to sawn heartwood material the results are not readily applicable to round timber where the heartwood is enclosed in a cylinder of less durable sapwood. The Laboratory has, however, undertaken fence post trials with round, half-round and quartered timber, but these were primarily designed to compare different methods of applying coal-tar creosote, and they were not concerned with either the comparison of different preservatives or the natural durability of the species of timber used. The results have not yet been published.

Apart from these experiments there has been no systematic testing of round fencing timber in Britain, although trials involving this type of material were set up by the Oregon Forest Research Center in the United States as early as 1928 (Graham and Miller, 1960).

The Present Experiments

Two series of experiments were set up; the first was started in 1957 in collaboration with the Department of Agriculture for Scotland at nine sites on their experimental farms; the second was started one year later in collaboration with the Ministry of Agriculture, Fisheries and Food at eleven of their experimental husbandry farms in England and Wales.

The objects were to study the effects of site on the durability of round fence posts made from readily available timbers, and to assess the value of treating them with a preservative applied by the simple open-tank method, which can be used by the farmer (both for waterborne and creosote preservatives) without elaborate equipment.

Past experience has shown that *pressure* treatment with the commonly used proprietary waterborne preservatives (which is normal commercial practice) or with coal-tar creosote would give a life of 35 or more years, and would thus mask the effects of site conditions.

One third of the material was treated with coal-tar creosote, one third was treated with a proprietary waterborne preservative of the fluor-chrone-arsenate type, and the remaining third was left untreated.

In Scotland the experiments were restricted to two species, Sitka spruce and birch.

In England and Wales, Scots pine was used at every site, together with a hardwood of a species readily available in the locality of the farm. At the experimental husbandry farms in Northern England this was invariably sycamore, in Wales it was birch, whilst in the remaining areas alder, ash, or elm was chosen. At Rosemaund Farm in Herefordshire, facilities were available to extend the experiment, and so fence posts in oak, European larch, Japanese larch, sweet chestnut, birch and elm were prepared as well as posts of Scots pine and ash for the main experiment. Additionally, posts of ash and Sweet chestnut on which the bases and points had been charred were made, in order to see whether charring has any appreciable preservative effect, as has frequently been claimed.

The conditions of soil and climate differed considerably from site to site; for example, the plot at Cuckoo Pastures Farm in Cambridgeshire is on Boulder clay at an altitude of 190 ft., and has an annual rainfall of 22 inches; contrasting sharply with the site at Pwllpeiran Farm in Cardiganshire, where the plot is on peat over shale at an altitude of 750 ft., and has an annual rainfall of 60 inches.

The posts, which were 5 ft. 6 in. long and 3 in. to 4 in. top diameter, were peeled, pointed, and stacked under cover for at least eight weeks before preservative treatment was applied. The treatment was carried out at Forestry Commission produce depots as follows:

(1) *Creosote*

The posts were immersed in creosote and the temperature maintained at 180°–200°F for two hours; the creosote was then allowed to cool below 90°F. It was finally reheated to 180°–200°F for about half an hour before the posts were removed.

Note: Most of the required creosote is absorbed during the cooling process; the reheating drives out any surplus.

(2) *Waterborne Preservative*

The posts were immersed in a solution of the preservative at a temperature of 180°F for four hours, and the fluid was then allowed to cool; there was no reheating period as there had been with the creosote. After treatment the posts were cross-stacked to facilitate air drying.

The erection of the posts was carried out by driving with a maul in the normal way. They were driven until there was eighteen inches of post below the soil level. The layout of the trial at each site was in accordance with a randomised design suggested by the Statistics Section; each species and type of preservative treatment was replicated four times at every site.

This paper presents the interim results four years after the trials were set up in Scotland, and three years after they were set up in England and Wales. While it has already been established that certain species and treatments are unsuitable, the assessments may have to continue for at least a further seven years before firm recommendations can be made.

Assessments

At each site a horizontal 50 lb. pull is gently applied once annually to the top of the post; a spring balance is used to check the load. The pull is sustained for about five seconds, care being taken to ensure that it is applied in the same direction at each assessment. A post is considered to have failed when it is completely broken, or when it becomes so badly cracked as to be unserviceable. In addition, the research foresters note the incidence and extent of fungal growth at the base of the post, when making the annual assessments. The experiment continues and is expected to yield useful information for some years to come. The results to 31st December, 1961 are given in Table 20 and Figures 7 and 8. (See pages 136, 138, and Plate 12.)

Discussion

The results to date demonstrate the superior durability of treated posts over untreated posts, including even those prepared from species with a durable heartwood. It is also notable that most of the Forest Products Research Laboratory classifications of natural durabilities of heartwood have been found to apply to these round posts, which include both heartwood and sapwood. Of the *untreated* posts, alder and birch, which are classified as 'perishable', have generally failed more rapidly than Sitka spruce, Scots pine and elm which are classified as 'non-durable'. On the other hand, ash, which is classified as 'perishable', has so far lasted as well as the 'non-durable' species.

The apparent effect of high rainfall, especially on peat sites, in retarding the rate of decay is also noteworthy. The earlier 'graveyard' tests of the Forest Products Research Laboratory indicated that the life of the test specimens in

Table 20

Failures of Fence Posts After Three Seasons (England and Wales) and Four Seasons (Scotland) in Field Trials (Treatments by Open-Tank Method)

	Percentage failures by third season			
	Untreated	Waterborne preservative	Creosote	Remarks
ENGLAND AND WALES				
Scots pine (eleven sites)	46	1	Nil	
Alder (one site)	100	25	Nil	
Ash (three sites)	29	2	Nil	
Birch (four sites)	60	12	Nil	
Elm (two sites)	38	9	Nil	
Sycamore (two sites)	38	Nil	Nil	
Oak } Rosemaund Farm, Herefordshire	19	Nil	Nil	
Chestnut } Rosemaund Farm, Herefordshire	Nil	Nil	Nil	
European larch } Rosemaund Farm, Herefordshire	Nil	Nil	Nil	
Japanese larch } Rosemaund Farm, Herefordshire	Nil	Nil	Nil	
				Charred points
Chestnut } Rosemaund Farm, Herefordshire				Nil
Ash } Rosemaund Farm, Herefordshire				100
SCOTLAND	*Percentage failures by fourth season*			
Sitka spruce (nine sites)	3	Nil	Nil	
Birch (nine sites)	23	Nil	Nil	

the low rainfall sites at Princes Risborough and Thetford was rather shorter than in the high rainfall site at Dolgellau. Observations of this type are to some extent confounded by differences in drainage, temperature and soil fertility between the sites. Nevertheless, in the current experiments there is some confirmation of this effect, for example, in England and Wales only 7 per cent of the untreated Scots pine posts have failed at those sites (two in number) which have an annual rainfall of 60 or more inches; this compares with an 'all sites average' of 54 per cent. In Scotland the same effect is observed in that the three sites with the lowest annual rainfall account for about two-thirds of the failures.

The failure of all of the charred ash posts within three years demonstrates that charring has no worthwhile preservative effect. In this connection it is interesting to note that only about half of the uncharred posts on the same site so far have failed; it is therefore probable that charring actually reduces the service life of a post by destroying some of the wood substance.

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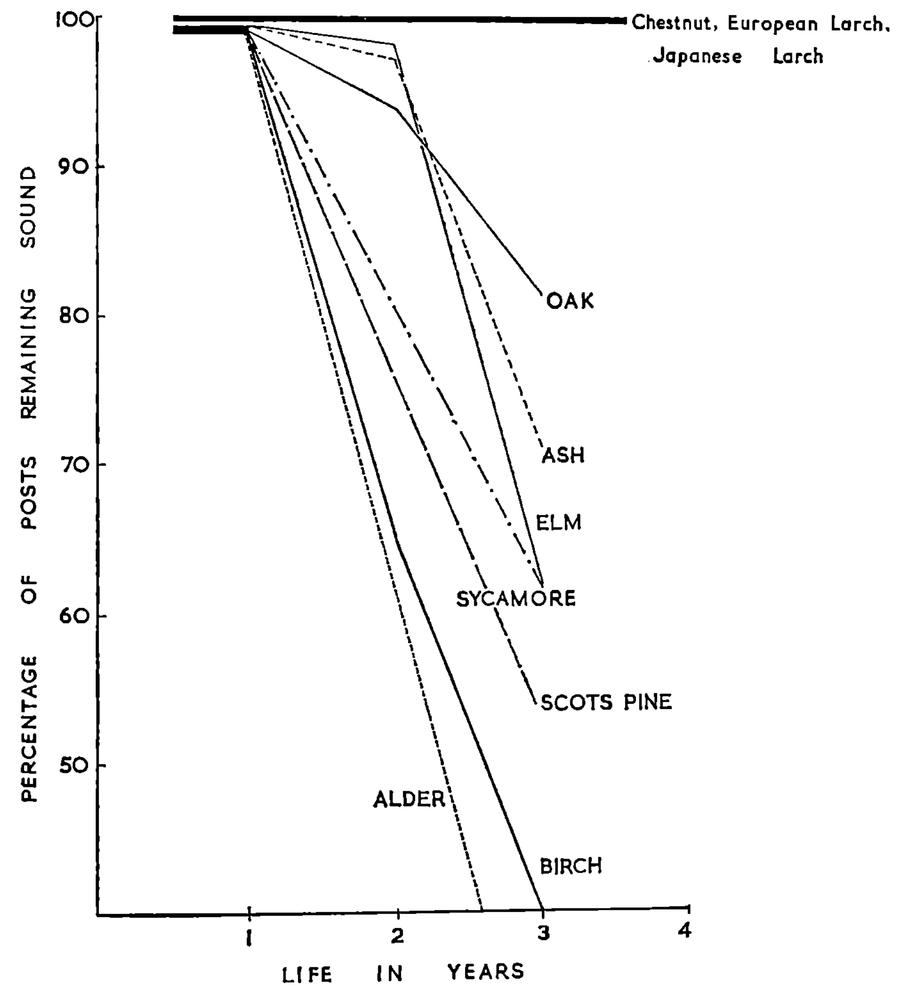

FIGURE 7. Natural durability of individual species.

TESTING OF POPLARS AND PINES AGAINST PINE TWISTING RUST, MELAMPSORA PINITORQUA

By C. W. T. YOUNG

The Tests

In 1951, Dr. C. Heimburger of the Department of Lands and Forests, Southern Experiment Station, Maple, Ontario, invited the co-operation of European workers in testing Red pine (*Pinus resinosa*) and the North American aspens for resistance to *Melampsora pinitorqua* Rostr., the Pine twisting rust, which produces its aecial stage on Two-needled pines and its uredial and telial stages on aspen (*Populus tremula*). At that time *M. pinitorqua*, which is common in Europe, had not been recorded in North America, and Dr. Heimburger wanted to prepare for any possible outbreak there. He was particularly interested

OPEN TANK PRESERVATIVE TREATMENT OF FENCE POSTS

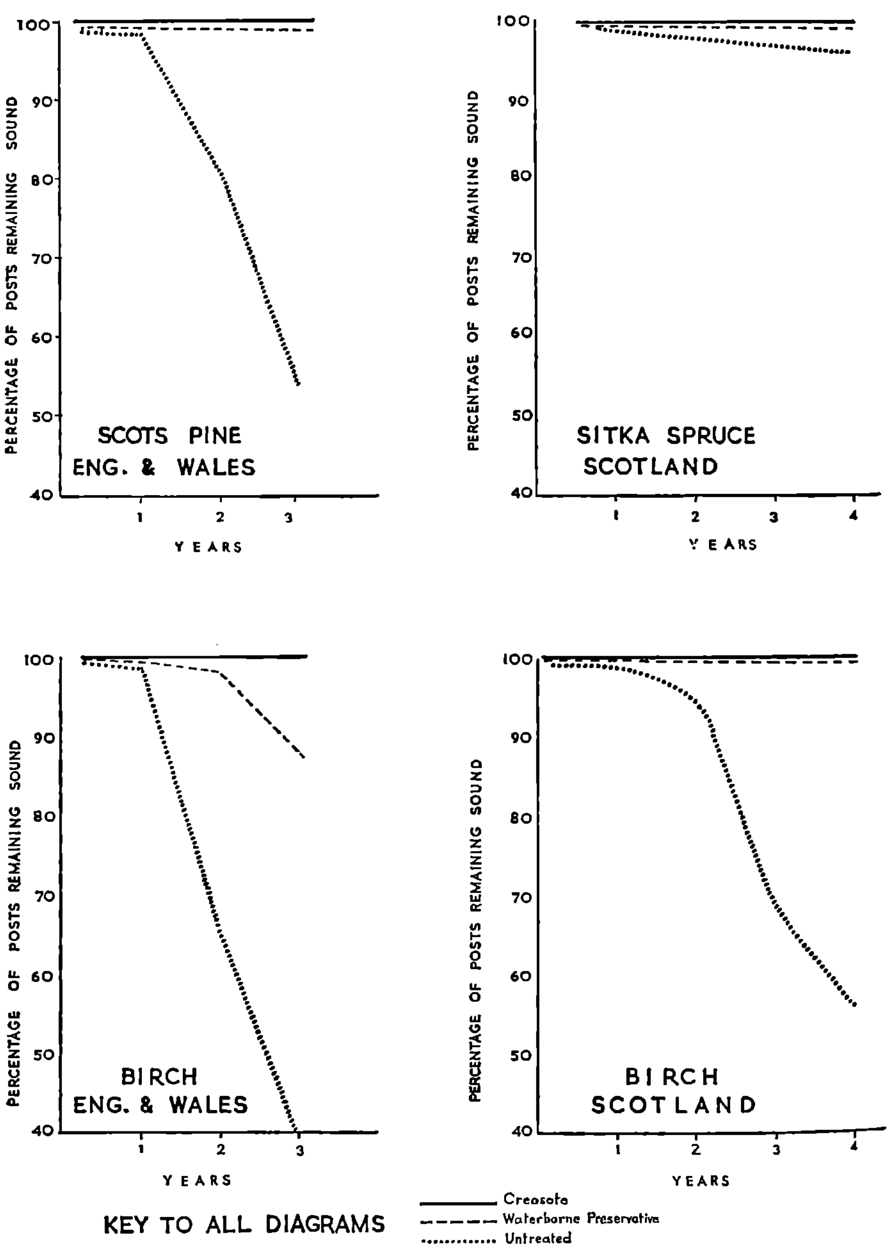

FIGURE 8.

Comparison of service life of untreated posts and posts treated with two different preservatives.

in testing Red pine and *Populus grandidentata*, as he considered them to be genetically more homogenous than *Populus tremuloides* and the other more important North American pine species; he felt that the disease was potentially more dangerous in them than in other more heterogeneous species, in which resistant strains or individuals might reasonably be expected.

In response to this request, *P. resinosa* was planted in several areas where the disease was present on Scots pine and aspen in south-eastern England. All these plantings failed, however, and in 1954 a trial was started under nursery conditions, in which it was hoped eventually to test a wide range of pine and poplar species and varieties, as well as those specified by Dr. Heimburger. Various poplars and pines, with Scots pine and aspen to provide sources of infection, were planted at close spacing, in rows one yard apart and ten yards long, and additions were made in following years whenever more species were available for testing.

Difficulty was experienced in establishing the disease. In 1954, 1955 and 1956, infected Scots pine shoots were collected and attached to branches of the aspens when aeciospores were being released, but no infection of aspen leaves resulted. In September 1956 infected aspen leaves were collected and scattered in the test bed. No weeding or cultivation was done round established plants at any time, so that infected aspen leaves could more readily remain preserved on the ground until the release of sporidia from the teliospores at about the beginning of June. In June 1957 considerable infection of Scots and Maritime pine (*Pinus pinaster*) occurred, and this was repeated in 1958, with some decline in the attack on Scots pine. In subsequent years no infection of Scots pine was found, and that of Maritime pine declined, only one or two infected shoots being found in 1960 and 1961. The reason for this decline was not established. Abundant infection of aspen occurred every year from 1957, so a source of infection was not lacking. Attacks observed on Scots pine in the field have been sporadic and closely limited to the vicinity of aspens (Peace 1944), and it seems likely that narrow critical climatic or microclimatic limits are involved in the infection of pine.

Results and Discussion

The test could thus be regarded as being effective in 1957 and 1958 only. The species in the test in these years are listed by rows in Table 21 and the number of each species in each row is given, together with the numbers found infected in June for pines and in September for poplars. Several additions, removals and replacements were made that account for any seeming inconsistencies in the list.

Neither Red pine nor *Populus grandidentata* were infected under conditions in which considerable infection of other species occurred, a reassuring result since *M. pinitorqua* has recently been found in British Columbia on Ponderosa pine (*Pinus ponderosa*) (Ziller, 1961). The disease has been recorded on White poplar (*Populus alba*) and on the American aspen, *P. tremuloides*, but was not found on the particular varieties used in the test. Two lots of *P. tremula* x *tremuloides* hybrids showed varying resistance, one remaining immune while the other was slightly infected.

Damage to Maritime pine has been recorded in France and in Italy (Moriondo, 1957), and in the present test it was more severely and persistently damaged than Scots pine. It was at one time thought to be resistant, and has been recom-

Table 21

Melampsora pinitorqua Test, 1957–58

Row	Species	1957		1958	
		Total	Infected	Total	Infected
	Pines				
1	P. sylvestris (Scots pine) . .	18	14	18	12*
5	„ „ . .	15	11	14	7*
11	„ „ . .	8	4	7	3
3	P. resinosa	18	0	18	0
7	P. pinaster	12	9	14	9
13	„	5	0	—	—
9	P. radiata	12	0	12	0
9	P. echinata	—	—	8	0
11	P. nigra var. calabrica (C.P.) . .	11	0	10	0
15	„ „ „ . .	50	0	31	0
13	P. contorta (Lodgepole pine) . .	—	—	27	0
14	P. muricata	—	—	24	0
16	P. densiflora	—	—	35	0
17	P. mugo (Mountain pine) . .	—	—	41	0
	Poplars				
2	P. tremula (Aspen) . .	23	23	16	16
18	„ „ . .	—	—	10	10*
4	P. tremuloides H	29	0	17	0
6	P. tremula x tremuloides H . .	29	24*	15	15*
8	P. grandidentata	19	0	18	0
10	P. alba A (White poplar) . .	—	—	10	0
12	P. tremula x tremuloides J . .	10	0	9	0

* Denotes slight infection.

mended as an alternative species to Scots pine on aspen sites in some publications. None of the other pines, *Pinus radiata*, *P. echinata*, Lodgepole pine (*P. contorta*), *P. muricata*, *P. densiflora*, Mountain pine (*P. mugo*), and Corsican pine (*P. nigra* var. *calabrica*), was infected.

The sporadic nature of the disease makes testing for resistance under natural conditions of infection unsatisfactory, and inoculation techniques should be used in any further work.

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THE EFFECT OF PHOSPHATE, APPLIED AT PLANTING, ON A CROP AT THE POLE STAGE ON UPLAND HEATH

By S. A. NEUSTEIN

Introduction

The benefits of phosphate on survival and crop growth on poor land are universally recognised, but the continuation of its effect into the pole stage has been studied less. An experiment at Teindland Forest in Morayshire (No. 41, P. 29) is the earliest from which the effect of phosphate can be ascertained on areas large enough to give information regarding the basal area, form and volume of the crop. The object of this article is to bring this study up-to-date and expand on the summary given by Zehetmayr (1960) in Forestry Commission Bulletin No. 32, *Afforestation of Upland Heaths* (pp. 112–113). Earlier experiments contained plots which were too small (less than 100 plants) to avoid interactions from mutual shelter, root invasion, or contamination by leaf-fall from treated plots. Table 50 of Bulletin No. 32 (Zehetmayr *ibid*) indicated a striking increase in production with phosphate at 26/27 years, viz. a 45 per cent increase in basal area and a 16 per cent increase in height, which corresponds to just over half a quality class for Scots pine. Since then, two more thinnings and assessments have been made.

It must be emphasised that this experiment provides but a single case, and the behaviour of crops in this stage of development might be different in other circumstances, for instance where the initial phosphate dosage had been heavier.

Description of the Experiment

The experiment lies in the Findlay's Seat Experimental Area, at an elevation of 750 to 800 feet, on a slight slope having a north-west aspect and moderately exposed in this direction. The soil is variable, but the bulk of the experiment has a thin peaty layer of about two to five inches over a very stony morainic soil. In places where the peat layer was deeper, there was much stagnant surface water prior to ploughing. The original vegetation consisted mainly of heather (*Calluna vulgaris*), cross-leaved heath (*Erica tetralix*), sphagnum moss (*Sphagnum acutifolium*), and the lichen *Cladonia sylvatica*, with patches in which deer grass (*Trichophorum caespitosum*) and sedges (*Carex* spp.) were abundant. The soil is of the type described by Muir (1940) as a peaty-gley podsol with hard pan.

The main object of the experiment was to test the use of a 'heavy plough' on difficult, heather-clad ground on a field scale. This plough, the Grant Standfast, was specially built in Craigellachie at the instigation of the late Professor M. L. Anderson. It was essentially a strengthened agricultural plough weighing about four hundredweights, or double the weight of an ordinary farm plough. It was drawn by three horses and cut to a depth of six inches and a width of fifteen inches where stones were not too frequent, and produced satisfactory shallow ploughing over most of the area. Three cultivation treatments were compared, viz.: no ploughing, strip ploughing (with spaced group planting), and ploughing in three-furrow bands. As only the last cultivation type (Section C) is considered in this article, it is described in greater detail. Section C (three acres) was ploughed in three-furrow bands at right-angles to the prevailing wind, all ridges lying the same way. These bands were about forty-five inches wide and five feet apart, from centre to centre, so that each was separated by a narrow unploughed belt (i.e. ploughing was 75 per cent complete). Ploughing was completed in the winter of 1928–29 and half the area was planted in April, 1929 with Lodgepole pine of slow-growing Alberta provenance (I.N. 26/58), and half the following year with the same provenance. The plants were notched at 5 ft. x 3 ft. spacing into the centre of the ploughed strip. The ploughing treatment was split into four plots, two of which received in 1930 two oz. basic slag per plant (3½ cwt. per acre), whilst the other two were untreated.

Results

At two years of age, a difference in colour was noted between slagged and unslagged plants. Survival was good over all, being 96 per cent in the controls and 99 per cent in the slagged plots. Subsequent height assessments are given in Table 22 below.

Table 22

Lodgepole pine, Teindland

Height Growth of Slagged and Untreated Plots (Feet)

	Type of Height Assessment							
	Mean Height				Dominant Height	Top Height		
Age of Crop (Years)	4/5	8/9	15/16	18/19	24/25	26/27†	29/30	32/33
No slag . . .	0·8	2·8	8·5	10·5	22·0	25·5	28·5	31·5
Slag . . .	1·6	5·5	13·5	15·5	26·0	29·5	33·0	36·0
Standard error ± .	—	0·11	0·38	0·52	0·69	0·31	0·24	0·12
Effect of slag, height difference . .	0·8	2·7**	5·0*	5·0*	4·0	4·0*	4·5**	4·5**
Effect of slag, % .	100	96	62	47	18	16	16	14

* Significant at 5% level
** „ „ 1% level

† Bulletin 32, Table 50

The beneficial effect of slag on height growth is obvious. Expressed as a simple height difference, the effect increased to a maximum in 15/16 years; and thereafter the lead was merely maintained. Expressed as a percentage of the height of the control trees, the effect naturally diminishes with the growth of the crops.

The difference in top height over the period is equivalent to approximately half a quality class in Scots pine (as noted by Zehetmayr), and it has remained steady, i.e. slag apparently had no further improving effect in height growth after the 15th year.

It should be observed that in the pre-thicket stage the mean height of *all* trees was assessed; at 20/25 years 'dominant height' (i.e. the tallest 220 to 240 trees per acre), and lastly the top height (100 trees of largest girth) was assessed. It is suggested later that the smaller trees benefited more from slag than the largest, and therefore it is probable that the change to dominant and top height assessment would tend to reduce the estimate of the effect of slag.

First measurements of basal area and volume were made at 26/27 years (four 1/10 acre assessment plots being sited in Section C) when the slagged plots received their first thinning. The unslagged plots were not ready for thinning until the age of 29/30, and even then only damaged, suppressed and occasional large coarse trees were removed. The thinning grade throughout has been C/D. At age 32/33 years (in 1961) the slagged plots were thinned for the third time and the unslagged plots for the second time. It is therefore on the basis of only three measurements of the main crop and thinnings that tentative conclusions can be based.

Tables 23 and 24 summarise the periodical basal area measurements of slagged and unslagged plots to date. At each assessment every tree was measured.

Table 23

Teindland, Lodgepole pine, Effect of Slag
Total Basal Area (Main Crop Plus Thinnings) per Acre (sq. ft.)

Basal Area	Age			Annual basal area increment last three years
	26/27 years	29/30 years	32/33 years	
Total basal area:				
No slag	99·5	117·4	128·8	3·8
Plus slag	148·8	169·3	180·7	3·8
Standard error	6·3	6·09	6·07	0·33
Effect of slag	49·3*	51·9*	51·9*	—
Effect of slag (%) . . .	+50%	+44%	+40%	—

* Significant at 5 per cent level

Table 24

Teindland, Lodgepole pine, Effect of Slag
Basal Area of the 100 *Largest Trees per Acre (sq. ft.) and*
Numbers of Main Crop Trees Only (after thinning)

	Age		
	26/27 years	29/30 years	32/33 years
Basal area 100 largest trees:			
No slag	11·7 (2,260)†	13·8 (1,860)	15·2 (1,213)
Slag	12·6 (2,070)	15·7 (1,533)	17·1 (1,067)
Standard error . . .	0·39	0·19	0·40
Effect of slag. . . .	0·9	1·9*	1·9
Effect of slag (%) . . .	+7·4%	13·8%	12·5%

* Significant at 5 per cent level.
† The number of main crop trees after thinning is shown in brackets.

The slag effect expressed as a percentage is considerably less on the 100 largest trees than on the mean of the whole crop, viz. 7 to 14 per cent as against 40 to 50 per cent (see Tables 23 and 24). Hence it would seem that on this particular site the most vigorous trees in the crop are able to obtain a high proportion of their phosphorus requirement, and in the long run the benefits of added phosphate are mainly conferred to the greater number of smaller trees, thus increasing the yield of thinnings.

The slag improved height increment up to the age of 15 years (see Table 22). Thereafter the difference was only maintained, i.e. the slag did not confer

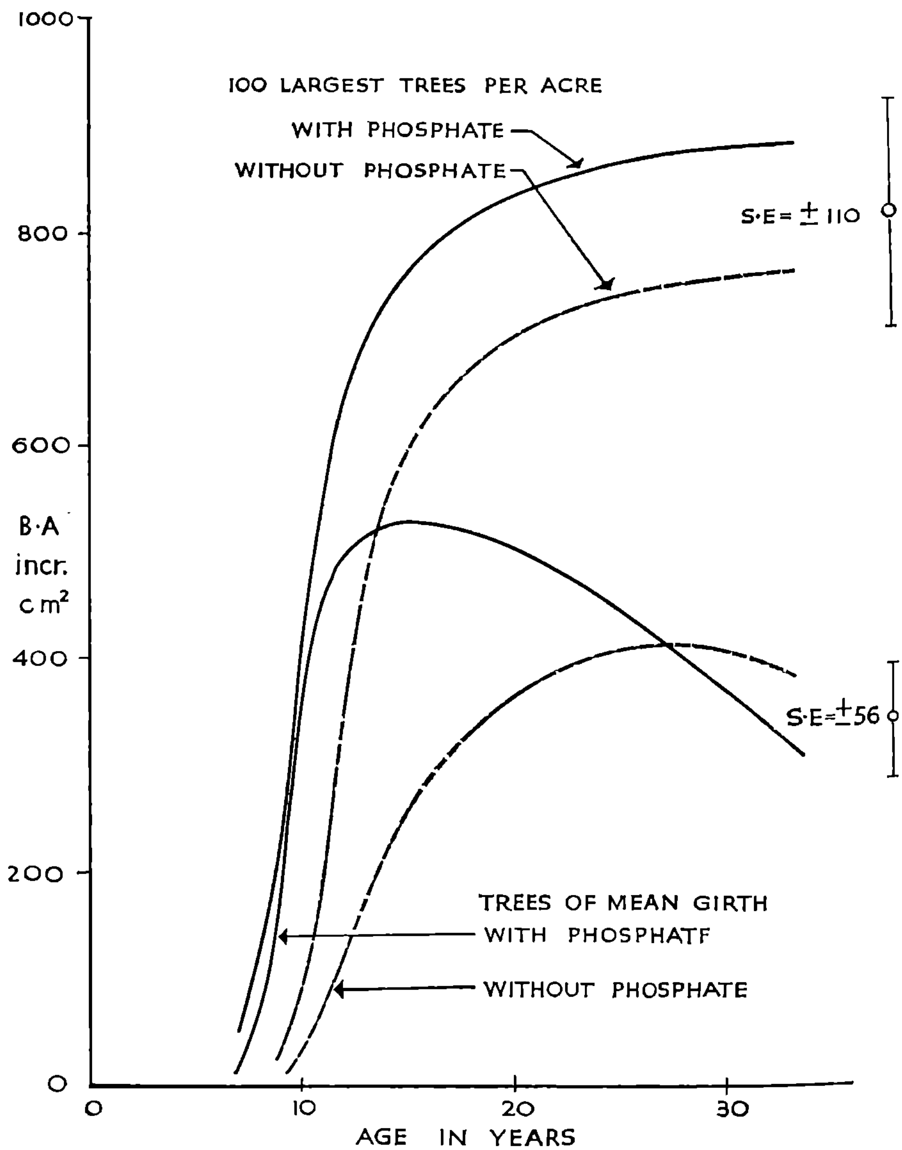

Figure 9. Comparison of Annual ring growth of trees of mean girth and "100 largest" trees per acre, with and without phosphate. B.A. incr. cm^2=Basal area increment in square centimeters.

additional benefits; this equality in growth is confirmed in Table 23, which shows the present basal area increment as the same in treated and untreated plots.

In order to investigate further the fall-off in the slag effect, sections were cut at breast height from four trees of mean girth (slagged and unslagged), and from three of the hundred largest trees (slagged and unslagged) rings were counted and their width measured (to nearest 1/10th mm.), converted to basal area (sq. cm.), and plotted against age. A hand-smoothed average curve for each category is shown in Fig. 9.

The number of samples is too small for statistical significance, but in spite of the considerable variation between individual trees, there are some fairly clear indications which are in accord with the results of the plot assessments.

The main points brought out by these stem analyses are:

(i) The slag effect is greater on the trees of mean girth than on the largest trees. (ii) The slag effect is largest on the trees of mean girth at 10 to 20 years. Thereafter it falls until annual basal area increment is the same as that of the unslagged trees. The crossing of the two curves is not regarded as significant – although it might suggest that the early 'boost' from slag has created a crop whose demands for nutrients are in excess of supply. However, the absence of a similar crossing of the curves for the hundred largest trees argues against this suggestion.

While due caution must be observed in considering these results, since differing sites, species, and fertiliser dosages may well produce other patterns, the experiment certainly confirms the desirability of studying fertiliser effects on the various components of the crop, and not merely on the crop as a whole. It also shows the usefulness of increment cores in studying the duration of fertiliser effects, and there might be a practical application here in identifying the point at which further dressings are required.

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SOME EFFECTS OF ISOLATING SELECTED PLANTATION TREES FOR THE FIRST SIXTEEN TO TWENTY-THREE YEARS AFTER PLANTING

By D. W. HENMAN

Introduction

The relationship between girth increment and the espacement of trees in plantations is quite familiar. In the extreme case of complete isolation, as in parks and arboreta, noticeable effects in the taper and branching of the trees are also seen. While there may be objections, on grounds of silviculture, management and potential yield, to growing timber crops under such conditions of individual isolation, it was decided in 1950 that some quantitative data should be obtained of the order of growth differences arising between 'normally' grown and isolated trees.

Sample Plots in different thinning grades provide a measure of the growth and form variations which result from increased growing space being given to most of the better stems (low thinnings) or to a favoured few of the best stems (crown thinnings), after crops have undergone a period of increasing mutual competition following canopy closure. The present preliminary study is of the effect on individual trees of eliminating this initial period of crown competition, by selecting the predominant stems in a young plantation, and cutting out each neighbouring tree as soon as any part of its crown over-lapped with that of a selected tree. In this way the selected trees always had complete overhead light and, because the removal of a neighbour left a gap for several years, a considerable amount of side light on most aspects at any time. For the latter reason also, the root competition with the selected trees was probably of a low order, though this point was not studied. The development of these 'isolated' trees was compared with that of similar predominant individuals around which the stand was allowed to close in the usual way until the normal time for first thinning, after which the crop was to be given crown thinning to favour the selected (control) trees. In fact, up to the present, thinning has been done in only one of the experiments, and that quite recently, so that its effect on the trees will be small.

The experimental treatments were thus:

Treatment C – Selected trees subjected to normal closure of canopy and increasing competition.

Treatment I – Selected trees isolated from direct crown competition since planting.

Predominant trees were chosen in crops of Douglas fir, Norway spruce and Sitka spruce from five to twelve years old; their heights were then 8 to 14 feet and they were distributed at 17 to 40 per acre in the various experiments. In each experiment, the selected trees were ranked in order of height or of current height increment, and allocated alternately between the two treatments. This use of single tree units enables statistical comparisons to be made between treatment effects, while reducing the amount of ground which would be required by replicated plots of each treatment.

Since the branches kept alive by isolation of the trees were expected to increase in thickness, forming knotty timber, additional trials were established in 1951 to test pruning of isolated trees on sites adjoining the original isolation/closed canopy trials. Trees were isolated at 47 to 64 per acre, when 10 to 20 feet high. They were ranked and allocated as in 1950 to the following treatments:

Treatment IP_0 – No pruning.

Treatment IP_1 – Pruned to 10 ft. and later to 18 ft., so as to leave about six live whorls on the pruned trees after each pruning.

At each experimental site (except Glenfinart) both trials (isolation/no isolation and pruning/no pruning) were represented, and each had one treatment (isolation without pruning) in common. As they were established on adjoining parts of the same stands, the trees may be considered as belonging to similar populations; but since the two trials were not replicated at each site this similarity cannot be estimated, and only limited comparisons may be made between the trials. The need for this caution is confirmed by dissimilarities in height or girth growth of the common treatment between the two trials at some of the sites.

The experiments and their treatments are listed in Table 25.

Table 25

List of Pruning and Isolation Experiments

Species	Forest and Experiment No.	P. Year	Begun 1950: Isolation (I) *versus* No Isolation (C)	Begun 1951: Pruning (P_1) *versus* No Pruning (P_0) of isolated trees
Douglas fir	Mabie 3/50	46	I and C	IP_0 and IP_1
Norway spruce	Ae 11/50	39	I and C	IP_0 and IP_1
	Glenfinart 1/50	42	I and C	—
Sitka spruce	Ae 12/50	39	I and C	IP_0 and IP_1
	Benmore 6/50	42	I and C	IP_0 and IP_1

The tabulated results which follow are based on means of 8 to 16 trees in each treatment. The trees were measured initially for height and breast-height girth, and finally for height and for girth at one foot, breast height, ten feet and eighteen feet above ground level. These final girth measurements are not sufficiently numerous to allow precise comparisons of tree form, as expressed by the diameter/height profile of the stems, but they have been used to compute the rate of stem taper between the points of measurement. Upper crown height (the point at which live branches are found on all sides of the stem) was measured at the final assessment, also the thickness of the branches in the first whorl above 6 feet and above 18 feet. These latter were measures with a metal V-gauge applied three inches from the stem, the diameter of the thickest branch and the mean diameter of the four thickest branches in each whorl being recorded. In

Table 26

Height Growth of Isolated (I) and Control Trees (C)

(feet)

Species and Forest	Height at end of Forest Year 50			Height at end of Forest Year 61			Height Increment (11-year Period)		
	Treatment		Standard Error	Treatment		Standard Error	Treatment		Diff. from C
	C	I		C	I		C	I	
Douglas fir									
Mabie . .	10·9	11·2	±0·23	39·9	38·3	±2·8	29·0	27·1	—1·9
Norway spruce									
Ae . . .	12·9	13·3	±0·18	38·1	38·6	±0·80	25·2	25·3	+0·1
Glenfinart .	10·2	10·2	±0·08	23·9	28·8	±0·92**	13·7	18·6	+4·9
Sitka spruce									
Ae . . .	13·8	13·6	±0·33	31·8	31·2	±1·1	18·0	17·6	—0·4
Benmore .	8·3	8·2	±0·05	24·9	24·9	±0·67	16·6	16·7	+0·1

Standard errors marked * or ** indicate that the differences between treatments are significant at probabilities of 5 and 1 per cent respectively.

Table 27

Breast-height Girth Growth of Isolated and Control Trees

(inches)

Species and Forest	Girth at end of Forest Year 50			Girth at end of Forest Year 61			B.H. Girth Increment (11-year Period)		
	Treatment		Standard Error	Treatment		Standard Error	Treatment		Diff. from C
	C	I		C	I		C	I	
Douglas fir									
Mabie . .	3·4	3·7	±0·14	18·4	24·1	±1·5*	15·0	20·4	+5·4
Norway spruce									
Ae . . .	7·9	8·6	±0·29	20·5	26·3	±0·72**	12·6	17·7	+5·1
Glenfinart .	5·3	5·0	±0·14	13·6	20·3	±1·02**	8·3	15·3	+7·0
Sitka spruce									
Ae . . .	9·0	8·5	±0·32	19·0	21·0	±1·1	10·0	12·5	+2·5
Benmore .	4·1	4·0	±0·09	15·8	22·2	±0·80**	11·7	18·2	+6·5

Standard errors marked * or ** indicate that the differences between treatments are significant at probabilities of 5 and 1 per cent respectively.

addition, the diameter of the stem three inches above the whorls was measured, and the ratio of the diameter of the thickest branch to diameter of stem was computed.

Comparison of Isolated and Non-isolated Trees (Treatments I and C)

Height and girth growth over the eleven-year period of the experiments are shown in Tables 26 and 27.

The effect of isolation on the height increment of the trees was very slight in most cases – less than half a foot greater or smaller over eleven years. In the Douglas fir, height increment was nearly 2 feet less in the isolated trees, though this difference was not significant. Only in the Norway spruce at Glenfinart was there an important height effect; there the increment of the isolated trees during the period was nearly 5 feet greater than that of the control trees, this difference being very significant. The reason for this exception is obscure; the whole crop has grown only slowly, with periods of sparse foliage and poor colour, although it appears to occupy a reasonable spruce site. Health and vigour have been noted to be generally better in the isolated trees; this may be due to reduced competition for moisture in the 17 inches of freely-draining soil over solid rock, especially during spring droughts.

Girth increment at breast height was greater in the isolated trees in all experiments, with differences ranging from 2½ to 7 inches after eleven years at the various sites. The greatest increase was in the slow-growing Norway spruce at Glenfinart, where it was 84 per cent greater than the growth of the non-isolated trees. On average in all experiments, a 45 per cent increase in breast-height girth increment was obtained. The differences in final girth were significant or very significant in all cases except the Sitka spruce at Ae.

The increased girth growth of the isolated trees at breast height was repeated at other levels in the stem, though to different degrees; at one foot above ground the increase was greater than at breast height, while at ten feet and eighteen feet (the highest point measured) it was less, with the net result that the stem taper of the isolated trees was increased. Taper in each of the three sections of stem has been determined and is expressed as 'percentage taper', that is, the change in diameter in inches per 100 linear inches of stem length. (For example, the rate of taper of one inch in seven feet, commonly used in pit-prop calculations, represents a percentage taper of 1·2). The results from the five experiments are shown in Table 28.

Table 28

Percentage Taper in Three Sections of Stem for Isolated and Control Trees

Experiment	Treatment	Stem Section		
		1 ft. to Breast Height	Breast Height to 10 ft.	10 ft. to 18 ft.
Douglas fir				
Mabie . .	C, control	2·8	1·0	1·2
	I, isolated	5·9	1·6	2·3
Norway spruce				
Ae	C, control	3·8	1·3	1·1
	I, isolated	5·9	1·9	1·7
Glenfinart .	C, control	2·8	1·6	1·6
	I, isolated	4·4	2·5	2·5
Sitka spruce				
Ae . .	C, control	4·1	1·4	1·4
	I, isolated	4·6	1·3	2·3
Benmore .	C, control	3·6	1·4	2·1
	I, isolated	5·6	3·0	2·8

Taper was increased in every section as a result of isolation, except in the 'breast height to 10 ft.' section in the Sitka spruce at Ae. Hence the overall taper from ground to 18 ft. was increased by isolation, and since diameter at 18 feet was always greater in the isolated trees, while total height was similar, taper must have been increased in the section from 18 ft. to the tip.

Other points of interest are the much greater taper in the 'butt-swell' section (below breast height) than in higher sections in both treatments (a well-known fact, but not often expressed quantitatively), and the fact that the change in taper due to isolation is more marked in this butt section than higher up. Also, that in the two upper sections (above breast height), taper is less in the taller trees (cf. Tables 26 and 28), demonstrating the normal progressive 'filling out' of the bole which accompanies height growth, irrespective of (thinning) treatment.

The volumes of the individual trees were not measured, but an approximate comparison of the effect of isolation on the volume of the trees has been obtained by assuming for each treatment in each experiment a hypothetical mean tree whose girth at one foot, breast height, ten feet and eighteen feet is the mean of all the trees in that treatment. These girths were then used as the mid-point girths in sections of stem 2, 4½, 7 and 9 feet long to compute the volume of the lower 22½ feet of the stem of the hypothetical mean tree. The volumes are shown in Table 29. In some experiments this volume accounts for most of the length of the stem (e.g. Benmore), while in others (e.g. Mabie) it represents rather more than half the length. The isolated trees had volumes 20 per cent to 92 per cent greater than the non-isolated trees, the greatest benefit being to the Norway spruce at Glenfinart.

Table 29

Volume of the Lower 22½ Feet of the Hypothetical Mean Tree at end of Forest Year 61

(Hoppus feet)

Species and Forest	Volume of Mean Tree: Treatment Control (C)	Volume of Mean Tree: Treatment Isolated (I)	Volume Difference from Treatment C	Difference as Percentage Treatment C
Douglas fir				
Mabie . . .	2·1	3·2	+1·1	+52%
Norway spruce				
Ae	3·1	4·9	+1·8	+58%
Glenfinart . . .	1·2	2·3	+1·1	+92%
Sitka spruce				
Ae	2·5	3·0	+0·5	+20%
Benmore . . .	1·5	2·6	+1·1	+73%

Suppression of the lower whorls of the crowns was retarded by isolation, but not eliminated. Table 30 shows that the height of the 'upper crowns' (the point at which live branches are found on all sides of the stem) of isolated trees was from 2½ to 10 feet lower than that of trees round which the canopy had been allowed to close. It is, of course, by means of this increased length of crown that the isolated trees have made their increased growth. The branches at the lower levels are considerably longer in isolated trees, since after eleven years the trees stand in gaps in the crop which range from 15 to 25 feet or more in diameter, i.e. more than half the height of trees.

The increased overall size of branches and their weight of foliage have resulted in increased branch thickness in the isolated trees, but the difference at the present stage is surprisingly small, as shown in Table 30 – generally about $\frac{1}{5}$ inch measured at a point 3 inches from the stem. In the lower part of the crown, about 6 feet above ground level, the branches of the isolated trees will soon be dead and the differences in thickness will not become any greater than shown in the table; the thickness relative to that of the stem just above the branch will then progressively decrease in both treatments; it may thus be said that isolation has not appreciably increased the knottiness of this part of the stems. At 18 feet above ground, well above the upper crown height in both treatments, branch thickness is again slightly greater in isolated trees, though the difference is small as yet, about $\frac{1}{10}$ inch. The ratio of thickest branch to stem diameter at

Table 30

Crown Heights and Branch Diameters of Isolated and Control Trees

Experiment	Treatment C = Control I = Isolated	Upper Crown Height (ft.)	Branch Diameters					
			First Whorl above 6 feet			First Whorl above 18 feet		
			Four Thickest Branches (in.)	Thickest Branch (in.)	Thickest Branch/ Stem Ratio (%)	Four Thickest Branches (in.)	Thickest Branch (in.)	Thickest Branch/ Stem Ratio (%)
Douglas fir								
Mabie . .	C	15·0	0·8	0·9	17	0·9	1·1	30
	I	5·1	1·2	1·5	23	1·0	1·1	28
Norway spruce								
Ae . .	C	14·0	0·7	0·7	12	0·9	1·0	25
	I	6·2	0·9	1·0	12	1·0	1·2	24
Glenfinart .	C	8·9	0·6	0·6	18	0·6	0·6	36
	I	2·1	0·8	0·9	17	0·7	0·7	37
Sitka spruce								
Ae . .	C	9·2	0·6	0·7	14	0·7	0·8	26
	I	6·6	0·8	0·9	16	0·8	0·9	30
Benmore .	C	12·6	0·7	0·7	17	0·6	0·6	41
	I	3·2	1·1	1·2	20	0·5	0·7	38

this level shows no consistent features throughout the experiments. It can be expected that the branches at 18 ft. and above in the isolated trees will remain alive and increase in size for many years yet, so that the stems at this level will certainly contain larger knots than at 6 ft. above ground, and will probably have larger knots than the control trees at the same level.

The difference in diameter between the thickest branch in a whorl, and the average of the four-thickest branches, was found to be very small, particularly in the control trees where there was frequently no difference at all. This suggests that for many purposes a sufficiently accurate determination of branch diameter may be made by measuring the thickest branch in a given whorl.

Comparison of Pruned and Unpruned Isolated Trees (Treatments IP_1 and IP_0)

Pruning is done with the main object of eliminating knots from the outer portion of a tree's trunk, that is, from the outer shell that will be formed *after* the pruning is done. In normal plantation management, pruning consists of removing the lower dead branches plus as much of the live crown as is considered permissible (up to the required length of pruned stem). In the case of isolated trees, pruning is required to remove continually-thickening green branches, and these persist almost to ground level; so the pruning of a practical length of stem will effect, suddenly and drastically, the reduction of crown length which under normal plantation conditions occurs gradually as the canopy closes. It can be expected that this loss of assimilating potential, together with the demand for healing of many pruning wounds, will result in a sharp reduction of growth relative to that of unpruned isolated trees.

These considerations set a problem in formulating a pruning schedule for the isolated trees. It was decided to prune in two stages, to 10 feet and to 18 feet, as soon as the stem girth at these heights reached 7½ inches. However, these girths were achieved at different ages by different trees, so the question arose

Table 31

Height Growth of Pruned and Unpruned Isolated Trees

(feet)

Species and Forest	Height at end of Forest Year 51			Height at end of Forest Year 61			Height Increment (10-year Period)		
	Treatment		Standard Error	Treatment		Standard Error	Unpruned IP_0	Pruned IP_1	Diff. from IP_0
	Unpruned IP_0	Pruned IP_1		Unpruned IP_0	Pruned IP_1				
Douglas fir Mabie†	14·7	16·2	±0·51*	37·0	37·3	±1·8	22·3	21·1	—1·2
Norway spruce Ae	16·8	16·2	±0·17	37·1	33·3	±0·72**	20·3	17·1	—3·2
Sitka spruce Ae	19·6	19·7	±0·52	38·9	39·0	±0·98	19·3	19·3	0
Benmore	12·8	12·4	±0·25	23·6	22·7	±0·65	10·8	10·3	—0·5

Table 32

Breast-height Girth Growth of Pruned and Unpruned Isolated Trees

(inches)

Species and Forest	Height at end of Forest Year 51			Height at end of Forest Year 61			Height Increment (10-year Period)		
	Treatment		Standard Error	Treatment		Standard Error	Unpruned IP_0	Pruned IP_1	Diff. from IP_0
	Unpruned IP_0	Pruned IP_1		Unpruned IP_0	Pruned IP_1				
Douglas fir Mabie†	6·6	7·1	±0·27	24·5	21·4	±1·4	17·9	14·3	—3·6
Norway spruce Ae	9·4	9·1	±0·23	24·5	19·1	±0·82**	15·1	10·0	—5·1
Sitka spruce Ae	12·0	11·7	±0·46	26·4	24·5	±0·91	14·4	12·8	—1·6
Benmore	8·8	9·0	±0·26	22·7	18·8	±0·91**	13·9	9·8	—4·1

Standard errors marked * and ** indicate that the differences between treatment are significant at probabilities of 5 and 1 per cent respectively.

† Initial heights and girths of the Douglas fir at Mabie are for the end of 1952, and the increments in the last two columns thus refer to a 9-year period.

whether to prune each tree when it became ready, or all trees at one time, and if the latter, whether to prune when one tree, or a proportion, or all the trees had reached the girth limit. (This kind of problem is common to the formulation of pruning prescriptions on any basis.) In the Sitka spruce at Benmore individual trees were pruned as they became ready, and an average girth of 8½ inches at 10 ft. was obtained. In the other three experiments all the trees were pruned when the smallest had reached the girth limit, giving average girths of 10½, 11 and 13½ inches at 10 feet, and of 8, 10½ and 10½ inches at the 18 feet height for the second pruning. A more consistent expression of the severity of these prunings is given by the number of whorls *left on the trees* after each pruning. The extreme variation was from four to eight whorls, but in the majority of cases five or six whorls remained. Non-isolated dominant trees of similar size and age, at customary spacing, usually carry seven or eight completely live whorls, so the pruning of the isolated trees reduced their crown lengths to about three-quarters of the length carried *under normal plantation conditions*, a severe pruning considering that the crowns before pruning occupied almost the whole height of the stems. In terms of percentage of live crown length removed, the pruning severities varied from 35 to 55 per cent, and the pruning cycles from 2 to 3 years in the different experiments.

First pruning was carried out when the Douglas fir was 11 years old, and when the spruces were 14 to 17 years old. The latest assessment, at the end of 1961, was made two to four years after the second pruning. The results of these prunings on the height and breast-height girth of isolated trees are shown in Tables 31 and 32.

In height, pruning reduced increment appreciably in only one experiment, the Norway spruce at Forest of Ae, where the final height of the pruned trees was very significantly less than that of unpruned trees. This is at least partly due to the adverse effects of heather growth in part of the experiment, which happened to affect more pruned than unpruned trees.

In breast-height girth, pruning invariably reduced increment. The reductions varied from 1½ to 5 inches in total increments of 14 to 18 inches. The smaller final girths in Norway spruce at Forest of Ae, and in Sitka spruce at Benmore, were very significantly different from those of the unpruned trees. Girth increment was also reduced at other levels in the stem of pruned isolated trees, viz. one foot, ten feet and eighteen feet above ground level.

Reduction of girth growth as a result of pruning was greatest near the base of the stem and least near the remaining crown, the relative reductions at each level being such as to reduce the taper of each of the three sections of stem. This is shown in Table 33.

The effect of pruning on the volume of the hypothetical mean tree is shown in Table 34.

Summary and Discussion

These experiments have confirmed and given quantitative expression to some of the growth effects resulting from the continued isolation of plantation-grown trees. From the biological standpoint, they may be more logically considered to demonstrate the converse, i.e. the effects of subjecting individually-planted trees to increasing mutual competition during the following closure of canopy; but for this purpose we have no assurance that the degree of freedom from competition afforded to the isolated trees was as great as if they had been quite openly grown, from much-wider-than-normal initial plant spacing.

Table 33

Percentage Taper in Three Sections of Stem, Pruned and Unpruned Isolated Trees

Experiment	Treatment	Stem Section		
		1 ft. to breast height	Breast height to 10 ft.	10 ft. to 18 ft.
Douglas fir Mabie	IP_0 unpruned	5·6	1·6	2·2
	IP_1 pruned	4·4	1·3	1·7
Norway spruce Ae	IP_0 unpruned	5·1	1·7	1·7
	IP_1 pruned	3·1	1·2	1·1
Sitka spruce Ae	IP_0 unpruned	6·7	1·3	1·7
	IP_1 pruned	5·1	1·2	1·5
Benmore	IP_0 unpruned	5·9	3·5	2·1
	IP_1 pruned	3·6	2·2	3·2

Table 34

Volume of the Lower 22½ Feet of the Hypothetical Mean Tree at End of Forest Year 61, *Pruned and Unpruned Isolated Trees*

(Hoppus feet)

Species and Forest	Volume of Mean Tree		Volume Difference from Treatment IP_0	Difference as % of Treatment IP_0
	Treat. IP_0 Unpruned	Treat. IP_1 Pruned		
Douglas fir Mabie	4·2	3·3	—0·9	—21%
Norway spruce Ae	4·2	2·7	—1·5	—36%
Sitka spruce Ae	5·4	4·7	—0·7	—13%
Benmore	2·9	1·9	—1·0	—34%

Within the limits of the treatments tested, height growth was unaffected except in one unusual case, whereas the girths of the isolated trees at 16 to 23 years old exceeded that of the non-isolated trees by amounts which the latter will probably never make up, even if a very heavy crown thinning were to be employed hereafter. Girth was increased at all points in the lower half to two-thirds of the stems, with a consequent increase in volume. The increases were more pronounced at the base of the stems, giving greater taper in the isolated trees. In general the greatest responses to isolation, in terms of improved girth and volume increment, were shown by trees in the less healthy or more slowly-growing crops.

Pruning of isolated trees to a height suitable for practical purposes was necessarily severe, since the crowns were live almost to ground level. It resulted in negligible loss of height growth in most cases. Though loss of girth and volume increment was considerable, compared with unpruned isolated trees, it was less than that which had resulted from progressive canopy closure in trees in the adjacent 'isolation/no isolation' trials, even though in the latter the actual reduction in live crown length had not been so drastic as by the pruning (compare Tables 27, 29 and 30 with Tables 32 and 34). So far as comparisons can be made between the adjacent trials, this supports the view that root competition plays a considerable part in the slowing down of individual tree growth under plantation conditions.

Increase in branch diameter as a result of isolation was, up to date, found to be not excessive, so timber sawn from the isolated trees in their present condition would have only slightly larger knots, and these would have the advantage of being live and therefore tight and sound.

Practical Application of 'Isolation Thinning'

From the point of view of increased girth and volume in individual trees, the practice of isolation described here has obvious advantages. However, the increase has been achieved only by a considerable sacrifice of neighbouring stems, at an early age when they may not have provided useful produce (in fact, the Norway spruce trials provided Christmas trees in season). Owing to the experimental design, with both treatments represented on the same area, it has not been possible to compare basal area or volume production per acre under each treatment, and hence determine whether an actual reduction in total yield has occurred; in any future work on the subject, experiments using replicated plots for yield determination must be established.

Considered in the broader context of thinning practices in general, the method may be placed within a series of progressively less 'selective' types of thinning (selective as regards the trees left standing), as follows:

(1) Wide-spaced Planting and Complete Isolation Throughout the Rotation

In its most extreme form this would mean planting at final-crop spacing; in a modified form it is represented in Forestry Commission experiments by the 'Q' series of 1935-36 Spacing Experiments, where 'very heavy' thinnings are made in crops originally planted at 8 ft. x 8 ft. spacing. The method is suitable only where there is little or no competition from ground vegetation, which may smother young plants or reduce subsequent growth. No early thinning of low-value stems is necessary; on the other hand, there is no latitude for the removal of undesirable stems, which demands a high degree of quality and uniformity in the genotype of the planting stock. In the more extreme cases, crops grown in this way will not be utilising the full yield capacity of the site, at least until the latter part of the rotation, although the effects of such treatments on the total yield of crops are still under investigation.

(2) Normal (4½ ft. to 6 ft.) Plant Spacing, with Subsequent Isolation of a Very Limited Number (about 30 per acre) of Stems to Prevent Canopy Closure Around Them

This is the method described in the main part of this paper. It gives some early control of vegetation, but is unsuitable where subsequent adverse invasion of the isolation spaces may occur, e.g. by heather, *Calluna vulgaris*, on ploughed heathland. Best results will depend on accurate recognition of the potentially most vigorous trees at the early stage at which selection for isolation must be made. As in (1) above, the method may not fully utilise the site potential; also, it requires frequent expenditure on (probably unprofitable) thinning operations, though losses on individual early thinnings may be justified by greater economic gains taken over the whole rotation.

(3) Normal Plant Spacing and Canopy Closure, Followed by Intensive Favouring of a Limited Number (about 60 per acre) of Selected 'Crop' Trees

This is typified by the Scottish Eclectic thinning (Macdonald, 1961). It postpones the selection of the trees to be favoured until a stage when recognition of the potentially most vigorous and best-formed is fairly certain. It is within the limits in which it may be assumed that thinning treatment will not affect the total yield of the site. Other features of the method, and comparisons with more usual crown and low thinnings, are treated by Macdonald (*ibid*).

(4) Other Crown Thinnings, Such as the Forestry Commission Heavy Crown and Light Crown Thinnings Described in Bulletin 31, Code of Sample Plot Procedure, Appendix III

These aim to favour more of the top-canopy stems than is the case in the Scottish Eclectic thinning.

(5) Low Thinnings

In these, release of the top-canopy stems from mutual competition is delayed until after most lower-canopy stems have been removed, the timing and degree of release depending upon the grade of thinning. In the heavier low thinnings, in particular, crown competition between top-canopy trees may eventually become similar to that in crown thinnings in general, though the latter may continue to experience root competition from lower canopy trees.

The variety of factors which might govern the choice of thinning method from among the above (or others) for a particular site and set of circumstances is beyond the scope of this paper. From the point of view of future research on thinning, these are some of the methods which might be compared.

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TRIALS OF 2,4,5-T FOR REMOVAL OF EPICORMIC SHOOTS ON HARDWOODS

By G. D. HOLMES

Several hardwood species, notably oak, poplar and elm, are prone to develop large numbers of epicormic shoots along their main stem in certain circumstances. These epicormic shoots may arise from dormant buds present since the original shoot was formed, or they may develop from entirely new, adventitious buds formed from groups of cells in the bast of the stem. There may be considerable delay in development of such shoots, and they may appear long after the lower part of the main stem has been cleaned of its original branches by natural or artificial pruning. Once developed, the shoots increase in size, and become incorporated as knots in the main stem as this increases in diameter, thus introducing a degrade in timber quality. Degrade from this cause may represent a considerable loss in timber value, notably where the objective is production of large dimension, high quality veneer logs, for which purpose it is essential that the outer layers of the trunk are knot-free. Normal methods for producing high-grade, knot-free timber will include periodic artificial pruning of the original lower branches, as in poplar, or close spacing to accelerate natural death and pruning of lower branches, as in oak. A variety of factors, some of which can be controlled, determine the extent to which epicormic shoots develop to produce a secondary lower branch system.

Epicormics are commonly produced as a reaction to 'replace' branches and foliage lost when normal branches are pruned off, or when foliage on the normal branch system is considerably reduced by heavy shading, or by insect or disease attack. Also, they may develop strongly with sudden changes of environment, as when closely-grown trees are suddenly freed by heavy thinning. Thus the incidence of epicormics can be reduced by avoiding drastic pruning of green branches, and by avoiding delays and sudden changes in grades of thinning. However, not all factors responsible can be foreseen and controlled, and the problem of removing epicormic shoots from selected stems may have to be faced in practice.

Development of New Pruning Methods

Epicormic sprouts may develop in large numbers on individual stems, and their removal using cutting tools can be time-consuming and costly. Also, other dormant and adventitious buds may be stimulated to develop, necessitating repeated pruning operations.

Splettstösser, in Germany in 1951, was the first worker to carry out trials using growth-regulator herbicides for controlling epicormic shoots on tree stems. The idea arose from observations in 'brush-control' work that foliage sprays of 2,4-D or 2,4,5-T solutions were rarely effective in killing the whole plant unless *all* leaves and shoots of the woody plant were covered. Treatment of part of the foliage area, or the foliage of one branch, frequently resulted in death of only the sprayed branch, leaving the rest of the plant unaffected. It seemed possible, therefore, that unwanted branches or epicormic shoots could be sprayed and killed back without serious damage to the parent stem.

In 1951, Splettstösser tested several growth regulators applied to epicormic branches of oak as directed foliage-sprays during the summer. He obtained promising results using a dilute emulsion of 2,4,5-T amyl ester in water, and trials of this compound were extended during the period 1953–56. He found that treated shoots shed their leaves within a few weeks, followed by rapid die-back and drying of the treated branches. Within 2 to 3 years, the sprayed branches fell off unaided or were readily brushed off. *Also*, resprouting was reduced compared with normally pruned stems. The stem and crown of treated trees seemed quite unaffected, and examination of timber in sprayed trees showed no abnormality or discoloration of the main stem wood. Anatomical studies by Meyer-Wegelin (1959) revealed that a layer of protective scar tissue is formed at the base of the dead branches within one year of spraying. This protective layer was reported to be similar to that developing following suppression and natural death of branches, and it seems important in sealing-off the dead branch and excluding infection of the main stem.

These results reported for oak were encouraging, and suggested that herbicide treatment of epicormics could provide a low-cost and effective method of pruning epicormic shoots. Also, compared with normal pruning methods, there were two advantages – that resprouting was reduced, and open wounds on the stem were avoided. As a result of work to 1956, Splettstösser concluded that for oak, the indicated treatment was 0·2 per cent amyl ester of 2,4,5-T water emulsion, applied so as to thoroughly wet all foliage and shoots of the unwanted growth during the period June to August, i.e. the stage of maximum vegetative growth. He recommended that the treatment be applied to a height of 10 to 20 ft., using a long spray-lance and knapsack sprayer, preferably on trees not exceeding 8 inches diameter at breast height for maximum production of knot-free timber. It was also indicated that a second treatment to kill-off any resprouts may be advisable 3 to 4 years after treatment, when remaining dead shoots are brushed off.

As a result of this work, preliminary trials were made in 1958 and 1960 in several Forestry Commission stands of oak, poplar and elm exhibiting epicormic growth. The main features and results to date of these trials are summarised below, and are illustrated in Plates 4 to 7.

Oak

1958 Trial

The first trial was made in summer 1958 at Alice Holt Forest in Hampshire, in a pure stand of 30-year-old oak. The trees selected for treatment were 3 to 4 in. diameter at breast height, and bore a large number of epicormic shoots 6 to 30 in. long, the shoots ranging from 1 to 3 years old.

2,4,5-T amyl ester was tested at two concentrations, 0·1 and 0·2 per cent (acid) in water emulsion, applied as a drenching spray to the shoots along the boles up to a height of 10 ft. The spraying was done in mid-August using a knapsack sprayer fitted with a long spray-lance. For comparative purposes the same numbers of trees were pruned by hand, using secateurs, removing all shoots flush with the stem. Treatment effects were assessed in 1958 and 1959 using a visual score to describe the extent of die-back of shoots, viz.:

1 = shoots alive and normal;
2 = shoot tips dead;
3 = shoot dead $\frac{1}{3}$-$\frac{1}{2}$ their length;
4 = shoots dead more than $\frac{1}{2}$ their length;
5 = shoots dead to the base.

Results appear in Table 35.

Both treatments caused rapid death of sprayed leaves, and die-back of the tip 1 to 2 in. of each shoot before winter 1958. There was little to choose between treatments until June 1959, when the higher concentration was slightly better than the lower. Only 1-year-old shoots were killed-back to the main stem, and one year after treatment almost all the older shoots were alive and apparently unaffected for the lower 2 to 3 in. of their length.

The hand-pruned trees resprouted strongly during 1959, producing appreciably more new shoots than sprayed stems. The stem and crown of sprayed trees showed no signs of damage from treatment.

Table 35

Die-back of Oak Epicormic Shoots Following Spray with 2,4,5-T

Treatment	Shoot Die-Back Score (1–5) Date of Assessment September 1958	November 1958	June 1959
0·1% 2,4,5-T (acid)	1·9	2·4	3·4
0·2% 2,4,5-T (acid)	1·8	2·4	3·8

Results were not considered satisfactory as many shoots were incompletely killed. Also, all sprayed shoots, including smaller shoots killed-back to the base, remained firmly attached to the main stem one year after treatment. These shoots, even though dead, had not become sufficiently dry and brittle to be removed easily.

1960 Trial

A further trial was established in 1960 in 59-year-old oak (average diameter 7 in. at breast height) in the Forest of Dean. In view of the partial failure of the 1958 treatments at Alice Holt, spray concentrations were increased to 0·2 and 0·4 per cent 2,4,5-T (acid) and tests were made with two ester formulations, namely amyl ester as before, and ethyl-butyl ester. The trees had been pruned in 1956 and 1958, and at the time of spray application on August 2nd, 1960, the boles carried a heavy crop of epicormic shoots 1 to 3 years old. As in the earlier trial, sprays were applied to a height of 10 ft. up each bole. The results of counts of epicormic shoots present at the time of treatment and at the end of the following season are given in Table 36.

Table 36

Average Numbers of Living Epicormic Shoots Per Tree

Treatment	No. live original epicormic shoots at: Treatment Aug. 1960	Sept. 1961	No. new epicormics developed since treatment September 1961	Total No. live epicormics September 1961
0. Hand-pruned . .	104	0	18	18
1. 2,4,5-T (amyl) 0·2% .	73	17	2	19
2. 2,4,5-T (amyl) 0·4% .	99	6	4	10
3. 2,4,5-T (ethylbutyl) 0·2% . . .	96	13	2	15
4. 2,4,5-T (ethylbutyl) 0·4% . . .	103	10	2	12

As in the 1958 trial, all spray treatments resulted in rapid death of foliage and die-back of shoot tips in the season of application. At the end of the second season after treatment, the number of living epicormics was markedly reduced by all treatments, the 0·4 per cent spray seeming marginally better than 0·2 per cent (see Table 36). The living shoots recorded in Col. 3 of Table 36 are likely to produce fresh sprouts. However, the great majority of original shoots were killed-back to within ½ in. of the main stem, and small one-year shoots were killed to the base. This is almost a repetition of the result of the 1958 trial, and increasing the concentration of 2,4,5-T to 0·4 per cent (acid) did not notably increase the proportion of older shoots killed totally to the main stem level.

The production of fresh epicormics following treatment was considerably less on sprayed trees compared with those hand-pruned.

The results of these small-scale preliminary trials on oak were somewhat disappointing. All treatments were effective in killing-back the smaller, one-year-old epicormics, but larger and older shoots were usually left with live bases extending ½ to 1 in. from the main stem. Also, there was little or no natural shedding of dead branches or portions of branches up to 18 to 24 months after treatment. At this time, the dead shoots remained firmly attached to the tree, requiring almost as much effort to remove as normal living shoots. It may be that branch shedding will occur about 3 years after treatment, but this seems unlikely at present. If left in position, the dead shoots will degrade the timber by incorporation of dead knots, and speedy fall or decay of the sprayed shoots seems essential before the treatments can be judged to be a practical success.

Poplar

1958 Trial

Two preliminary trials were started concurrently on Black Italian poplar and Balsam poplar at Monmouth Forest in South Wales, in August 1958. The species formed part of a poplar variety trial, and both were 12 years old, averaging 7½ in. diameter at breast height at the time of treatment. The trees had been hand-pruned in 1957 and again in 1958, and 1 to 2-year epicormic shoots were present on all stems up to a height of 20 ft. at the time of spray application on August 15th, 1958. As in the trial on oak in 1958, the spray treatments consisted of 2,4,5-T amyl ester at 0·1 and 0·2 per cent (acid). The results of counts of epicormic shoots are summarised in Table 37.

The foliage and shoot tips of both species died-back within a few weeks of spraying, and shoot die-back continued during 1959 and 1960, until, by the end of 1960, no shoots survived except for 1 to 2 shoots per tree in the case of Balsam poplar. There was very little resprouting on the Black poplar, and by 1961 all treatments were almost free of live shoots. However, resprouting was stronger in Balsam, particularly following hand-pruning and 0·1 per cent spray treatment. Resprouting was notably reduced at the higher 0·2 per cent 2,4,5-T concentration.

In terms of numbers of shoots killed, and the limited extent of resprouting, the results with the 0·2 per cent spray seemed promising for both species. The Balsam resprouted more vigorously than Black poplar, but the number of live epicormics present two years after spraying was small, and appreciably less

Table 37

Average Numbers of Living Epicormic Shoots Per Tree

Treatment	Number of *live* epicormic shoots at treatment (August 1958)				Number of original epicormics alive at:		Numbdr of new epicormics developed since treatment	Total number live shoots present at:
	Shoot Age (years)			Total No.	June 1959	Dec. 1960	Dec. 1960	Dec. 1960
	1	2	3					
(*a*) *Black Italian Poplar* Hand-pruned . .	8	1	0	9	0	0	0	0
0·1% 2,4,5-T . .	6	1	0	7	0	0	1	1
0·2% 2,4,5-T . .	7	4	0	11	0	0	0	0
(*b*) *Balsam Poplar* Hand-pruned . .	22	6	1	29	0	0	8	8
0·1% 2,4,5-T . .	20	12	0	32	6	2	10	12
0·2% 2,4,5-T . .	17	11	1	29	6	1	2	3

than on hand-pruned stems. However, as was observed for oak, results were unsatisfactory in two respects:

(i) Larger shoots were not killed-back to the main stem. Usually, some ½ in. length of shoot at the base remained alive, with a well-defined bark constriction, and commencement of occlusion at the junction of live and dead tissue.

(ii) Dead branches remain attached to the stem for at least two years after spraying. At this stage they were still tough and springy, and difficult to remove without a cutting tool.

1960 Trial

The trials were continued on Black Italian poplar at Wensum Forest (Swanton) in East Anglia, in August, 1960, using higher concentrations, i.e. 0·2 and 0·4 per cent 2,4,5-T (acid) as amyl and ethyl-butyl esters. The trees were 11 years old, and having been pruned some four seasons earlier, bore a heavy crop of 1 to 4-year-old epicormic shoots at the time of treatment on August 3rd, 1960. The early results followed the pattern of the 1958 trials, i.e. rapid death of foliage and shoot tips. Assessment of shoot death at the end of 1961 showed highly effective control of the smaller 1 to 2-year-old shoots, notably at the 0·4 per cent concentration of both ester forms. The smaller shoots withered and disappeared during the season following treatment. Results on older shoots, i.e. 3 to 4 years old, were unsatisfactory in that they were killed along only about half their length, leaving several inches of live branch base, which produced new foliage the season following spraying.

In general, the results with poplar were promising for dealing with shoots less than one year old. Such shoots were killed-back rapidly, and shrivelled and fell from the stem within a season. However, older and larger shoots remained alive at the base, sometimes resprouted (see Plate 4), and the dead portions remained firmly attached to the tree for at least two seasons. Liese (1957) carried out similar trials on poplar in 1957, and expressed some concern based on his observations on development of potentially pathogenic fungi on the dead branches left after spraying. In particular, he mentions *Dothichiza populea*, and *Cytospora chrysosperma* which developed and fructified on dead branches. The risks of serious infection of healthy tissues and other trees arising from such centres is hard to assess, but it is a warning to heed. No such fructifications were observed in the course of the trials here reported, and it seems unlikely that this would become important if treatments are confined to spraying of developing shoots less than one year old, which seems to be the most effective treatment.

In no case was any damage observed to the main stem or crown of Black or Balsam poplars within two years of spraying.

Elm

A trial was established on elm (average diameter 6 in. at breast height) at Thetford Chase Forest in early August 1960, using 0·2 and 0·4 per cent 2,4,5-T (acid) as amyl and ethyl-butyl esters. Profuse 1 to 3-year-old epicormic shoots present at treatment were killed-back rapidly in the first year. However, once again, death of shoots was complete only with shoots one-year-old or less at time of treatment. Larger branches remained alive at the base, producing fresh sprouts in the season following treatment. The dead portions of all but the smallest shoots still remained firmly attached to the trees in early summer 1962. Spray treatments have caused no apparent damage to the main stems of elm.

Costs of Treatment

The small scale and preliminary nature of the trials did not permit accurate costing. However, it is estimated that labour required for spray treatment is 25 per cent or less than that required for hand-pruning, which represents a substantial saving. Additional costs of chemicals and equipment are relatively small. Thus, spraying required 0·1 to 0·2 gallons of spray per tree, depending on size, etc. Assuming treatment of, say, 100 selected trees per acre, this requires 10 to 20 gallons spray per acre. At 0·4 per cent 2,4,5-T (acid), this involves expenditure of ten to fifteen shillings per acre on chemicals, which is considerably less than the anticipated saving in labour cost compared with hand-methods.

Conclusions

(1) Preliminary trials confirmed that 2,4,5-T ester at 0·2 to 0·4 per cent (acid) in water is effective in killing a large proportion of epicormic shoots on oak, poplar and elm.

(2) In nearly all trials, shoots older than one year were not killed completely, leaving a live base to the shoots capable of resprouting. Increasing spray concentration to 0·4 per cent 2,4,5-T (acid) did not solve this problem. Spraying earlier in the season may assist here.

(3) After treatment, the great majority of branches more than one year old at spraying remained firmly attached to the main stem for at least two years.

There is frequently a clear junction between live and dead tissue on sprayed branches, but little evidence of branch abscission.

(4) Shoots up to one year old were usually effectively killed-back to stem level, and tended to shrivel and disappear during the season following treatment.

(5) Production of new epicormic shoots was frequently retarded compared with hand-pruned control trees.

(6) No damage to the stems or crowns arising from spray treatment was recorded for oak, poplar or elm.

(7) The persistence of the dead portions of the larger shoots was a disappointing feature. These shoots remained springy and tough, and even two years after spraying required almost as much effort to remove as normal living shoots. This is clearly unsatisfactory in practice, and some means of accelerating the fall or easing the removal of branches is essential.

Smaller shoots up to one year old, on the other hand, were usually killed and lost during the season after treatment. This could have some practical value in removing heavy crops of epicormics in the year of formation.

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THE EFFECT OF CREOSOTE ON POPULATIONS OF TRYPODENDRON LINEATUM BREEDING IN STUMPS

By R. M. BALFOUR and R. C. KIRKLAND

It has been accepted that the presence of tree stumps enables *Trypodendron lineatum* Oliv. to maintain a high endemic level of population. Work on related species in West Africa (*Rept. W. Afr. Timb. Borer Res. Unit*, Lond. 1959) suggested that creosote can enhance the attractiveness of logs to beetle attack. Since this material is in routine use for the protection of stumps against *Fomes annosus*, its effect upon stump colonisation by *T. lineatum* is of obvious importance to the forester.

An investigation was therefore carried out during the autumns of 1960 and 1961, into the relative susceptibility of creosoted and untreated stumps in Argyll, West Scotland.

Methods and Techniques

In 1960, five plots were set up at both Glenduror and Inverliever forests. Each plot consisted of approximately 100 Sitka spruce stumps, half of which had been creosoted while half had been left untreated immediately after felling in December, 1959. The choice of December for the month of felling was based on the fact that timber from this period had been shown to be most susceptible to the following spring's generation of beetles. Within each plot, 10 creosoted and 10 untreated stumps were selected at random, and these were examined in September, 1960. Certain of the plots contained no infested stumps and it was therefore necessary to disregard the experimental design in order to obtain data. In such cases attacked stumps of both categories lying as close as possible to the randomly selected ones were located and examined.

In October, 1961, the investigation was continued with rather different aims in mind, and became more or less a survey of forests known to have been infested at one time or another. In each, sample areas were selected to provide material derived from a variety of felling dates (covering the period April, 1960 to March, 1961), and in these areas all stumps were examined. A total of 1,310 stumps were studied including Norway spruce, Sitka spruce, Japanese larch and Douglas fir; and all had been creosoted.

Stumps were barked for examination and the total number of borings were recorded, together with their depth as measured with a flexible wire gauge. In lightly infested stumps all emergence holes were followed up and the gallery systems opened with axe, saw and scalpel. In heavily infested ones, samples representative of aspect and position on stump were taken. Measurements of tunnels and the biological history of the broods they had contained were then noted.

Results

Remarkably few successful broods were observed in stumps (see Tables 38 and 39) and this suggests that stumps may not be the major breeding ground they have been assumed to be. Only at Glenduror were there slightly higher numbers of untreated stumps attacked than creosoted ones, though this difference was not large enough to be statistically significant. In both this forest and Inverliever, however, the success of broods seemed to have been greater in the creosoted material. A high percentage of the holes were abortive, i.e. entrance tunnels had been excavated, but no brood galleries had been bored and therefore no eggs laid, and these abortive borings were slightly more numerous in the untreated than in the creosoted stumps. Fungi and slime organisms were common in the gallery systems, as were insect predators, and it is felt that these may have been an important contributory cause of *Trypodendron* mortality.

In the 1961 investigation the only other species of tree found attacked was Japanese larch, and, apart from the December 1960 fellings, only stumps of trees felled in April/May had been infested. Prior to the investigation, a few representative log samples had also been examined and the gallery systems in all seemed to be normal, with a high percentage of successful emergences.

Summary

Investigations were carried out in the autumn of 1960 and 1961 into the incidence of *T. lineatum* in conifer stumps, mainly of Sitka spruce, and into the effect upon this insect of creosote as a stump treatment. It was found that the incidence of attack was generally low in Sitka spruce stumps, whether creosoted or not, and that the successful emergence of adults was rare compared with that from logs.

Table 38

Trypodendron lineatum,
Record of 1960 *and* 1961 *Stump Analyses*

Stump Diameter in inches	Forest, Treatment, Species and Felling Date	Total No. of Holes	No. of Holes Dissected	No. of Mother Tunnels	No. of Abortive Holes	No. of holes where development stopped at: (a) Egg Stage	(b) Larval Stage	(c) Pupal and Immature Beetles	(d) No. of holes with successful emergences	No. of successful emergences	No. of holes with Predators	No. of holes with Fungus Slime, etc.
14	Glenduror, Creosote, Sitka spruce, Nov./Dec. 1959	6	6	11	1	1	1	2	1	4	1	1
15		29	29	60	7	2	7	6	7	21	7	2
13¾		109	28	30	17	2	9	0	0	0	4	12
5¾		4	4	2	3	0	1	0	0	0	0	2
16	Glenduror, Untreated, Sitka spruce, Nov./Dec. 1959	7	7	12	3	1	2	1	0	0	1	2
16¼		51	51	75	14	3	31	0	3	6	4	23
5½		12	12	16	6	0	5	0	1	2	1	5
18	Inverliever, Creosote, Sitka spruce, Nov./Dec. 1959	9	9	13	3	0	3	0	3	4	0	7
23		98	39	70	9	0	12	0	18	109	6	12
18¾	Inverliever, Untreated, Sitka spruce, Nov./Dec. 1959	21	21	18	16	2	3	0	0	0	1	7
12½		1	1	2	0	0	1	0	0	0	0	1
16		101	42	42	27	0	12	0	3	9	5	17
18	Glenduror, Creosote, Sitka spruce, April/May 1960	31	17	26	6	0	6	0	5	51	5	12
11½		6	6	10	1	0	0	0	5	16	2	0
14		4	4	9	1	0	0	0	3	15	0	3
11		11	7	9	4	0	1	0	2	8	1	1
24		14	6	10	1	0	1	0	4	27	0	5
12½	Glenduror, Creosote, Japanese larch, December 1960	72	36	39	20	3	13	0	0	0	1	30

(a) Egg niches with no extension.
(b) Egg niches with extension made by larvae.
(c) Egg niches with widened extension for pupae.
(d) Well-developed pupal niche without remains.

Table 39

Trypodendron lineatum,
Infestation of Creosoted and Untreated Stumps

Year	Forest	Type of Stump	Number examined	Percentage attacked	Felling Date
1960	Glenduror	Creosoted, Sitka spruce	96	6·2	December, 1959
		Untreated, Sitka spruce	94	9·6	
	Inverliever	Creosoted, Sitka spruce	235	1·3	December, 1959
		Untreated, Sitka spruce	232	1·7	
1961	Glenduror	Creosoted, Sitka spruce	8	62·5	April/May, 1960
			80	0	Nov./Dec., 1960
	Other forests	Creosoted, Sitka spruce	952	0	Mar./Dec., 1960
		Creosoted, Other species	360	0·28	Jan./Dec., 1960

THE ELECTRONIC DIGITAL COMPUTER IN FOREST RESEARCH AND MANAGEMENT

By J. N. R. JEFFERS

Introduction

There is probably no more exciting field of application of electronic digital computers than that of forest research and management. In part, this is because of the very wide range of the applications, ranging from the simulation of complex natural and semi-natural processes, to problems of stock control and the compilation and summarisation of forest enumerations. In part, it is because of the unusual elements of the applied science of forestry, e.g. the long time scale and the complex interaction of many biological entities, and because of the many ways in which the basic data may arise.

It is not, therefore, surprising that foresters have, in general, been quick to sieze upon the opportunities presented by such machines. In many countries, but particularly in the United States of America, Canada, Sweden, Germany, France and Holland, the application of electronic digital computers to forestry problems has been one of the important features of modern forestry research and management, although a few forest organisations have actually acquired computers to be used solely for forest research.

In Great Britain, as in other countries, the use of electronic computers has formed part of the programme of forestry research. This work has been carried out by the Statistics Section of the Research Branch, and much of the time and energy of that Section has gone into this particular aspect of research. Electronic digital computers are now used for a very wide range of practical problems, and almost all of the computing undertaken by the Section is done on these machines.

The object of this paper is to give a history of the introduction of electronic digital computers to the work of the Research Branch, and to outline the main fields of application at the present time.

History of the Use of Computers by the Research Branch

Electronic digital computers have been used regularly for the work of the Research Branch since 1957. At that time, a number of different computers were investigated, and it became apparent that, of the machines then available, the Ferranti Pegasus computer was the most suitable for the wide range of tasks in view. It was reasonably fast in operation and relatively easy to programme, and an extensive library of computer programmes immediately useful to the Research Branch already existed. By kind permission of the Director of the Royal Aircraft Establishment at Farnborough, Hampshire, arrangements were made for much of the computing of the Statistics Section to be carried out on the Pegasus computer of the Guided Weapons Department (now Space Department) of the Royal Aircraft Establishment, which is situated only about ten miles away from the Forestry Commission Research Station at Alice Holt. Provision was also made for the use of other machines if, for any reason, this particular Pegasus computer was not available.

Two members of the Statistics Section were trained to programme the Pegasus computer, and all members of the Section, and a small number of people outside it, were taught the simplified methods of computer programming described below. All the tape-punching and editing equipment necessary for the preparation of programme and data tapes was purchased, and the staff of the section trained in their use, so that all stages of data preparation for the computer could be carried out at Alice Holt.

The work placed on the computer was at first restricted, but as knowledge of the machine and its associated programming techniques became more widespread and more detailed, actual computing was quickly increased to about two hours a week, the amount done in these two hours being roughly equivalent to six months' work on an electric desk calculator. From this modest start, the wide range of possible applications quickly became apparent, and new uses for the computer, plus the new methods of statistical analysis which the computer made possible, resulted in an increased demand for computer time. In 1961, the amount of computing was six hours per week, each six hours work being roughly equivalent to two years' work on an electric desk calculator.

It was not found possible to increase the time available on the Pegasus computer beyond this, largely because of pressure of work from the department owning the computer. For this reason, and because the demand for computing time was increasing rapidly, the possible use of other machines was explored. A limited amount of work was done on other Pegasus computers, notably at the Northampton College of Advanced Technology and at the Ferranti London Computer Centre. Some computing was also done on the much larger Mercury computers at the Royal Aircraft Establishment and at the University of Oxford, but the greater expense of hiring these machines was not offset by greater output, and the library of programmes available for statistical computations on these machines was severely limited.

A number of computers made by manufacturers other than Ferranti were also tried, but were not found to have any specific advantages, and suffered from the serious disadvantage of not having programming facilities and tape codes compatible with Pegasus, the machine most frequently used by the Section.

In the search for a possible alternative computer to Pegasus, however, a great deal of attention was given to the small, transistorized Sirius computer, also made by Ferranti. This machine was found to be capable of dealing with almost all of the work of the Research Branch, and to have many advantages over the

Pegasus computer for some of this work. Many of the programmes written for Pegasus can be run on Sirius, without any changes being made in the programmes, at about twice the speed with which they are carried out on Pegasus, and the slightly greater cost of hiring Sirius was offset by its ability to do more computing in a given time. Most of the work that could not be placed on the Pegasus computer at the Royal Aircraft Establishment has been placed, therefore, on the Sirius computer at the London Computer Centre, and four members of the staff of the Statistics Section have been trained to programme Sirius.

The Ferranti Pegasus and Sirius Computers

Descriptions of the Pegasus and Sirius computers are available in a number of books, and in the maker's specifications (Ferranti, 1958; Ferranti, 1961). A brief summary of the main features of each machine is, however, worth giving at this point.

Both computers have some features in common. Thus, both are primarily designed to receive information in the form of punched-paper tape, although both can also read information from punched cards, provided that the necessary card readers are attached. Similarly, the output from the computers is primarily in the form of punched-paper tape which is subsequently read by teleprinters to produce a printed version of the results. Again, information can be put out in the form of punched cards, if the machines are provided with card punches. The computers used by the Research Branch, however, have been fitted only with punched-paper tape input and output.

The Pegasus Computer

The Pegasus computer is a medium-sized digital computer, designed for technical, scientific, and industrial calculations. The main store of the machine takes the form of a magnetic drum capable of storing 4,096 words, each of 39 binary digits – equivalent to about 11 decimal digits – with an average access time of 9 milleseconds. This store can be extended by the use of a magnetic tape backing store, and on some machines, though not the one used by the Research Branch, can be replaced by a larger drum capable of storing 7,168 words. There is, in addition, an immediate-access store of 55 words, including seven accumulators. The time taken for the majority of individual arithmetic operations is 0·3 milleseconds, but multiplication takes 2 milleseconds and division 5·5 milleseconds. All the display facilities of the computer, and methods of entering numbers via the keyboard of the machine, make use of the binary notation.

The Sirius Computer

The Sirius computer is a small, transistorized computer designed for technical, education and commercial calculations, and for data processing. There is only one level of store, apart from nine immediate-access accumulators, and this takes the form of delay lines, using torsional propagation. The size of this store can vary from 1,000 words to 10,000 words, according to the requirements of the purchaser of the machine, but, on most machines, including that used by the Research Branch, is 4,000 words, each of ten decimal digits. Access time to the store is 4 milleseconds (one millesecond = 1,000th part of one second), and while most arithmetic operations are completed in 240 microseconds (one microsecond = 100,000th part of a second), the average time taken for multiplication and division is 8 milleseconds. In general, the speed of the machine is such that about 1,000 instructions are obeyed per second. Although basically a slower machine than Pegasus, the input and output facilities are considerably faster than those fitted to most existing Pegasus installations, and for many types of work, including statistical analysis, this factor gives almost comparable computing speeds for Pegasus and Sirius. As a decimal machine, Sirius has a marked advantage over Pegasus in that all display facilities show the contents of the store in their familiar decimal form, and numbers and instructions can be entered into the machine by means of a keyboard similar to that of a desk calculator.

The main features of the Pegasus and Sirius computers are given in tabulated form in Table 40.

Table 40

Main Features of Pegasus and Sirius Computers

Feature	Pegasus	Sirius
Number base	Binary	Decimal
Word length	39 bits	10 decimal digits
Instruction code	Modified single address	Modified single address
Arithmetic unit		
Type	Serial	Serial
Add/subtract time	0·3 milleseconds	240 milleseconds
Mult./Div. time	Multiplication 2 milleseconds Division 5·5 milleseconds	8 milleseconds (average)
Storage		
Quick access		
Type	Delay line	Delay line
Capacity	55 words	9 words
Access time	Immediate	Immediate
Main store		
Type	Magnetic drum	Delay line
Capacity	4,096 words	1,000–10,000
Access time	9 milleseconds (average)	4 milleseconds
Backing store		
Type	Magnetic tape with up to five	None
Capacity	mechanisms	
Input equipment	Punched tape, 300 characters Punched cards, 200 cards/min.	Punched tape, 250 characters Punched cards, 120 cards/min.
Output equipment	Punched tape, 300 characters Punched cards, 100 cards/min.	Punched tape, 300 characters Punched cards, 120 cards/min.
Valve or transistor	Valve	Transistor

Programming Methods

Perhaps even more important to the practical user than the physical features of the machines are the methods by which they can be instructed to carry out the computations necessary for the solution of a particular problem. The series of instructions given to the computer is known as a *programme*, and it is the computer's ability to obey such a series of instructions, held in the store of the machine, which distinguishes it from all other types of calculating machine. Methods of programming computers differ markedly from machine to machine, and the closeness with which a computer programme can be made to approximate to the form in which the solution of a problem is conceived in the mind of the programmer is a measure of the usefulness of the computer. Both Pegasus and Sirius can be programmed in several different ways, and it is of value here to review these ways before discussing the main fields of application of these machines to the work of the Research Branch.

Machine Orders

The basic methods of programming any particular computer are known as the *machine orders.* These orders comprise the code of instructions which have been built into the machine by the designers, and necessarily differ from machine to machine. The earliest designs of computers frequently imposed a very heavy burden upon the programmer, in requiring him to use a complex series of instructions and at the same time to make his own arrangements for checking the correctness of the arithmetic carried out and the 'optimisation' of the speed with which individual operations were completed. Later designs removed most of this burden, and enabled programming by machine orders to be carried out more simply. Both Pegasus and Sirius are reasonably easy to programme in this way.

Pegasus Machine Orders

The order code for the Pegasus computer consists of a comprehensive series of instructions for the addition, subtraction, multiplication, and division of numbers held within the immediate-access store, and for the transfer of numbers from one register to another within the immediate access store, and to and from the main store. A number of special orders are also provided to perform various logical functions upon numbers held within the machine. More complex operations, such as the calculation of square roots, logarithms, and trigonometric functions, are provided by means of sub-routines, that is, by special sequences of instructions which can be called into any programme from a library of such sub-routines as required. The ease of assembling a complex programme from a great number of separate parts and sub-routines is one of the special features of the programming facilities for Pegasus. The necessity for transferring blocks of programme and data from the main store of the computer to the immediate-access store makes for difficulties in programming Pegasus in terms of machine orders, but apart from this slight complication, coding of the instructions for the computer is reasonably easy, once the logical steps in the computation have been determined. (Ferranti, 1955.)

Sirius Machine Orders

The basic machine orders for the Sirius computer are even easier to learn and to use than those for the Pegasus computer, largely because the numbers held within the store of the computer are in decimal form, and because no transfers of blocks of programme or data are necessary within the single level of store of the machine. The order code consists of more than 60 instructions, covering all the usual arithmetic and logical operations. As in Pegasus, special provision has been made for the assembly of programmes from a library of sub-routines. (Ferranti, 1960.)

Although both Pegasus and Sirius are reasonably easy to programme in their basic machine languages, the task is still sufficiently difficult to delay the use of the computers for many computations for which efficient programmes do not yet exist, the programme language being still fairly remote from the solutions to the problems as conceived by the programmer. As a result, methods of simplifying the task have been sought, even if these methods have resulted in a slight increase in the time taken for the computer to carry out the computations. The loss of efficiency in computing speed is frequently more than compensated by the reduction in the time taken to programme the solution. These simplified methods of programming usually take the form of Autocodes or Interpretive Schemes, and some of those available for the Pegasus and Sirius computers are described below.

Pegasus/Sirius Autocode

This Autocode is a special algebraic language for programming scientific, technical and commercial applications of the computers. The numbers stored within the computer are regarded as being held in a sequence of registers identified symbolically, and while the programme is being written it is inappropriate to consider the values of the numbers, as they will be different each time that the programme is used. The instructions therefore refer to the registers by their appropriate symbols, and calculate a number from one or two numbers previously calculated or read into the machine. A full range of arithmetic, functional and logical operations is available within the algebraic language of the Autocode, and the correspondence between the form of these instructions and the usual notation of algebra is sufficiently close for research workers to write computer programmes after only one or two days' training, and for experienced programmers to write useful programmes in only a fraction of the time necessary in machine orders. A fuller description of the Autocode is given in Ferranti, 1959.

The Autocode languages used by the Pegasus and Sirius computers are almost identical, and programmes in this language can therefore be run on either machine. The way in which the two computers make use of the language is, however, very different, and illustrates an important trend in computer techniques. In Pegasus, the Autocode instructions are stored within the machine, and are translated into the necessary machine orders each time that the programme is obeyed. In Sirius, a new programme in machine orders is compiled by the computer as the Autocode is read for the first time. The use of compilers for several different languages is a technique which is gaining prominence in computer applications.

The use of Autocode considerably slows down the speed of computation on Pegasus, but the reduction in the time needed for programming usually compensates for this loss of computing speed. On Sirius, the loss of computing speed is less marked, and Autocode programmes run at least twice as fast as on Pegasus. The ease of programming given by the use of Autocode, and the fact that programmes written in this language can be run on either machine, have resulted in most Research Branch programmes being written in this form, at least as a test of the logic of the solution. Where the programme is to be used many times, it may subsequently be speeded up by rewriting all, or parts, of the Autocode programme in machine orders. As a language, Autocode has also come to be used as a means of communication between different members of the Statistics Section, or between members of the Section and members of other Sections of the Research Branch.

Matrix Interpretive Scheme

Many statistical computations may be very conveniently expressed in the notation of matrix algebra, so that the notation itself provides a powerful and highly condensed description of the computations that need to be carried out for the solution of a practical problem. Most electronic computers therefore provide special facilities for the programming of computations expressed in this way, and these facilities usually take the form of an interpretive scheme, by which the computer compiles a programme in machine orders from a symbolic representation of the matrix algebra describing the calculation. The Matrix Interpretive Scheme for the Pegasus computer, which is again compatible with that for Sirius, has therefore been of particular value in the application of these computers to problems of statistical analysis, and is described in more detail in Ferranti, 1957. An additional feature of interpretive schemes for matrix algebra is their importance as an international language for the programming of statistical calculations, since most computers have such a scheme and can very easily be programmed to provide solutions to problems formulated in matrix algebra.

Filecode

None of the programming methods described above are particularly useful for the handling of alphabetic data on the computer, or for the handling of mixtures of alphabetic and numerical data. Programmes for such operations can, of course, be written in the appropriate machine orders for the computer, but, because of difficulties in the use of input and output sub-routines designed mainly to deal with numerical data, are somewhat tedious. Similarly, programmes involving sorting of numerical and alphabetical data, or requiring random access to data held within the store of the computer, are usually less easy to write than those involving straightforward arithmetic computation. A special interpretive scheme for the Sirius computer, known as Filecode and described in Ferranti, 1962, has therefore been of value for systems analysis and data processing. This scheme is also notable for its use of ordinary English words to describe the operations carried out by the computer, and provides a foretaste of some of the advantages and disadvantages of other programming languages under active development, e.g. ALGOL, COBOL and NEBULA.

Generalised Special-purpose Programmes

General-purpose interpretive schemes like the Pegasus/Sirius Autocode and the Matrix Interpretive Scheme merge almost indistinguishably into completely generalised, special-purpose programmes. Such programmes provide the solution to a wide variety of a general class of problems, the selection of the essential parts of the whole programme being achieved by the use of short steering programmes, or by setting a small number of essential parameters. Examples of many of these programmes are given later in this paper, and include programmes for multiple regression analysis, analysis of variance, linear programming, and Monte Carlo simulation.

Applications in Forest Research and Management

So profound has been the effect of the electronic digital computer on the work of the Research Branch, that it is difficult to make any adequate summary of the individual applications. The main fields of application can, however, be broadly classified, and give some idea of the ways in which the computer is making its impact upon important problems of forest research and management.

Analysis of Designed Experiments and Surveys

About one third of all the work done on the computer has been concerned with the analysis of data arising from designed experiments and surveys, the basic statistical technique being the analysis of variance. Originally, this work was met by a series of separate programmes written for each type of experimental or survey design, e.g. randomized blocks, Latin and Graeco-latin squares, factorial designs, stratified random samples, etc. These programmes were reasonably easy to write in one or other of the available programming languages, and were suitably amended as they were found to contain undesirable restrictions. It gradually became apparent, however, that greater efficiency of analysis could be achieved by the use of a small number of general 'analysis of variance' programmes. The first of these to be written was a programme for the analysis of non-orthogonal experimental designs with two or three constraints, and this proved to be successful in dealing with a wide class of forest experiments, including those which had become unbalanced by the accidental loss of experimental material (Freeman and Jeffers, 1962). Similar programmes have now been developed for orthogonal designs, and most of the earlier special programmes have been rendered obsolete by these more general programmes.

In addition to the much greater speed of analysis achieved by the computer in the interpretation of designed experiments and surveys, most analyses taking only a few minutes, particular benefit has come from the ability to test the validity of the assumptions which must be made in the analysis of variance. When computing on desk machines, most of these tests must necessarily be omitted, with the resulting possibility of invalidation of the analysis. More efficient testing of the hypotheses formulated by experimenters is also possible with the greater power of analysis provided by the computer. Covariance analysis, to remove effects disturbing those of the experimental treatments, can also be undertaken as a routine, and may greatly increase the precision of forest experiments.

Multiple Regression Analysis

Multiple regression analysis, in which one variable is related to a number of other variables believed to be associated with it, is one of the forms of statistical analysis that has only become capable of intensive application with the development of the electronic computer. All forms of multiple regression analysis can be programmed very easily by means of the Matrix Interpretive Scheme, but a general multiple regression programme is available for the Pegasus computer, and this programme has been widely used by the Research Branch. A description of this programme, and the many facilities available with it, is given in Jeffers, 1959. Applications of this programme to problems of forest research include the study of the relationship between compressive strength of home-grown pitprops and their size, moisture content, straightness, and rate of growth; studies of the growth and uptake of nutrients by pole-stage forest crops; studies of the economics of private and state forestry; the construction of volume tables, yield tables, and other forest mensuration studies; and studies of the relationships between physical properties and times taken to complete forest operations in work study.

Special forms of multiple regression analysis, such as polynomial curve fitting, autocorrelation and serial correlation, fitting of hyperbolic and exponential curves, and time series analysis, has also formed an important part in the work of the Section, and efficient computer programmes exist for all of these types of analysis.

Multivariate Analysis

The experience gained in the application of the multiple regression technique to a wide variety of problems, made possible by the programmes described above, has revealed the inappropriateness of this technique for many important problems, and the need for the more powerful methods of multi-variate analysis described by Rao, 1952, and by Kendall, 1957. The necessary computations for this type of analysis are readily programmed by means of the Matrix Interpretive Scheme, provided that special programmes are available for the calculation of latent roots and vectors (eigenvalues and eigenvectors), and for the evaluation of determinants. These programmes are all available on both Pegasus and Sirius, and have enabled a wide range of multivariate techniques to be applied. For the particular problem of principal component analysis, however, a programme has been written for the Pegasus computer by the British Iron and Steel Research Association, and has proved valuable in many forest problems. Another special programme, for the analysis of ecological associations, has also been written for the Pegasus computer and has proved useful (Williams and Lambert, 1960).

The more important applications of these techniques to forest problems include studies of the properties of timber, pitprops and pulpwood from different stands, taxonomic studies of tree species (Jeffers, 1962, and Gardiner and Jeffers, 1962), analysis of the factors contributing to labour wastage, and many problems of quantitative economics of forestry and forest operations.

Working Plan Enumerations and Production Forecasts

The development of Working Plans for Forestry Commission forests and of methods of production forecasting coincided with the introduction of electronic computers to the work of the Research Branch. In view of the large amounts of computing involved in both these activities, this coincidence was fortunate, if not vital, for their rapid progress. An extensive series of forest enumeration has been made possible by the use of the computer for all caluclation and summarisation of the volumes of timber present, and the use of the computer in this way has ensured that the field enumeration teams can concentrate on the difficult task of collecting accurate information. A number of programmes for working plan enumerations were written for this work, and some of the main features of these programmes are described in Jeffers, 1962. Further work on this important aspect of forest management is now in progress, and is concentrating on the use of data collected in the course of working plan surveys in the formulation of thinning and felling prescriptions for future application. Ultimately, it is hoped to construct a complete mathematical model of every working plan area, so as to be able to simulate the whole process of the production and exploitation of the area. In this way the effects, both physical and economic, of various courses of action can be tested on the model before being put into practice.

Concurrently with the development of the working plan surveys, and their associated computer programmes, a special project dealing with the compilation of long-term and short-term forecasts of production from thinnings and fellings has been going ahead. The data compiled in this project have also been used to construct mathematical models of the production from Forestry Commission plantations, but, in addition, have enabled predictions to be made of the principal areas of production, and the sizes and species of timber likely to be available within defined areas.

Filing, Sorting and Catalogueing

While electronic digital computers are most frequently associated with numerical computations, a great number of clerical and logical operations are also more efficiently performed by these machines than by the more traditional methods. The division of computer applications into scientific and commercial fields is a highly artificial one, since scientists are frequently much concerned with the maintenance of files of information which may later be required in many different forms. Examples of these applications in forest research are to be found in lists of experiments, lists of the species present in an arboretum, lists of classified seed stands, etc. Frequent sorting, keeping up to date, and extraction of data in such lists suggests the value of preparing the list in some form suitable for direct access to a computer, and programming of the computer to carry out the necessary operations. Applications of computers in this way have been found to be extremely valuable in the work of the Research Branch, not only in saving time and money, but also in stimulating research workers to think about the information contained in the lists in a new way. The commercial Autocode, Filecode, of the Sirius computer has been particularly useful for this purpose.

Operational Research and Simulation

The use of mathematical models to simulate practical situations has been mentioned frequently in the fields of application described earlier in this paper. Indeed, this is probably the most important technique made available by the introduction of electronic digital computers. The possibilities of this technique appear to be limited only by the lack of knowledge of foresters and forest administrators of their existence. Some of the models that are being constructed have already been described, but many others have been explored, or are under active consideration at the moment. These include models describing production planning and forecasting, the labour structure and the wastage of industrial labour in the Forestry Commission, an economic model of the Forestry Commission's activities, the allocation and distribution of the money spent on fire protection, and the production and allocation of nursery plants. The relative ease of programming of the two computers mainly used by the Research Branch has contributed very greatly to the possibility of using these techniques over so wide a field. Both Autocode and the Matrix Interpretive Schemes enable complex structures of mathematical equations to be built up and exploited; the several useful programmes for the solution of linear programming models on these machines have also been frequently employed in the construction of decision models. For the types of simulation requiring

Monte Carlo methods, a special Autocode for such simulations, known as Montecode, and again written by the British Iron and Steel Research Association, has been invaluable.

Other Applications

In addition to the main fields of application of electronic digital computers to problems of forest research and management described briefly above, there are a great many other applications which do not fit conveniently into the broad classification adopted.

These include:

- Estimates of animal population from trap records;
- Summarization of questionnaires (e.g. on damage by mammals);
- Critical path analysis;
- Analysis and maintenance of flow charts describing research projects;
- Evaluation of chemical constituents of soil and foliage samples from laboratory determinations;
- Generation of random numbers for audit, and other, sampling;
- Graph plotting;
- Calculation of discounted revenues for forest plantations; and,
- Survey calculations.

Data Processing

The speeding up of the stage of the computation which used to take the greatest amount of time has revealed the inadequacy of the methods of data processing previously used in the Research Branch, in that the complex analysis which used to take hours or days, or even weeks, now takes only minutes to complete, but summarization of the original data into suitable forms for such an analysis may still take weeks, or even months. There is the added complication that the existing methods of filing data very often make prohibitive the task of extracting it for further analysis. There was, therefore, a prime need for a complete review of the methods of collecting, summarizing, and storing data within the Research Branch.

As a result of this review, a start has been made on the introduction of a completely integrated data processing system for the collection, summarization, storage, and analysis of forest research and management data. Ultimately, this system will include, where appropriate, the direct recording of measurements and observations on punched-paper tape in the forest or the nursery, and the early processing of this field tape by computer. This first processing will screen the data for obvious errors, and produce a primary storage tape suitable for direct entry to the computer for the analysis of the basic hypotheses set up by the experimenter. At the same time as the results of the first analysis are produced, a second storage tape is produced, in a form suitable for the combination of data from a whole group of experiments. This secondary storage tape may be punched-paper tape, or, for more extensive collections of data, magnetic tape, and will be used mainly for the complex analysis of variance implied in the analysis of groups of experiments, or for various types of multivariate analysis.

The main advantages expected from this advanced system of data processing in biological research are as follows:

(1) Faster data processing, in the sense of a much shorter period of time between the first collection of the measurements and observations, and the production of the final report on these measurements for the experimenter.

(2) Fewer mistakes, such as are due to bad recording, or more frequently, from the copying of results from the field sheet to the summary sheet, or from the summary sheet to the analysis sheet or tape.

(3) Faster access to data which have been stored for future use. It will only be necessary to find the correct tape and to insert it in the appropriate part of the computer for the data required for the solution of a particular problem to be available within minutes.

Portable Encoding Tape Punch

The basis of the procedure for automatic data processing described above is the device which allows for direct recording of assessments in the forest. Such a machine does not yet exist in any fully-developed form. Indeed, when it was first suggested that direct recording of measurements was necessary, and the idea was explored with several leading equipment manufacturers, it was clear that no suitable machine existed, and also that none of the manufacturers had recognised that a demand for such a machine existed. To this end, a Swiss graduate, M. René Badan, who was at the time working at Alice Holt, designed a prototype machine, which was subsequently made by two local schoolmasters. The prototype punch, though somewhat crude in design and operation, was sufficient to interest one of the manufacturers, and from this first prototype an improved version has been made and tested. Further development work is now going ahead, and it is hoped that the final version of the field punch will enable all types of measurements commonly taken in forest research and management to be recorded directly on to punched-paper tape.

Photographs of the present prototype appeared in the *Research Report* for 1961, as Plates 4 and 5. Basically, the device consists of a steel tape which can be used for girthing or, alternatively, attached to a caliper for measuring diameters, fixed round a tape punch in such a way that, as the tape is pulled out, the distance through which it is extended is recorded as a series of holes on 7-hole punched-paper tape, using a special code designed to cut down errors in rounding-off the measurement. In the later verions of this tape punch it will be possible to record, besides girth or diameter, height or elevation, the angles subtended by trees or by lengths of ground, as in surveys, and to enter digital information on any other type of measurement or observation. The problems in the development of the device that still remain to be solved are not trivial, but it now appears that it will be possible to develop a useful encoding tape punch which is sufficiently light for a man to carry and use all day.

Future Developments

The work so far done on the application of modern methods of statistical analysis to problems of forest research and management has been based on a limited access to electronic digital computers, with all the attendant difficulties in programme development and production computing. Nevertheless, it is clear that the electronic computer has already made a significant contribution to the work of the Research Branch. The study of the methods of statistical and mathematical analysis made possible by the use of computers has shown that greater unification of the theory is now possible, and that more powerful methods of analysis than anything that has so far been explored are now available to all workers in the field of forestry research and management.

Future development of this work will depend partly upon the availability of computer time for forestry problems, and partly on the degree of acceptance of modern techniques by foresters at all levels within the administration of research and management.

WIND TUNNEL STUDIES OF THE FORCES ACTING ON THE CROWNS OF SMALL TREES

By A. I. FRASER

Damage by winter gales, either in the form of windthrow or stem-breakage, is a common occurrence in Britain. The problem may be studied from various aspects. Attention is being paid to the stability of trees and stands in relation to the general environment, and an account of the early stages of such work has been published elsewhere (Fraser, 1962).

This paper describes a study of the forces exerted on small trees by winds of varying velocities generated in a 24 ft. diameter wind tunnel.

Consideration of the Forces Acting on a Tree

The two basic forces acting on a tree are gravity, acting vertically, and the wind, acting horizontally. The effect of gravity can readily be determined from the tree's weight, and the point through which the force acts can either be measured or calculated with reasonable accuracy.

The effect of wind, however, is much less predictable, and in fact few actual measurements of the forces on tree crowns produced by the wind have been made, although some work has been done by Fons (1940) and Reifsnyder (1955) on the variation of wind velocity in and around forests.

Objects of Wind Tunnel Studies

The main object of studying trees in the wind tunnel was to determine the relationship between wind velocity and the forces acting on the tree. These forces could be measured as the horizontal force in the direction of the wind, termed the Drag, and the vertical force, termed the Lift. (Because of the usual symmetry of a tree crown the component of horizontal force, acting across the wind direction, was considered to be negligibly small, and was ignored throughout these studies). In addition to this main object, it was also desired to study variation between species, and variation between crown density in each species.

It was hoped that if any definite relationship was found, small models could be constructed which would exhibit the same characteristics, so that more extensive trials could be carried out later, as a joint project with the National Physical Laboratory.

Method of Study

The trees selected were cut to 27 ft. in length, and the lower 3 ft. was inserted in a steel pipe mounted below the base of the tunnel. Thus 24 ft. were actually in the air stream, and of this length the lower 4 ft. were cleared of branches.

The species used were Douglas fir (*Pseudotsuga taxifolia*), Scots pine (*Pinus* *sylvestris*), Norway spruce (*Picea abies*) and Western hemlock (*Tsuga heterophylla*). Four trees of each of the first three species, and two of the last were represented, covering a range of crown densities from light to heavy.

The steel pipe mounting had a 6 in. internal diameter, with three wedges (thin end up) at its base. The butt of the trees were chamfered in order to conform with the wedges, and the tree was then secured by driving additional wedges in round the top of the pipe. The trees varied in diameter from 4·25 to 6 inches. The base of the pipe was bolted to a triangular steel frame, and the top of the pipe was guyed to the frame on the windward side to prevent bending. (See Plate 1). The frame was then m ounted on two balances which enabled the drag and lift to be measured.

The trees were placed in the tunnel one at a time by an overhead crane, and while this was being done, they were suspended horizontally so that their centre of gravity could be located. Once they were firmly secured in the pipe, their weight was measured on the lift balance.

The tree was then photographed from the front, so that measurements of frontal area could be made. The fan in the tunnel was started, and the wind velocity increased to 17·75 knots and the drag and lift measured. This process was repeated at the following wind velocities, which corresponded as nearly as possible to 5-knot intervals:

23·7 knots, 29·7 knots, 35·5 knots, 39·8 knots, 45·1 knots, 50·5 knots.

Note: A knot is a unit of speed equivalent to 1·151 miles per hour.

Some of the trees were photographed at each wind velocity, and Plates 2 and 3 show the same Douglas fir at rest, and at the maximum velocity of 50·5 knots. In addition films were made either of the front or side view of the other trees, and these have been kept as a permanent record.

Two trees were tested a second time with some of their branches removed, but all the other trees were removed immediately and taken away for weighing.

At the conclusion of the test all branches were carefully removed and weighed, together with the upper part of the stem (i.e. 3 inches and under in diameter) to represent the crown, while the remainder of the stem was weighed separately.

Results

For a rigid body which does not change its shape in the wind, it is usually found that the drag force D varies as the square of the wind speed. The shapes of the tree crowns, however, were found to deform and become more 'streamlined' as the wind speed increased, and the measurements revealed that for all crowns tested, the drag increased approximately in direct proportion to the wind velocity, so that the relationship can be expressed by the formula:

$$\text{Drag} = m\,V + C \qquad (1)$$

where m and c are constants, whose value can be calculated for each tree. Figure 10 shows the regression lines for each tree. Table 41 shows the values of m and c measured for each tree, tabulated with the tree's weight, which is ranged in descending order of magnitude.

The values of c are all negative because at wind velocities below about 18 knots, drag does not increase in direct proportion to velocity, but the relationship is a curve rising from the origin.

Observations suggested that the wind pressure increased rapidly in the lower wind velocities, which would explain the curve, but at about the lowest velocity measured, the tree took up a streamlined shape resulting in a reduction in the

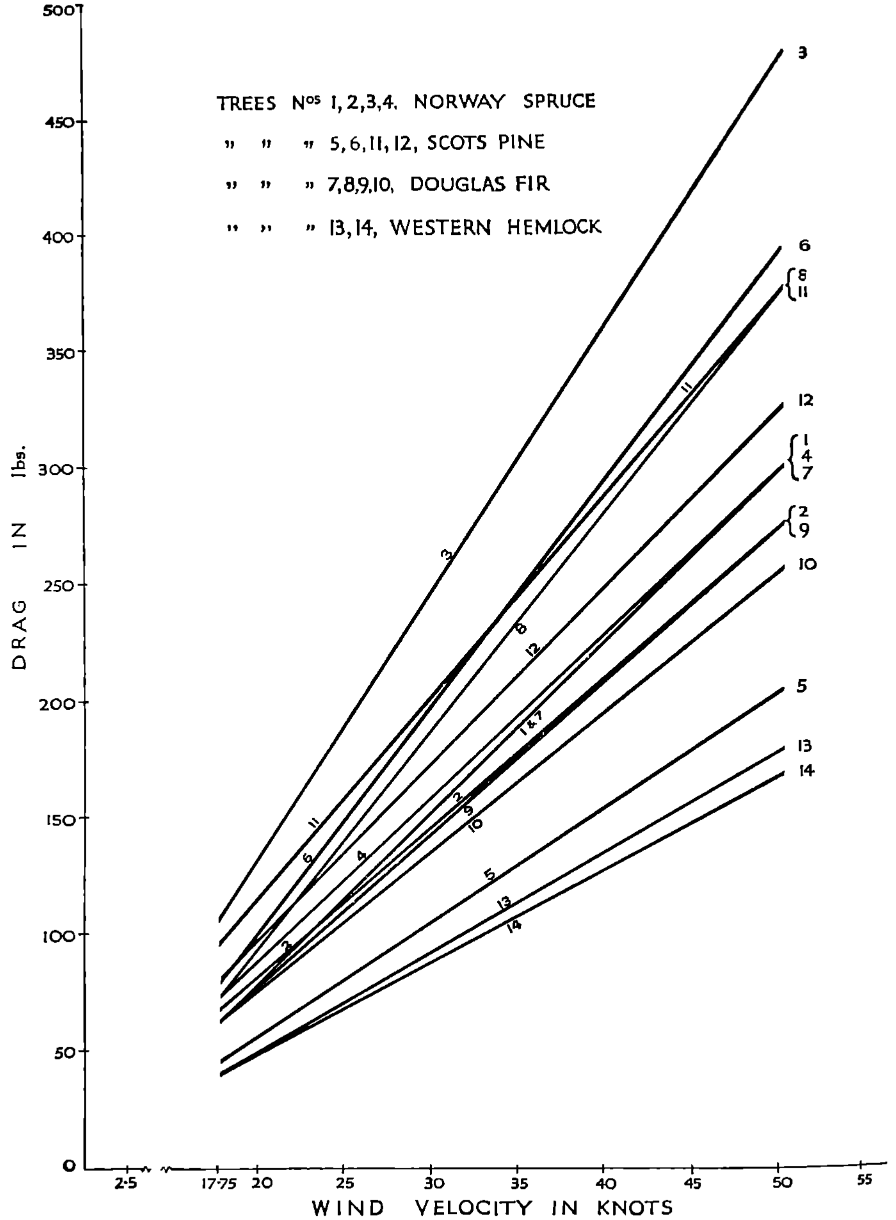

Figure 10. Relationship between drag and wind velocity.

rate of increase of the drag. Beyond this velocity, the streamlining became increasingly pronounced, so that the drag did not increase as much as would be expected in a rigid body.

It can be seen from Table 41 that the values of m are closely related to the stem weight, and it was found that this relationship was not significantly different between species. It is therefore possible to use the regression:

$$m = 0{\cdot}029\ W + 1{\cdot}442 \qquad (2)$$

Table 41

Tree Weight and Drag/Velocity Regression Constants

Tree No.	Species	Tree wt. (lb.)	m	c
3	Norway spruce	350	11·55	—101·4
6	Scots pine	266	9·65	—96·9
8	Scots pine	246	9·19	—91·0
11	Douglas fir	245	8·57	—55·8
7	Scots pine	232	7·29	—70·1
4	Norway spruce	201	7·21	—58·8
12	Douglas fir	180	7·04	—35·3
1	Norway spruce	180	6·94	—49·5
2	Norway spruce	154	6·09	—36·3
9	Douglas fir	146	6·34	—45·0
10	Douglas fir	132	5·77	—34·0
5	Scots pine	132	4·79	—40·6
14	Western hemlock	95	3·75	—22·3
13	Western hemlock	93	4·12	—29·6

for estimating the value of m for any tree of this class from its total weight (W). Similar relationships were found with crown weight and stem weight.

This relationship is extremely interesting, in showing that the drag is dependent on the tree's weight and the wind velocity only, as it indicates that within the limits of the study the factors of species, and of frontal area, are accounted for by weight. Thus a tree with a small dense crown would have a very similar drag to a tree with a much larger, more open crown, if their weights were the same. On the other hand, two trees with the same size of crown but with different densities will have very different drags.

$$\text{The regression: Drag} = 1 \cdot 441\ V + 0 \cdot 029 VW - 0 \cdot 328\ W + 7 \cdot 426 \qquad (3)$$

(where V is velocity in knots and W is tree weight in lb.) will give an estimate of the drag (in lb.) with a mean standard deviation of $\pm 17 \cdot 4$ lb.

The variation increases with increase of velocity from $\pm 11 \cdot 90$ lb. at 17·75 knots to $\pm 25 \cdot 35$ lb. at 50·50 knots, but even at the higher values of drag this deviation only represents 5 to 10 per cent of the actual value. None of the drags estimated varied from the measured value by more than twice the deviation.

As mentioned earlier, two trees were tested a second time with some branches removed. One tree, with all branches on one side cut off, showed the same relationship as it had with all its branches on, except that it behaved as if it were a lighter tree.

The second, with the lower half of the crown removed, was more interesting, in that it showed less ability to steamline at the higher velocities. This was reflected in the value of the drag after pruning, as a fraction of the drag on the tree before pruning, rising from slightly less than a half (0·455) at 17·75 knots to slightly over a half (0·502) at 50·50 knots.

Limitations of the Studies

There are several obvious limitations to this type of study. The steady wind conditions in the tunnel are plainly different from the real thing, and the behaviour of an isolated tree may well be different from that of a group.

Other factors which will differ under natural conditions are the shape of the trees; the velocity over the whole crown of the tree, which increases with height; and the flexibility of a root system, as opposed to the rigidity of the mounting at the base. However, under natural conditions, all these factors can vary so much that it makes collection and interpretation of records extremely difficult. Besides this, there may be long periods between gales of similar direction, mean velocity, gustiness factor, etc., so that repetition of the readings becomes almost impossible.

Complementary Field Studies

In order to study the applicability of the results obtained in the wind tunnel, some similar investigations are being carried out on a tree in a moderately exposed situation.

An additional interesting application was made of the drag, weight, velocity regression, in relation to observed values of wind velocity, tree weight, and resistance to being pulled over, in a 60 ft. tall crop of Douglas fir, where some trees had been uprooted by the wind.

The figures in Table 42 represent the resistance to being pulled over of a sample of trees, measured before and after a gale, in which the mean gust speed was 50 knots. The figures given represent the measured maximum overturning moment acting at the base of the tree, and the overturning moment estimated from the formulae derived in the wind tunnel studies for a wind velocity of 50 knots assumed to be acting at half the tree's height.

Table 42

Relationship Between Measured Overturning Moment and the Value Estimated for the Drag at 50 knots, Calculated with Regression [3]

Tree No.	Tree wt. (lb.)	Ht. ft.	Maximum Moment*	Estimated Drag	Estimated Moment*
1	870	61	37,000 lb. ft.	1,055 lb.	37,680
2	980	60	39,700 lb. ft.	1,248 lb.	43,380
3	1,200	65	58,180 lb. ft.	1,425 lb.	49,800

Note: *Both values of Moment include a small value for the tree's weight Moment.

Trees 1 and 2 were pulled over some time before the gale, and the figures suggest that they might not have withstood it, but tree 3 was one that had withstood the gale, and was pulled over about a month later. As shown, its resistance was found to be considerably greater than the estimated overturning force produced by the wind. The trees were all pulled over with a standard technique, involving the use of a small hand winch and dynamometer. The method is described in more detail by Fraser (1962).

It can be seen that the estimated overturning moment is very close to the tree's measured resistance to overturning. Thus although the regression is strictly only applicable to the size of tree tested in the tunnel, these figures would suggest that it would not be far out if applied to bigger trees.

Further Developments

As mentioned earlier, photographs were taken of each tree in the tunnel, so that an estimate of its frontal area could be made. This estimated area was then used to calculate a drag coefficient from the formula:

$$C_D = \frac{D}{\frac{1}{2} p V^2 A}$$

where D = drag, p = air density, V = wind velocity and A is the frontal area.

The mean drag coefficient, using the 'no-wind' frontal area, was 0·71 at a wind velocity of 30 knots, and this value has been used in the construction of models. A design has been produced whose external dimensions are similar to a tree, and whose drag coefficient is 0·71. Trials with groups of these models in a 7 ft. wind tunnel, to represent plantations, will be proceeding in due course.

Conclusions

(1) The ability of a tree to assume a streamlined shape in high wind velocities is such that the drag varies linearly with the wind velocity, rather than with the square of the velocity, as in rigid bodies.

(2) The four tree species tested behaved in a very similar manner, so much so that the weight of the tree accounted for almost all the variation in the relationship between drag and wind velocity. This has enabled the calculation of a regression of tree weight and velocity on drag.

(3) The variation of crown densities in each species did not alter the above relationships.

(4) Pruning, however, did alter the relationship given in (2) above, to some slight degree.

(5) The values of overturning moments calculated from the regressions obtained are very close to those actually measured when trees are pulled over.

(6) While the wind tunnel studies have obvious limitations and results derived from them are only strictly applicable under similar conditions, some confirmation has been obtained that the forces are of the right order, and appear to provide a reasonable basis for design of models for further studies.

Acknowledgements

I am very grateful to Dr. J. Williams of the Royal Aircraft Establishment, Farnborough, for permission to use the wind tunnel, and to Mr. Spense, Mr. Eyre and Mr. Goswell of the R.A.E. for assistance during the studies. Thanks must also go to Mr. Scruton, Mr. Raymer and Mr. Walshe of the National Physical Laboratory for help and advice on the project as a whole.

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Figure 11. Approximate Situation of Experimental Areas mentioned in Appendix I (pages 185-189)

APPENDIX I

Main Experimental Projects and Localities

While most of 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 concentrated. These listed below; and the approximate position of each named forest will be found on the map opposite (page 184) by reference to the number given in brackets.

NURSERY EXPERIMENTS

Benmore Nursery, near Dunoon (Argyll) (33)
Bramshill Nursery (Hampshire) (91)
Bush Nursery, near Edinburgh (36)
Fleet Nursery, Gatehouse of Fleet (Kirkcudbright) (46)
Inchnacardoch Nursery, near Fort Augustus (Inverness) (19)
Kennington Nursery, near Oxford (84)
Newton Nursery, near Elgin (Moray) (8)
Sugar Hill Nursery, Wareham (Dorset) (105)
Tulliallan Nursery, near Alloa (Fife) (32)

AFFORESTATION EXPERIMENTS ON PEAT

Achnashellach Forest (Wester Ross) (12)
Beddgelert Forest (Caernarvon) (54)
Inchnacardoch Forest (Inverness) (19)
Kielder Forest (Northumberland) (42)
Strathy Forest (Sutherland) (1)
Watten (Caithness) in conjunction with Department of Agriculture for Scotland (2)
Wauchope Forest (Roxburgh) (39)
Isle of Lewis (Inverness) (110)
Isle of Hoy (Orkney) (111)

NUTRITION OF ESTABLISHED CROPS

Ardross Forest (Easter Ross) (4)
Bramshill Forest (Hampshire) (91)
Durris Forest (Kincardine) (20)
Exeter Forest (Devon) (106)
Tarenig Forest (Cardigan) (65)
Wareham Forest (Dorset) (105)
Wilsey Down Forest (Cornwall) (107)

AFFORESTATION EXPERIMENTS ON HEATHLAND

Allerston Forest, Harwood Dale (Yorkshire) (49)
Allerston Forest, Wykeham and Broxa (Yorkshire) (49)
Land's End Forest, Croft Pascoe (Cornwall) (109)
Taliesin Forest (Cardigan) (64)
Teindland Forest (Moray) (11)
Wareham Forest (Dorset) (105)

CONVERSION OF COPPICE

Alice Holt Forest, Marelands (Hampshire) (93)
Cranborne Chase (Dorset) (100)
Forest of Dean, Penyard and Flaxley (Gloucestershire) (81)

PROVENANCE EXPERIMENTS

Scots Pine:	Findon Forest (Easter Ross) (6)
	Thetford Chase (Norfolk) (67)
Lodgepole pine:	Achnashellach Forest (Wester Ross) (12)
	Allerston Forest, Wykeham (Yorkshire) (49)
	Ceiriog Forest (Denbigh) (56)
	Clocaenog Forest (Denbigh) (52)
	Millbuie Forest (Easter Ross) (9)
	Taliesin Forest (Cardigan) (64)
European larch:	Coed-y-Brenin (Merioneth) (57)
	Mortimer Forest (Herefordshire) (71)
	Savernake Forest (Wiltshire) (90)
European and Japanese larches:	Clashindarroch Forest (Aberdeen) (17)
	Drummond Hill Forest (Perth) (23)
	Lael Forest (Wester Ross) (3)
Douglas fir:	Glentress Forest (Peebles) (37)
	Land's End Forest, St. Clement (Cornwall) (109)
	Lynn Forest, Shouldham (Norfolk) (62)
	Mortimer Forest (Shropshire) (71)
Norway and Sitka spruce:	Newcastleton Forest (Roxburgh) (41)
	The Bin Forest (Aberdeen) (15)
Sitka spruce:	Clocaenog Forest (Denbigh) (52)
	Glendaruel Forest (Argyll) (31)
	Kielder Forest (Northumberland) (42)
	Mynydd Ddu Forest (Monmouth) (79)
	Radnor Forest (Radnor) (69)
	Taliesin Forest (Cardigan) (64)
	Wilsey Down Forest (Cornwall) (107)
Beech:	Queen Elizabeth Forest (Hampshire) (99)
	Savernake Forest (Wiltshire) (90)

PRUNING EXPERIMENTS

Drummond Hill Forest (Perth) (23)
Monaughty Forest (Moray) (10)

PLANTING EXPERIMENTS ON CHALK DOWNLANDS

Friston Forest (Sussex) (102)
Queen Elizabeth Forest (Hampshire) (99)

ESTABLISHMENT OF OAK

Dymock Forest (Gloucestershire and Hereford) (80)
Forest of Dean (Gloucestershire and Hereford) (81)

POPLAR TRIALS AND SILVICULTURAL EXPERIMENTS

Bedgebury Forest (Kent) (96)
Blandford Forest (Dorset) (101)
Cannock Chase (Staffordshire) (60)
Creran Forest (Argyll) (22)
Doncaster Forest (Yorkshire) (51)
Dyfnant Forest (Montgomery) (59)
Forest of Dean (Gloucestershire) (81)
Lynn Forest, Gaywood (Norfolk) (62)
Quantock Forest (Somerset) (94)
Rogate Forest (Hampshire) (98)
Stenton Forest (East Lothian) (35)
Thetford Chase, Harling (Norfolk) (67)
Wentwood Forest (Monmouthshire) (87)
Wynyard Forest (Durham) (47)
Yardley Chase (Bedfordshire & Northamptonshire) (73)

SPECIES PLOTS

Beddgelert Forest (Caernarvon) (54)
Bedgebury Forest (Kent) (96)
Benmore Forest (Argyll) (33)
Minard Forest, Crarae (Argyll) (28)
Thetford Chase (Norfolk) (67)
Wareham Forest (Dorset) (105)

LONG-TERM MIXTURE EXPERIMENTS

Gisburn Forest (Lancashire) (50)

GENETICS

Propagation Centres

Alice Holt (Hampshire) (93)
Bush Nursery (near Edinburgh) (36)
Grizedale Nursery (Lancashire) (48)
Kennington Nursery (near Oxford) (84)
Westonbirt Arboretum, near Tetbury (Gloucestershire) (89)

Tree Banks

Alice Holt (Hampshire) (93)
Bradon Forest (Wiltshire) (88)
Bush Nursery (near Edinburgh) (36)
Newton Forest (Moray) (8)
Aldewood Forest (Suffolk) (72)

Seed Orchards

Newton Forest (Moray) (8)
Ledmore Forest (Perth) (24)
Drumtochty Forest (Kincardine) (21)
Archerfield & Whittingehame Forests (East Lothian) (34)
Alice Holt (Hampshire) (93)
Bradon Forest (Wiltshire) (88)
Forest of Dean (Gloucestershire) (81)
Aldewood Forest (Suffolk) (72)
Shouldham Forest (Norfolk) (63)

Crossing Experiments

Allerston Forest, Wykeham & Harewood Dale (Yorkshire) (49)

Progeny Trials

Gwydyr Forest (Caernarvon) (53)
Clocaenog Forest (Denbigh) (52)
Coed-y-Brenin Forest (Merioneth) (57)

Treatment of Seed Stands

Thetford Chase (Norfolk and Suffolk) (67)

PATHOLOGICAL RESEARCH AREAS

Elm Disease Trials

The King's Forest (Suffolk) (70)
Kesteven Forest (Lincs. and Rutland) (61)
Ettisley Wood (Huntingdonshire) (74)

Top Dying of Norway Spruce

Knapdale Forest (Argyll) (29)

Fomes annosus

The Bin Forest (Aberdeen) (15)
Lael Forest (Ross) (3)
Thetford Chase (Norfolk and Suffolk) (67)
Kerry Forest (Montgomery) (66)
Clocaenog Forest (Denbigh) (52)

PATHOLOGICAL RESEARCH AREAS—*continued.*

Bacterial Canker of Poplar

Aldewood Forest, Fen Row Nursery (Suffolk) (72)
Lynn Forest, Gaywood Nursery (Norfolk) (62)
Thetford Chase, Mundford Nursery (Norfolk) (67)

Rhizina undulata—Group Dying of Picea sitchensis

Muirburnhead (Duke of Buccleuch) (Dumfries-shire) (44)

Keithia thujina Trials

Alice Holt (Hampshire) (93)
Ringwood Nursery (Dorset) (103)
Sugar Hill Nursery, Wareham Forest (Dorset) (105)

Crumenula sororia

Ringwood Forest (Dorset) (103)

ARBORETA

Bedgebury Pinetum (Kent) (96)
Westonbirt Arboretum, near Tetbury (Gloucestershire) (89)
Whittingehame Garden (East Lothian) (34)

RE-AFFORESTATION EXPERIMENTS

Forest of Ae (Dumfries) (40)
Newcastleton Forest (Roxburgh) (41)
Thetford Chase (Norfolk and Suffolk) (67)

ENTOMOLOGY

Birds and Bupalus piniarius

Culbin Forest (Moray and Nairn) (5)
Cannock Chase (Staffs.) (60)

Anoplonyx destructor

Drumtochty Forest (Kincardine) (21)
Mortimer Forest (Hereford and Salop) (71)

Neomyzaphis abietina

Inverliever Forest (Argyll) (25)
Dovey Forest (Merioneth and Montgomery) (58)
Bramshill Forest (Hampshire) (91)
Alice Holt Forest (Hampshire) (93)
New Forest (Hampshire) (104)

MENSURATION AREAS

Thinning Experiments

(Replicated plots)

Bowmont Forest (Duke of Roxburgh) (38)
Loch Eck Forest (Argyll) (30)
Alice Holt Forest (Hampshire) (93)
Edensmuir Forest (Fife) (27)

(Unreplicated)

Culbin Forest (Moray and Nairn) (5)
Achvochkie Forest (Seafield Estate) (Moray) } (13)
Kurrwood Forest (Seafield Estate) (Moray) } (13)
Deer Park (Crown Woodlands) (Moray) (7)
Glentress Forest (Peebles) (37)
Drumtochty Forest (Kincardine) (21)
Ardgartan Forset (Argyll) (26)
Forest of Ae (Dumfries) (40)
Cairn Edward Forest (Kirkcudbright) (43)

Kielder Forest (Northumberland) (42)
Dovey Forest (Merioneth and Montgomery) (58)
Mynydd Ddu (Brecon and Monmouth) (79)
Pembrey Forest (Carmarthen) (82)
Tintern Forest (Monmouth) (83)
Coed Morgannwg (Glamorgan) (85)
Brechfa Forest (Carmarthen) (78)
Caeo Forest (Carmarthen) (76)
Forest of Dean (Gloucestershire) (81)
Bodmin Forest (Cornwall) (108)
Brendon Forest (Somerset) (95)
New Forest (Hampshire) (104)
Micheldever Forest (Hampshire) (92)
Aldewood Forest (Suffolk) (72)
Thetford Chase (Norfolk) (67)

Spacing Experiments

Mortimer Forest (Hereford and Salop) (71)
Allerston Forest (Yorks) (49)
Thetford Chase (Norfolk) (67)
Aldewood Forest (Suffolk) (72)
Forest of Dean (Gloucestershire) (81)
Clocaenog Forest (Denbigh and Merioneth) (52)
Kerry Forest (Montgomery) (66)
Myherin Forest (Cardigan) (68)
Tintern Forest (Gloucestershire) (83)
Ebbw Forest (Monmouth) (86)
Crychan Forest (Brecon) (75)
Coed Morgannwg (Glamorgan) (85)
Caeo Forest (Carmarthen) (76)
Brechfa Forest (Carmarthen) (78)
Brecon Forest (Brecon) (77)
Drumtochty Forest (Kincardine) (21)
Fleet Forest (Kirkcudbright) (46)
Dalbeattie Forest (Kirkcudbright) (45)

Underplantings

Exeter Forest (Devon) (106)
Dymock Forest (Gloucestershire) (80)

Comparison of Species

Gwydyr Forest (Caernarvon) (53)
Forest of Dean (Gloucestershire) (81)
Thetford Chase (Norfolk) (67)
Brechfa Forest (Carmarthen) (87)
Glentress Forest (Peebles) (37)
Glen Urquhart Forest (Inverness) (16)
Benmore Forest (Argyll) (33)
Cairn Edward Forest (Kirkcudbright) (43)
Achnashellach Forest (Wester Ross) (12)

APPENDIX II

Staff engaged in Research and Development as at 31st March, 1962

FOREST RESEARCH STATION: Alice Holt Lodge, Wrecclesham, Farnham, Surrey.
Tel.: Bentley 2255

T. R. Peace, M.A.	Conservator, Chief Research Officer
T. D. H. Morris	Senior Executive Officer

SILVICULTURE (SOUTH)

R. F. Wood, B.A., B.Sc.	Divisional Officer
G. D. Holmes, B.Sc.	Divisional Officer
J. M. B. Brown, B.Sc., Dip.For.	District Officer
J. R. Aldhous, B.A.	District Officer
M. Nimmo	District Officer
A. I. Fraser, B.Sc.	District Officer
J. Jobling, B.Sc.	District Officer
W. H. Hinson, B.Sc., Ph.D.	Senior Scientific Officer
G. M. Buszewicz, Mgr.Ing.	Experimental Officer
R. Kitching, B.Sc., A.R.C.S.	Scientific Officer

MANAGEMENT

D. R. Johnston, B.A.	District Officer
A. J. Grayson, M.A., B.Litt.	District Officer
D. Y. M. Robertson, B.Sc.	District Officer
R. T. Bradley, B.A.	District Officer
D. G. Pyatt, B.Sc.	District Officer
P. A. Wardle, B.Sc.	District Officer

STATISTICS

J. N. R. Jeffers, F.I.S.	Principal Scientific Officer
H. G. M. Dowden, B.Sc.	District Officer
D. H. Stewart, B.Sc.	Experimental Officer

FOREST PATHOLOGY

D. H. Phillips, B.Sc., M.Sc., Ph.D.	Principal Scientific Officer
R. G. Pawsey, B.Sc., M.Sc., Ph.D.	Senior Scientific Officer
S. Batko, D.Ing.	Experimental Officer

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D. Bevan, B.Sc.	District Officer
J. T. Stoakley, M.A.	District Officer
Miss J. M. Davies, B.Sc.	Senior Scientific Officer
Miss J. J. Rowe, B.Sc. (Mammal Research)	Scientific Officer

FOREST GENETICS

J. D. Matthews, B.Sc.	Divisional Officer
A. F. Mitchell, B.A., B.Ag.	District Officer

LIBRARY AND DOCUMENTATION

R. M. G. Semple, B.Sc.	District Officer

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I. A. Anderson, F.I.B.P.	Principal Photographer
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D. W. Henman, B.Sc.	District Officer
J. Atterson, B.Sc.	District Officer

MANAGEMENT

A. M. Mackenzie	District Officer
G. M. L. Locke, B.Sc.	District Officer

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R. S. Howell, A.I.S.	Scientific Officer

FOREST GENETICS

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UTILISATION DEVELOPMENT

E. G. Richards, M.C., B.Sc.	Conservator
B. W. Holtam, B.Sc.	Divisional Officer
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J. W. L. Zehetmayr, B.A.	Divisional Officer
E. S. B. Chapman, B.Sc.	District Officer
R. E. Crowther, B.Sc.	District Officer
S. Forrester, B.Sc.	District Officer
N. Dannatt, B.Sc.	District Officer
J. P. Vérel, B.Sc.	District Officer
J. B. Wharam	Senior Executive Officer

APPENDIX III

List of Publications

This list includes all items published in the year ended 31st March, 1962. Prices are only quoted for Commission issues; those in brackets include postage.

Aldhous, J. R.	Experiments in hand-weeding of conifer seedbeds in forest nurseries. *Weed Research* 1(1) 1961, (59–67).
Aldhous, J. R.	A preliminary experiment on conifer seedbeds with 2, 6-dichlorobenzonitrile. *Proc. 5th Brit. Weed Control Conf.* 1960. (617–622).
Bevan, D.	Starling roosts in woodlands. *Quart. J. For.* 56(1) 1962, (59–61).
Begley, C. D. and Coates, A. E.	Estimating yield of hardwood coppice for pulpwood growing. *Rep. For. Res. For. Comm.*, Lond. 1960.
Buszewicz, G.	The longevity of beechnuts in relation to storage conditions. *Proc. Int. Seed Testing Assoc.* 26 (3) 1961 (504–515).
Buszewicz, G. and Holmes, G. D.	A Summary of ten years' seed testing experiment with Western hemlock. *Rep. For. Res. For. Comm.*, Lond. 1960 (110–119).
Christie, J. M. and Lewis, R. E. A.	*Provisional Yield Tables for Abies Grandis and Abies Nobilis.* Forest Record No. 47, 1961 (H.M.S.O. 3*s.* 0*d.*, (3*s.* 3*d.*).)
Faulkner, R.	Some aspects of a Pine breeding experiment. *Arbor.* Aberdeen 3 (5) 1961 (4–7).
Faulkner, R.	Seed Stands in Britain and their management. *Quart. J. For.* 56 (1) 1962 (1–15).
Faulkner, R. and Matthews, J. D.	The management of Seed Stands and Seed Orchards. *Proc. Int. Seed Testing Assoc.* 26 (3) 1961 (366–387).
Grayson, A. J.	The influence of log size on value. *Timb. Tr. J.* 238 (4434) 1961 (75–78).
Grayson, A. J.	An American approach to sawmill management. *Timb. Tr. J.* 240 (4459) 1962 (87 and 92).
Henman, D. W.	Natural regeneration of Scots pine woods in the Highlands. *Scot. For.* 15 (4) 1961 (235–42).
Hinson, W. H.	An ion exchange treatment of plant ash extracts for removal of interfering anions in the determination of Calcium by atomic absorption. *Spectrochim. Acta* 18 1962 (427–429).
Holmes, G. D.	Chemical weed control in forests. '*Span*' 4 (4) 1961 (180).
Holmes, G. D.	The Lake States tour of the Fifth World Forestry Congress. *Jour. For. Comm.*, Lond. 29 1960 (5).
Holmes, G. D. and Fourt, D. F.	The use of Herbicides for controlling vegetation on forest fire breaks and uncropped land. *Rep. For. Res. For. Comm.*, Lond. 1960 (119–37).
Jeffers, J. N. R.	The electronic digital computer in forestry. *Unasylva* 15 (4) 1961 (175–177).
Jeffers, J. N. R. and Crowcroft, P.	Variability in the behaviour of wild House mice (*Mus. musculus* L.) towards live traps. *Proc. Zoo. Soc. London.* 137 (4) 1961 (573–582).
Jobling, J.	Recent developments in Poplar planting. *Quart. J. For.* 55 (4) 1961 (287–292).
Johnston, D. R. and Haggett, G. M.	Thetford Forest inventory. *Emp. For. Rev.* 40 (2) 1960 (142–153).
Johnston, D. R. and Waters, W. T.	Thinning control. *Forestry* 34 (1) 1961 (65–74).
Lines, R.	Report of visit of Silvicultural Group of R.S.F.S. to Dunkeld. *Scot. For.* 15 (3) 1961 (187).

Lines, R.	Report of visit of Silvicultural Group of R.S.F.S. to Cardrona and Glentress. *Scot. For.* 16 (1) 1962 (56).
Locke, G. M. L.	Appendix C to "The growing of hardwoods for pulpwood" by E. G. Richards. *Quart. J. For.* 55 (3) 1961 (219–222).
Locke, G. M. L.	Forestry contribution to "The soils of the Denbigh and Rhyl region". *Men. Soil. Surv. Gt. Britain,* H.M.S.O. London.
Matthews, J. D.	The silviculture of Teak in India. *Joinery Managers' Association Journal.* 8, 3. 1962 (15–18).
Matthews, J. D.	F.A.O. Expanded Technical Assistance Programme. Report No. 1349. Rome 1961. *A programme of Forest Genetics and Forest Tree Breeding Research.*
Matthews, J. D. and Jobling, J.	The propagation of some forest trees under mist. *Kent Farm and Horticultural Institute, Swanley.* 1961 (45–50).
Matthews, J. D. and Jobling, J.	Propagation of Elms and Poplars from summer wood cuttings. *Rep. For. Res. For. Comm.* Lond. 1961 (180–188).
Neustein, S. A.	Peatland Forestry Symposium at Belfast. *Scot. For.* 16 (1) 1962 (26–28).
Peace, T. R. and Thompson, H. V.	The Grey squirrel problem. *Quart. Jor. For.* 56 (1) 1962 (33–42).
Richards, E. G.	The growing of hardwoods for pulpwood. *Quart. J. For.* 55 (3) 1961 (206–222).
Shaw, R. G.	Machinery in British Forestry. *J. Inst. Brit. Agric. Engrs.* 17 (4) 1961 (110–114).

GENERAL

Report on Forest Research for the year ended March, 1960. (H.M.S.O., London, 12s. 0d. (12s. 9d.).)

Since the close of the year, the succeeding issue, *Report on Forest Research for the Year ended March* 1961, has been issued, and is available from H.M. Stationery Office, London, at 14*s.* 0*d.* (14*s.* 9*d.*).

In addition, members of the Research and Development Staff assisted with the review and revision of the following Commission publications which were re-issued during the course of the year ended 31st March, 1962.

Alignment Charts and Form Height Tables for Determining Stand Volumes of Conifers, Oak and Beech.

Forest Record, No. 37. Revised 1961.
(H.M.S.O. 1*s.* 9*d.* (2*s.* 0*d.*).)

Bedgebury Pinetum and Forest Plots.

Forestry Commission, Guide. Revised 1962.
(H.M.S.O. 3*s.* 6*d.* (3*s.* 11*d.*).)

Fomes annosus.

Forestry Commission—Leaflet No. 5. Revised 1961.
(H.M.S.O. 1*s.* 0*d.* (1*s.* 3*d.*).)

General Volume Tables for European Larch in Great Britain.

Forest Record No. 9. Revised 1961.
(H.M.S.O. 2*s.* 0*d.* (2*s.* 3*d.*).)

General Volume Tables for Norway Spruce in Great Britain.

Forest Record No. 10. Reprinted 1961.
(H.M.S.O. 2*s.* 0*d.* (2*s.* 3*d.*).)

Honey Fungus.

Forestry Commission—Leaflet No. 6. Revised 1961.
(H.M.S.O. 6*d.* (9*d.*).)

General—*continued.*

The Manufacture of Wood Charcoal in Great Britain.
Forest Record No. 19. Revised 1962.
(H.M.S.O. 3*s.* 0*d.* (3*s.* 4*d.*).)

Oak Leaf Roller Moth.
Forestry Commission—Leaflet No. 10. Reprinted 1962.
(H.M.S.O. 9*d.* (1*s.* 0*d.*).)

Pine Sawflies.
Forestry Commission—Leaflet No. 35. Revised 1962.
(H.M.S.O. 2*s.* 0*d* .(2*s.* 3*d.*).)

Provisional Yield Tables for Oak and Beech in Great Britain.
Forestry Commission, Forest Record No. 36. Revised 1961.
(H.M.S.O. 2*s.* 6*d.* (2*s.* 9*d.*).)

Two Leaf-Cast Diseases of Douglas Fir.
Forestry Commission—Leaflet No. 18. Reprinted 1962.
(H.M.S.O. 8*d.* (11*d.*).)

Westonbirt Arboretum.
Forestry Commission, Guide. Revised 1961.
(H.M.S.O., 6*d.* (9*d.*).)

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