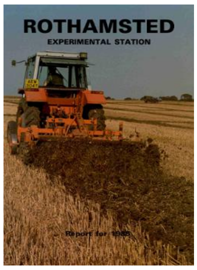
Rothamsted Experimental Station Report for 1985



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General Report

Rothamsted Research

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GENERAL REPORT

Last year's Report heralded a period of reassessment and new thinking about agricultural research and production in the United Kingdom. A year later a Forward Policy for the organization and management of research funded by the Agricultural and Food Research Council (AFRC) is to hand, and the scene is set for considerable change both in the pattern of institutes constituting the research service and in the broad objectives of the research programme. Later sections of this General Report will assess the impact of the new policy on Rothamsted, its governance and staffing, and upon its probable future rôle in the national research effort. Other sections record events of 1985, or present brief accounts of topical research activities.

Lawes Agricultural Trust Committee. No changes in the membership of the Committee took place during the reporting year. The forthcoming changes in the structure of institutes forming the research service are likely to be accompanied by alterations in their governance; with this in mind, the Committee has given initial consideration to important issues involved in their stewardship, and in that of the Trustees.

Staff. Two Heads of Divisions left to take up new appointments. P. B. Tinker joined the Natural Environment Research Council as the Director of Science with responsibility for the Council's terrestrial and freshwater research. He had joined Rothamsted in 1977 taking charge of the Soils and Plant Nutrition Department, newly formed by amalgamation of the previous Chemistry and Pedology Departments. He developed a broad and strong departmental research programme that included an important biological component concerned with the rôle of soil-borne mycorrhizae in crop nutrition. When divisions were created in 1983, he became the first Head of the Soils Division, and was appointed a Deputy Director. As a senior scientist in the agricultural research service, he has acted also as coordinator of two inter-institute programmes concerned with the Causes of Yield Variation and with Straw Incorporation. B. J. Miflin joined Rothamsted as Head of the Biochemistry Department in 1973 yet, notwithstanding his relative youthfulness, he was the longest-serving Head of Department when he departed. He has moved to Basel to lead the Seeds Sub-Division of Ciba-Geigy's Agricultural Division. When he took charge of the department, it had only 13 permanent scientific staff. He leaves a thriving department with some 50 staff and always a large corps of visiting scientists and students, that has attracted international esteem for its pioneering studies in assimilatory mechanisms for carbon and nitrogen and their regulatory control in plants. In 1983, he became Head of the Molecular Sciences Division. At all times he played an active rôle in Rothamsted's scientific management and in the general life of the Station. P. R. Shewry has been appointed as Head of the Biochemistry Department from January 1986.

For three years R. K. Scott has acted both as Head of Broom's Barn and as Head of the Agronomy and Crop Physiology Division, but at the end of the year he relinquished the divisional headship to devote his whole attention to the sugar-beet programme at Broom's Barn, and to satisfy the wish of the funding organization for a full-time Head of the Suffolk Station. As Chairman of the Working Party for Field Experiments, Scott had made a most valuable and informed input into the planning of Rothamsted's field programme.

D. Mackney retired from the Soil Survey of England and Wales (SSEW) in March after seven years as its Head, and a lifetime of service to the organization. He had provided positive leadership for the Survey, bringing his personal enthusiasm and determination to many issues, and in particular to ensuring the successful completion of both the National Soil Map at a scale of 1:250000 and the associated set of six regional bulletins. He was succeeded by P. Bullock, appointed first to the Survey staff in 1958.

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M. Elliott completed a 14-month period as a Visiting Scientist, following his formal retirement in 1984. He joined Rothamsted in 1948 to undertake chemical work on the constituents of pyrethrum flowers, developed a research programme relating chemical structure to biological activity in pyrethrin and allied synthetic compounds, and ultimately provided the agrochemical industry with a group of insecticides combining remarkable potency against insects with high levels of safety to mammals. These synthetic pyrethroids have been exploited worldwide and now represent about a quarter of the total usage of insecticides: to date, they have provided the British Technology Group with their second largest source of royalty income from patented inventions, and annual worldwide sales of pyrethroids are still rising. For a period between 1979 and 1983, Elliott acted as Head of the Insecticides and Fungicides Department, and as a Deputy Director. He plans to spend the next two years at the Berkeley campus of the University of California.

The Station's staff complement has decreased during the year to reflect the reduction in the 1985–86 budget, and to anticipate a further marked fall in the expected budget for 1986–87. Staff who retired or left Rothamsted in 1985 after long periods of service include: R. Bardner (Entomology, 32), W. J. Byford (Broom's Barn, 27), B. M. Church (Statistics, 38), A. J. Clarke (Nematology, 30), J. A. Currie (Soils and Plant Nutrition, 28), R. A. Dunning (Broom's Barn, 28), C. A. T. Edwards (Entomology, 25), P. Etheridge (Insecticides and Fungicides, 30), G. N. Festenstein (Biochemistry, 30), D. C. Findlay (SSEW, 34), R. E. Goodchild (Insecticides and Fungicides, 32), R. D. Green (SSEW, 32), D. R. Henden (Plant Pathology, 27), J. M. Hill (Biochemistry, 29), D. H. Lapwood (Plant Pathology, 30), J. R. Lofty (Entomology, 35), D. T. Pritchard (Soils and Plant Nutrition, 26), Clara Smith (Insecticides and Fungicides, 27), P. J. Welbank (Physiology and Environmental Physics, 28); parentheses show an individual's final department and years of service.

Buildings. The construction of the Station's new Conference Hall has reached the finishing stage, and the building should be handed over by the contractor in the first few weeks of 1986. The adjacent water garden should be completed and planted in early spring 1986, and the new facility opened officially in June 1986; the occasion should provide an opportunity for members of the Station to express formally their gratitude to the many organizations who have sponsored financially the building.

Users welcomed the completion in June 1985 of a new range of computer-controlled glasshouses that replaced the antiquated facilities previously available to members of several departments. The design concept appears to have been proven in practice, and the houses should be more convenient and efficient in energy use.

A major programme of roof renewal was undertaken in the second half of the year; large sections of the flat roofs of the Bawden, Fisher and Ogg buildings were replaced, fortunately largely in dry weather. The Station's main district heating system was upgraded to provide greater efficiency of energy use and to increase the flexibility of heat output. Microprocessor-controlled gas burners and calorifiers were installed, the pressure and temperature increased in the main plant, and better pipe insulation installed at many points on the circuit.

The climate for research

Current financing. The 1984 Report described the difficult financial climate in which research on arable crops was likely to be undertaken in the period 1984–87. Then the combined budget of Rothamsted and the AFRC Letcombe Laboratory (which duly closed at the end of March 1985) was expected to fall in real terms by about 25% over the three-year period. The actual situation has become even more dire, because cuts then foreseen have been compounded by additional budgetary reductions, taking effect in 1986–87 and arising

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from a further shortfall in the funds that AFRC derives from the Department of Education and Science (DES) and from the loss of some £5M of commissioned monies previously provided by the Ministry of Agriculture, Fisheries and Food (MAFF). On two occasions, difficult decisions to reduce the staff complement were necessary and eventually some 40 posts will be lost. In addition a few vacancies arising by retirement or resignation of staff members will not be refilled. Such rapid, enforced contraction causes traumatic personal difficulties for those individuals made redundant, and poses many problems for the effective planning of future research. The Station has been active and successful in seeking alternative sources of research funding, and in 1985–86 received funds exceeding £1M from external sources: a further £215K is provided by AFRC New Initiative and MAFF Open Contract projects. These extra funds support 74 staff.

The Soil Survey of England and Wales receives a separate budget from that of the main Station, its work being wholly commissioned by MAFF. This budget will fall to one half of the current level in the year 1986–87, and thereafter will be further tapered. Government Ministers have indicated that the Survey should seek alternative sources of funding, and the new Head has mobilized his staff in the active pursuit of external contracts, to be gained either at home or overseas. Meanwhile, the permanent complement of the Survey will be reduced by about 30 posts to adjust to the loss of MAFF funding, and leave a core of experienced and flexible soil surveyors around whom a contract project system might be built.

Forward Policy. Towards the end of 1984, the problems created by European surpluses of some major agricultural commodities gave rise to statements by Government Ministers and a policy document from the National Farmers' Union recognizing that in future higher yields and production would no longer be considered paramount among the objectives of UK agriculture. This indicated change in national agricultural strategy, and other considerations, led AFRC to re-examine its research policy. In May, the Council produced a discussion paper entitled 'A Long-Term View', and invited responses from individuals and organizations representing a broad spectrum of agricultural interests, from education, research, commerce and practice. The discussion paper, and its successor 'Forward Policy', recognized that an enormous body of expertise resided in the physical and biological scientists working in institutes, and that new and exciting directions for applying this corporate knowledge would emerge as agricultural objectives changed. The Council's future research aims would then be the maintenance of a balanced programme of strategic and applied research of relevance to the country's agriculture and food industries, and the provision of new knowledge upon which to base future options for land use benefitting both agriculture and the countryside environment, for enhancing the quality of agricultural produce, and for developing alternative crops or products, or alternative uses of existing crops. To attain these goals at a time of declining financial support for research, the Council outlined a new institute structure. The Directors of Research of new institutes, eight in number, under the Chairmanship of the Secretary to the Council, will form a Management Board for the Research Service. The Board will be expected to participate directly in the strategic management of research; it will formulate policy options for consideration by the Council, implement Council's decisions, and generally be responsible for the coordination of work within and between the new institutes in line with the most efficient use of staff and other resources.

The eight new institutes will be formed by amalgamations between the large number of separate research stations now funded by the Council. Three of the new larger institutes will be concerned with research on animals, three with work on plants and soils, one will be devoted to food research, and another to agricultural engineering. Rothamsted is likely to form the largest component of an Arable Crops Research Institute, in conjunction with the

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Long Ashton Research Station, and sections of the Plant Breeding Institute. The arable institute's brief will include crop production, crop protection and plant breeding, but the research interface with the proposed Plant Science Institute awaits clearer definition. The Directors of Research of the new institutes will have overall responsibility for the scientific investigations proceeding at the several sites under their charge; each site will be managed by a Head responsible to the Director. The Council envisages that the nature and number of Governing Bodies and Advisory Groups may need to change, allowing a Director to work primarily in concert with a single body. The Council also anticipates that all staff will become AFRC employees, when employer status of the Governing Bodies of grant-aided institutes would disappear. In regard to Rothamsted, these and other matters will need to be resolved by careful discussion between representatives of the Council and the Lawes Agricultural Trust.

Scientific interchange: people and information

In recent years, the Station has increasingly recognized the need to disseminate the findings of research widely among scientists, and to benefit the ultimate users or practitioners within the agricultural industry. As part of this process, the Friends of Rothamsted organization was launched in 1983: the membership has risen rapidly during the year, and now has reached 250, largely represented by leading arable farmers. The Friends meet twice annually at Rothamsted, and their gatherings promote a lively interchange of ideas and experience that benefit researcher and farmer alike. The availability of the new Conference Hall in early 1986 will permit the Station to entertain larger groups, and the Friends organization will welcome further members.

Information dissemination represents a major, successful purpose of the Friends organization, whose members farm mainly in eastern England. Now, the Station has augmented its information service by agreement with two viewdata systems providing national coverage for farming: one is Prestel Farmlink in association with British Telecom and the other, Agviser, is part of Imperial Chemical Industries. A package of information, available on both systems, provides topical information throughout the year on the Station's work concerned with practical crop management; the changing levels of mineral nitrogen in soil and of nitrogen in winter wheat will be traced from the time of drilling to the main spring fertilizer-N dressing, information that forms the basis of a computer-based N prediction system for the crop; data on pests, particularly aphid monitoring, will be presented in spring and summer, and be related to the likelihood of potato virus Y and cereal BYDV infections and the need for chemical control measures; and year-round information on the cultivation and practical husbandry of the sugar-beet crop will flow from the research at Broom's Barn. In addition, a summary of the results of the more important and interesting field experiments conducted on our farms will be included as appropriate. Such viewdata systems have been featured and explained prominently at agricultural events during the year, and this medium for information exchange seems likely to become increasingly popular and important.

Our scientists have exhibited and described their research findings at several agricultural shows and demonstrations. These included the Cereals '85 event and the Royal Show at the National Agricultural Centre, Stoneleigh, the Cultivations and Straw Disposal demonstration at Huntingdon, and the Sprays and Sprayers display at Ciba-Geigy's Whittlesford Centre. Other presentations, more strongly science-based, were included in the Royal Society's annual Soireés and in many poster demonstrations included in the programmes of national scientific societies or of international congresses.

Fuller cooperation with research groups in Europe and elsewhere and a greater contribution through research and technical support to the needs of Third World countries were included among the research aims set out in the AFRC's Forward Policy statement.

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Rothamsted has a long and impressive tradition in international exchanges of scientists and information, and of providing training in new ideas and methods for scientists from developing countries. In pursuit of these objectives, the Station welcomed nearly 60 overseas visitors, from 26 countries representative of all five continents, for periods of research collaboration and training: many more made shorter visits for purposes of discussion or information exchange. In reverse, a number of Rothamsted's scientists spent periods in research or consultancy overseas: our contacts with China under the British Council's Academic Links with China Scheme took A. J. Cockbain and R. D. Woods to Nanjing Agricultural University; P. B. Tinker visited centres of soils research in China; J. Lacey and J. F. Jenkyn visited India to promote the further development of the bilateral programme in aerobiology; and two biochemists, S. W. J. Bright and J. F. Antoniw, have each joined overseas laboratories, in California and The Netherlands respectively, for one-year periods of research. The UK Agricultural Research Service has close links with its counterpart in France (INRA) and some ten Rothamsted staff visited INRA centres to pursue cooperative research projects. About 130 additional overseas visits were made by staff, mainly to scientific conferences, but occasionally to provide advice on problems or training in research methods or agricultural practices.

Weather and crops

The performance of crops, and the results of field experiments, are influenced strongly by seasonal factors, attributable mainly to vagaries of weather. In 1984, most factors combined favourably and the UK cereal harvest attained record levels. The 1985 crops were produced under more difficult weather conditions. Those overwintering had been sown in autumn 1984 in rather wet and poor drilling conditions, their growth in early spring was checked by cold periods, and high rainfall in June caused much lodging in cereals. Harvest was late and conducted in difficult conditions, because no long spell of dry weather occurred in August or early September. Cereal yields in England and Wales were generally 10–20% lower than those of 1984, and were depressed further in northern England and Scotland, where summer rainfall was exceptionally heavy and prolonged. Poor weather delayed the harvesting of oilseed rape, and resulted in some shedding of seed from split pods. Winter beans were rather disappointing, the poor sowing conditions and wet summer producing problems. Residual herbicides did not persist sufficiently long to give effective weed control, and chocolate spot spread rapidly and several fungicide sprays were required to keep the disease under control. A fine autumn allowed potatoes to be lifted in good, although hard, soil conditions; yields generally were very good and the tubers went into store in clean condition. The sugar-beet harvest likewise was not too difficult, and yields were generally good: nationally, the crop averaged $6{\cdot}7\ t\ ha^{-1}$, the fourth highest yield recorded for the UK. Drilling of autumn-sown crops for the 1986 season was completed without difficulties.

Multidisciplinary field experiments and alternative crops

A subsequent section of this Annual Report, commencing on page 23, provides full details of the results of Rothamsted's multidisciplinary field experiments conducted in the 1984–85 growing season. This part of our crop research programme seeks a fuller understanding of the importance and interplay of agronomic and pathological factors that restrict the realization of the full potential of the genetic material provided by the plant breeders. The results of experiments on individual arable crops give information on the relative importance of different husbandry treatments, and aid farmers in making decisions regarding their own cropping systems. The programme of multifactorial experiments reported this year includes the results of the fifth and final year of the winter bean series, the penultimate year of a six-

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year winter barley series, and the start of a new series on winter oilseed rape. The initial series of experiments conducted on winter wheat ended with the 1984 harvest, but winter wheat forms the subject for our first problem-oriented multidisciplinary team beginning an investigation of alternative strategies for straw disposal and incorporation; this forms part of an AFRC coordinated programme involving several institutes.

Researchers, advisers and farmers alike are displaying an increasing interest in crops that might be grown successfully as alternatives to cereals, now in surplus in the EEC. The expansion of the oilseed rape crop during the last ten years has been spectacular, and the area devoted to the crop in the UK is now larger than that planted to either potatoes or sugar beet. Our multifactorial experiment on this crop is thus timely, and is expected to provide information on the best use of inputs. The 1985 season clearly demonstrated the overriding importance of favourable weather at harvest for, despite good growth and crop management, wet conditions seriously delayed cutting and much seed was lost by shedding. Measurements on the experiment allowed this loss to be quantified (mean value of 1·3 t ha^{-1}) and identified the crop treatments contributing most significantly to the loss by hastening pod and seed maturity. Lupin and sunflowers form other alternative crops studied in our field experimental programme. Plant breeders have recently been successful in developing earlier maturing varieties of sunflowers, some of which may be suitable for the climate of southern England. This year 41 varieties have been grown at Rothamsted in a single-plot observation trial and some in a replicated crop protection trial. Yields have been encouraging, despite the unpromising wet season. However, until more information is available from future trials, farmers' doubts will still centre on the possible lateness and difficulties of harvest.

Selected research investigations

The remainder of this General Introduction provides short accounts of some research activities chosen from work in progress in the scientific divisions. The selection seeks to draw the reader's attention to work that is particularly timely in relation to agricultural needs, or where the scientific findings are especially interesting or novel. Successful progress towards research objectives has often been dependent upon contributions by research scientists experienced in different disciplines and the advice and support of statisticians and computer specialists, and field experiments and farm staff.

Soils and crop production research

Cultivations. A group of staff transferred to Rothamsted on the closure of the AFRC Letcombe Laboratory at the end of March. At that time Rothamsted accepted responsibility for two major long-term field experiments that had featured in the Letcombe programme. One of these, at Northfield, Baulking, Oxfordshire, represented the longest running investigation of straw disposal on heavy clay soils. The effects of incorporating cereal straw into soil by various methods and to different depths on the subsequent growth and yield of autumn sown cereals, usually winter wheat, have been determined each year since 1979, and the results compared with those obtained following straw burning. Shallow incorporation was very detrimental to yield, but deeper incorporation, tested for the first time this year, gave yields identical to those after burning and cultivation to the same depth. This conclusion was in agreement with other work conducted as part of the AFRC's coordinated programme on straw disposal, where a new series of experiments indicated that there was little yield penalty when straw was incorporated in the top 15 cm of soil either by ploughing or by mixing with discs and tines, either singly or in combination. The other experiment,

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located at Brimstone Farm, Faringdon, Oxfordshire, is conducted jointly with the MAFF Field Drainage Experimental Unit. It tests the interaction between cultivation systems (direct drilling and ploughing) and drainage (undrained or mole- and tile-drained) for arable crops. Impermeable barriers between plots isolate them hydrologically, and enable drainage waters arising under these diverse tillage and drainage systems to be collected separately and analysed. Emphasis is placed on measurement of the amounts of nitrate lost in drainage which together with measurement of N lost by denitrification processes allows the construction of more complete nitrogen balances for different cultivation systems. The work thus forms a facet of a broader programme of research seeking to devise husbandry practices commensurate with high efficiencies of fertilizer-N use. The timing of N applications for greatest efficiency of utilization by winter wheat crops has been tested in previous multi-disciplinary studies: usually, increased wheat yields resulted when a late rather than an early application (mid-April compared with early-March) was made, but more detailed data analysis suggests that the earlier timing may be preferable if take-all is likely to be severe, or if mineral-N levels in soil are low.

Spatial analysis of soils. Another facet of Rothamsted's research on soils concerns their spatial analysis. The distribution of soil properties varies continuously yet apparently haphazardly over the land surface. By treating soil properties as random variables, however, their spatial variation can be described quantitatively by the semi-variogram of geostatistical theory. A suitable model is chosen for the semi-variogram and fitted by least squares approximation. Then, by combining the model with sample data, values of a soil property can be estimated optimally at unvisited sites and over larger blocks of land by kriging. A powerful suite of software has been written in Fortran for the analysis. It has been applied successfully in a wide variety of situations to map nutrient reserves, trace metal concentrations and mechanical compositions of soil, and the sulphur contents of wheat on scales ranging from 1 ha plots to an area represented by the whole of Great Britain. One of the most promising applications of the techniques is in combining data from remote sensors and field surveys. Work on behalf of the International Livestock Centre for Africa has already shown the feasibility of this approach, which will be developed along with new research on remote sensing of soil and crop growth.

Sugar beet production. National sugar yields during the 1980s have improved markedly over those typical of the 1970s and the years 1982 to 1985 have given, respectively, the first, fifth, second and fourth highest UK yields on record: the 1985 yield was 6·7 t sugar ha^{-1}. Thus the benefits of investment in research are now evident in enhanced sugar yield, and farmers and processors hopefully will provide continued financial support for future programmes designed to further increase productivity to reduce costs. There is scope in particular to improve plant establishment, to use more efficiently irrigation water, fertilizers, herbicides and pesticides, and to reduce losses caused by poor soil conditions associated with tractor wheelings or headlands. Continued monitoring and control of recurring or new diseases is also vital. Rhizomania, a disease caused by beet necrotic yellow vein virus transmitted by the common soil fungus *Polymyxa betae,* continues to spread throughout northern Europe: a strenuous effort is being made to keep Britain free of the virus, and this calls for extensive inspection and testing of beet crops. Two older problems, Docking disorder caused by the beet cyst nematode *Heterodera schachtii* and weed beet, may be exacerbated by changes in farming practices: the removal of restrictions on the frequency of cropping of beet makes nematode damage more likely unless nematicides are used with maximum effectiveness, whilst an increase in the area sown to fodder beet is providing additional sources of alien pollen conducive to weed beet development. All these aspects of sugar beet research are included in the programme of Broom's Barn.

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Plant physiology and metabolism

Recent emphasis on plant molecular biology and genetic engineering research may produce a situation in which knowledge in these fields will outstrip immediate opportunities for the effective exploitation of the new technologies because crucial features of the physiology and intermediary metabolism of crop plants remain unclear. Projects chosen from the work of various departments illustrate ways in which Rothamsted's scientists are helping to extend our understanding of plant processes.

Sub-cellular compartmentation of plant nutrients. Work on physiological aspects of potassium deficiency in barley, described in last year's Report (p. 184), has been developed further. X-ray microanalysis of frozen leaf tissues has revealed that potassium concentrations in the vacuole and cytoplasm of mesophyll cells respond differently to changes in tissue potassium concentration. Vacuolar K concentrations decreased markedly in deficient leaves while those in the cytoplasm remained more constant. This finding highlights the importance of the vacuolar membrane, the tonoplast, in maintaining the ionic composition of the cytoplasm, and work has commenced to define the transport properties of the membrane in greater detail. X-ray microanalysis also showed that calcium, accumulated in response to potassium deficiency, was located in epidermal cells and not in the mesophyll. Although previous work had shown that growth and tissue calcium concentration were inversely related, the fuller understanding of crop responses to potassium deficiency will require knowledge of both inter- and intra-cellular compartmentation of solutes.

Factors regulating nitrogen fixation in legumes. The fixation of atmospheric nitrogen by rhizobia in the legume root nodule is paradoxical. Large amounts of oxygen are required by the energy-producing processes facilitating symbiotic nitrogen fixation, yet the crucial enzyme system (nitrogenase) responsible for fixation is irreversibly damaged by free oxygen. Nature has evolved an elegant mechanism to reconcile these apparently conflicting requirements. The legume root nodule contains a barrier layer of cells that delicately regulates the rate of inward diffusion of oxygen to match the rate of its consumption and so maintains low concentrations in the inner part of the nodule where nitrogenase is located. Recent work at Rothamsted and the Animal and Grassland Research Institute has shown that the resistance of this barrier can change rapidly in response to carbohydrate supply to regulate oxygen transport and maintain balanced concentrations under different environmental conditions. The effectiveness of this system is determined by the genotype of both the host and bacterial symbiont, and the variable performance of different nitrogen-fixing legume crops under environmental stress may be a consequence of this situation. These mechanisms must be understood clearly before symbiotic performance can be guaranteed, or engineered into the root systems of other crops.

Mycorrhizal symbioses. The efficiency of various combinations of host plant and mycorrhizal symbiont can be assessed in pot experiments, where small soil samples can be sterilized to remove indigenous endophytes. In field conditions, where sterilization is not practical, different species of vesicular-arbuscular mycorrhizal fungi coexist in soils and it has been difficult to identify the species actually infecting host root tissues, and so to determine whether particular mycorrhizal inocula have proved effective by establishing symbioses. Now, electrophoresis using polyacrylamide gels has been developed to establish banding patterns of certain isoenzymes that characterize particular endophyte species. For three common species studied, the patterns are distinctive; they also differ from those obtained from the host roots. The technique then provides a basis for recognizing whether root infection has occurred, and for identifying the mycorrhizal species involved.

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Photosynthesis and photorespiration. Photosynthetic carbon assimilation depends upon the action of the enzyme, ribulose bisphosphate (RuBP) carboxylase, that catalyses initial fixation of atmospheric CO_2. The enzyme is unusual in catalysing a second competitive reaction, in which oxygen is used to split the normal C_5 ribulose bisphosphate substrate, and leading through a series of further reactions to an evolution of CO_2, and ammonia. This alternative process, termed photorespiration, is counter-productive to photosynthesis; it also places an energy burden on the plant for the reassimilation of the ammonia released, and for the recycling of organic carbon compounds produced concomitantly with CO_2 evolution. Little natural variation in the properties of the enzyme, particularly the relative affinities for CO_2 and O_2, is apparent in crop species, and so there is very limited scope for improvement via traditional plant breeding. However, many research groups are seeking a better understanding of the structure of the enzyme in relation to its functional activities, believing that developments in molecular biology and genetic engineering soon may present opportunities to introduce modified and improved forms of the enzyme into crop plants.

RuBP carboxylase is a complex enzyme structurally, and that from higher plants consists of eight large and eight small polypeptide sub-units (L_8S_8). Genes for both polypeptides have been isolated, and can be used to transform the bacterium, *Escherichia coli.* However, the transferred gene products have not yet been expressed as carboxylase activity because the subunits fail to assemble into the holoenzyme. The carboxylase of certain photosynthetic bacteria (cyanobacteria) exhibit a similar complexity of structure, but their sub-units are bound together less tightly and also reassemble more readily; the isolated genes for these sub-units are expressed after introduction into *E. coli* as carboxylase activity. Therefore, *in vitro* mutagenesis of the polypeptides forming these enzymes can be studied as a model system with the prospect that modified L_8S_8 holoenzymes can be made to test the molecular basis of their specificities towards CO_2 and O_2, and for their general kinetic properties.

For some years, barley mutants obtained by use of chemical mutagens have been used in our biochemistry programme, and such mutants are now employed in the investigation of photorespiratory carbon metabolism and ammonia recycling. Mutants with lesions leading to the loss, in part or wholly, of the activity of key enzymes implicated in these processes have been selected: knowledge of the genetics of these mutant lines, and of their photosynthetic capabilities is providing confirmation of the central features of the metabolic cycling of carbon and nitrogen in crop plants.

Crop protection projects

Crop protection strategies evolve continuously as new knowledge is gained about the biology and epidemiology of pests and pathogens, as new chemicals or biological control agents are developed, and as a response to the greater social concern for environmental issues now that sufficiency in major crop production has been achieved in western Europe. Many of the activities of the Crop Protection Division are serving to improve the accuracy and sophistication of monitoring and predictive systems, to extend the range of chemicals available for insect control, or to understand more fully the behavioural biology and genetics of important pathogens and pests.

Radar detection of airborne insects. Aphids are the major pests of agricultural crops in the UK and it is highly desirable to provide up-to-the-minute information on their aerial abundance and movement. Recently, a ground-based radar system has been developed to detect insects flying at heights between 12·5 and 250 m: recording is computer controlled, fully automatic and immediate. The computer calculates the target insect's velocity, height, bodyweight, shape and orientation; this data can be transmitted to a remote central computer. The success of this new approach for which the term 'Radar Taxonomy' has been

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adopted, will depend ultimately upon the degree to which insects exhibit a radar signature allowing them to be typed to species or species groups. Co-location of radar and suction trap installations is foreseen at several sites within the UK, and the combined system will provide day-to-day aphid pest warnings and longer-term forecasts of possible damaging infestations.

Aphid behaviour-controlling chemicals. (E)-β-farnesene is produced by aphids and released as an alarm pheromone. Last year's Report (p. 19) noted that when (E)-β-farnesene is used in conjunction with a synthetic pyrethroid, contact is enhanced between the aphid and the foliar-applied insecticide by increasing insect movement, and a higher percentage kill results from a given dose rate. Now a cycloaddition product of (E)-β-farnesene has been used in the field to control an aphid-transmitted virus disease: the material, applied to autumn-sown barley, substantially decreased the spread of barley yellow dwarf virus, and thereby increased yield by 12%. This is the first report of a successful field application of a behaviour-controlling chemical for the control of a virus disease; it then heralds a possible new and exciting avenue of enquiry, albeit the particular compound employed in our studies proved insufficiently persistent and active for commercial development. Future investigations will concentrate on alternative aphid antifeedant compounds derived from plants.

Aphid vectors of potato virus Y (PVY). This virus is the most important factor limiting the production of once-grown seed potatoes. It is transmitted non-persistently by aphid vectors. Originally *Myzus persicae* was regarded as the all important species, but recent work has suggested that the large numbers of *Brachycaudus helichrysi* and other species that visit, but do not colonize or breed on potato foliage, contribute significantly to virus spread. These observations provide a basis for the development of more rational strategies for disease control in a situation in which currently available pesticides may fail to contain the rapid transmission of viruses of this type. The best treatments in our recent field trials of synthetic pyrethroids and paraffinic mineral oils applied regularly to crops gave 86% control of PVY, suggesting that economic control of this virus is possible if accurate timing of such treatments is achieved based on vector phenology, and that control of the important group of non-persistently transmitted viruses may also be possible in future.

Dispersal of fungal spores. The Station has a distinguished record of research concerning spore dispersal mechanisms; two interesting but contrasting disease situations have been investigated in the past year. Light leaf spot on oilseed rape and other brassicas is caused by *Pyrenopeziza brassicae* infection of foliage; spores of the pathogen were believed to be dispersed in rain-splash droplets, but new experiments have shown spores to be in the air, both high above and far downwind of an infected crop, several hours after rain ceased. The heights and distances suggest that, in addition to dispersal by splash, a quite different release and dispersal mechanism may operate and be responsible for disease transmission over long distances to other brassica crops. A root-infecting fungus, *Polymyxa graminis* acts as a vector for barley yellow mosaic virus (BaYMV), a disease now observed widely in the UK. Both winter and spring barley cultivars are susceptible but, in the field, symptoms are seen only in late winter and early spring on autumn-sown crops. Now, methods have been devised for culturing *P. graminis* and BaYMV and optimum temperatures have been defined for production of the mobile zoospore stage of the fungus and for development of virus symptoms. These findings provide a basis for the development of tests to screen cultivars for resistance to the virus and its vector, and will facilitate studies of infection processes in the crop.

Nematological investigations. Potatoes and sugar beet are crops that can suffer severe damage by nematode infestations. Now, with the rapid increase in area in the UK devoted to

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the oilseed rape crop, concern is developing about the potentially damaging effects of beet and brassica cyst nematodes (both widely indigenous in soils traditionally used for these crops). Buildup of nematode populations to levels that cause appreciable damage often takes ten years or more, but reports of damage attributable to brassica cyst nematode now exist.

The relationship between a nematode and its host plant is often highly specific, and genetically and morphologically complex. New emphasis then is being given to augmenting microscopical techniques for species identification by newer biochemical characterization methods so that agriculturally important nematode-species complexes, host races and pathotypes can be defined with greater precision. Gel electrophoresis of soluble proteins and modern serological methods are being applied in particular to root knot nematodes (that form major pests of many tropical and sub-tropical crops), to cyst nematodes and to the genus *Ditylenchus,* that includes important species and host races, inadequately defined by traditional methods, and thus good material for testing novel approaches.

Developments in pesticide chemistry. An extensive knowledge of structure-activity relationships provided a firm basis for the development of the highly successful synthetic pyrethroid insecticides. In recent years, a similar approach has been applied to another class of potential insecticides, the *N*-alkylamides of which pellitorine forms a naturally-occurring example. Novel active compounds of this type have been tested against insecticide-susceptible and resistant strains of houseflies with striking results. In particular, strains whose resistance depends upon the *super-kdr* mechanism (which confers very strong resistance to DDT and the pyrethroids, and is considered to be intractable) are two to fourfold more susceptible to the *N*-alkylamides than insecticide-susceptible strains. The *N*-alkylamides then may represent a new and valuable class of compounds for the control of *kdr*-resistance selectively and specifically, and patents have been obtained in association with the British Technology Group.

Control of many pathogens and pests would be facilitated if pesticides could be designed to move downwards in plants after application to foliage. A small team of chemists and biologists has investigated the structural features necessary in compounds to promote their movement in the phloem of plants, concentrating their studies on a series of neutral and weakly acidic chemicals and using *Ricinus communis* (castor bean) as a test species because its phloem can be sampled readily. Subsequently, the experimental approach was extended to barley, potatoes and beans. The results indicated that good phloem transport is governed largely by the extent to which compounds are retained within the phloem rather than recognition by specific carrier mechanisms controlling access to the phloem. Many compounds examined entered the phloem freely but left equally readily and so moved mainly in the xylem. Relatively polar, neutral chemicals move in the phloem to some extent but weak acids that are strongly accumulated in phloem by virtue of its higher pH are transported best. The ionization constant and the partition coefficient, between octanol and water, of the acid, together with the molecular environment of the acidic functional group, appear to control movement in phloem. The molecular features governing the phloem movement of compounds are thus being defined gradually, and on the basis of the criteria established it may be possible to design downward-moving insecticides, fungicides and nematicides more rationally.

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