ROTHAMSTED RESEARCH

Report for 1982 - Part 1

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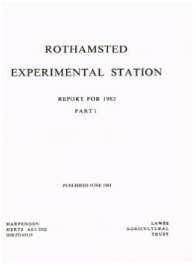

General Report

L. Fowden

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GENERAL REPORT

L. FOWDEN

Lawes Agricultural Trust. During the year Dr L. E. Sutton, who had served as Treasurer for the past 4 years, assumed the office of Chairman of the Trust Committee, and Mr J. S. Martin became Treasurer. We were saddened by the death in February of Dr A. Spinks, who had been appointed a Committee member only in late 1980; the President of the Royal Society nominated J. L. Montieth, Professor of Environmental Physics at the University of Nottingham, to the vacancy.

Staff. C. P. Whittingham retired in September; he had led the work of the Botany Department since 1971, and under his leadership the established research in crop physiology had been augmented by a strong programme on carbon metabolism in relation to photosynthesis and photorespiration. T. Woodhead left Rothamsted at the end of the year to take up a post at the International Rice Research Institute in the Philippines. He had been Head of the Physics Department since 1976, and in his period of office had worked untiringly to provide his colleagues with good equipment and facilities to promote their researches. These Headships have not been refilled because scientific activities are being regrouped gradually. The Station's Librarian, T. Cawley, and the Head of the Chemical Liaison Unit, K. A. Lord, also retired during the year after having completed 20 and 39 years' service, and were succeeded in their respective posts by Judith M. Palmer and G. R. Cayley. Five other members of staff retired after periods of service longer than 20 years (Department and year of appointment in parentheses): B. W. Avery (Soil Survey, 1948), L. Bailey (Entomology, 1951), C. W. Fearne (Computer, 1958), K. A. Jeffs (Station Safety Officer, 1957) and G. E. G. Mattingly (Soils and Plant Nutrition, 1951).

C. A. Edwards received Individual Merit promotion to the grade of Senior Principal Scientific Officer.

It is with sadness that we report the death of N. J. Wells, who had served in the Engineering and Maintenance Services for 19 years.

Honours. Her Majesty the Queen conferred the honour of Knight Bachelor on L. Fowden in the Birthday Honours List. T. Cawley was made a Member of the Order of the British Empire in the New Year Honours List, 1983.

Buildings. The second phase of the new glasshouse development on Ninnings field was completed in early summer, and this site now provides almost all of the glasshouse requirements of the Biochemistry Department, and supplementary glass for the Insecticides and Fungicides, Soil Microbiology and Soils and Plant Nutrition Departments. The refurbishing, often entailing a complete redesign, of the laboratories of the Soil Microbiology Department was finished on schedule in autumn.

Demonstrations of research

Subject days were held in the second week of June and attention was focused mainly on field experiments, classical and modern. The similarities and contrasts existing between the two types of experiments, designed at very different times to investigate factors affecting the yield of arable crops, particularly cereals, were explained to visitors on three successive days. A small indoor exhibit traced the history of the Broadbalk continuous wheat experiment and indicated how many new lines of investigation have

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developed from observations made originally on Broadbalk crops. The event attracted about 500 scientists, advisers and farmers.

Other events. At the Royal Show held in July at the National Agricultural Centre, Stoneleigh, Rothamsted featured its studies of subsoil cultivation using the Wye double digger to relieve deeper soil compaction, and the consequent effects on crop yields, with and without P and K enrichment of the subsoil. The Soil Survey also demonstrated techniques for measuring soil particle size distributions and the use of such data in agricultural practice, and exhibited various soil maps and other interpretative maps. In a later event at Stoneleigh, organized jointly by the Potato Marketing Board and the Royal Agricultural Society of England (RASE), an exhibit described the incidence of several storage diseases of tubers in relation to handling damage, storage temperature and freedom from soil contamination, and the efficiency of various chemicals and application techniques used to control diseases.

The Station contributed an exhibit on earthworms as part of a Darwin centenary review included in the Royal Society's Soirées; emphasis was placed on their role in the disintegration of organic matter in soils, and on the opportunities for the mass culture of earthworms in animal wastes leading to the production of well-structured composts and a new source of animal protein.

Visits and visitors. Whilst the Subject Days provided an excellent opportunity to describe the Station's experimental studies in crop production to a wide public, we have also welcomed visits from smaller groups enquiring about the mechanisms whereby the results of research are translated into practice. Members of the JCO Consultative Board made a site visit for this purpose in July and had a full and profitable day examining research and subsequent development of methods for insect monitoring and prediction, for the mass culture of earthworms, and for the prediction of nitrogen requirements in intensive cereal production. A similar visit was made by members of a National Farmers' Union Research and Development (R & D) Working Party, whose task was to identify the framework for communication between those involved in R & D and the practitioners in the agricultural and horticultural industries.

The Station hosted a number of small scientific meetings. An EEC Workshop on Diseases of Legumes was attended by about 40 scientists from eight European countries and particular emphasis was placed on the epidemiology of legume diseases, the detection and control of seed- and soil-borne diseases, and the opportunities to breed for resistance to diseases of economic importance. Our pathologists and entomologists also organized a Teach-In for the National Association of Seed Potato Merchants concentrating on black scurf and powdery scab diseases and the relationship between aphids and virus diseases.

Many visits were made by individuals or groups to learn about current research. We welcomed Mr W. Shelton, MP, Parliamentary Under-Secretary of State, Department of Education and Science (DES) in May, and Sir James Hamilton, Permanent Secretary, DES in June. Earl Ferrers, a Minister of State at the Ministry of Agriculture, Fisheries and Food (MAFF) made visits in June and December. The Liberian Minister of Agriculture, Capt. Fromayan, spent a day at Rothamsted as part of a UK tour organized by the Central Office of Information (COI). Delegations of overseas scientists included a Chinese group of soil microbiologists, a Brazilian agricultural mission, and a group of Russian plant physiologists led by the Deputy Minister of Agriculture of the USSR, Professor V. S. Shevelukha. The Director Generals of two International Agricultural Research Institutes, IITA in Nigeria and IRRI in the Philippines, made visits to assess opportunities for collaboration in research. Large groups composed of members of the

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Agriculture Group of the Society of Chemical Industry and of the Ninth International Colloquium of Plant Nutrition visited in May and August respectively to gain an insight into the span of the Station's work in the fields of soils and plant nutrition research. The number of overseas visitors attached to scientific departments for periods of research again showed a small increase—a total of 80 coming from 31 different countries.

The Station was represented significantly at several major international meetings in disciplines relevant to our researches: a group of statisticians attended the Compstat 82 and Biometrics 82 conferences held in Toulouse, whilst several entomologists and nematologists participated in a meeting sponsored by the International Organization for Biological Control in Stuttgart. Four members of the Insecticides and Fungicides Department visited Japan for the 5th International Congress of Pesticide Chemistry, and J. E. Beringer and S. W. J. Bright travelled to Japan for other conferences. B. J. Legg and R. W. Payne spent periods of research attached to CSIRO Institutes in Australia, and J. M. Day and K. E. Giller undertook collaborative work on biological nitrogen fixation in tropical grain legumes at ICRISAT, Hyderabad: P. Bullock, J. A. Catt, R. R. Furness and P. B. Tinker attended the 12th International Congress of Soil Science in New Delhi, and P. B. Tinker took the opportunity to discuss arrangements for future collaboration in soils work between the Indian Agricultural Research Institute and Rothamsted. P. R. Shewry spent 3 weeks in the Soviet Union evaluating recent Russian work on the genetic basis of cereal seed storage proteins, and J. E. Beringer visited Institutes within the Peoples Republic of China to discuss the genetics of *Rhizobium* in relation to the efficiency of legume root nodulation and nitrogen fixation.

The support and organization of research

Financial aspects. In the year under review, the grant-in-aid provided by the Agricultural Research Council (ARC) fell short, in real terms, of that needed to sustain the Station's research effort at the previous level, and so its provision was coupled with a requirement that the staff complement be reduced slightly. It has been possible to effect this reduction by blocking some vacancies, whilst continuing to provide equipment and facilities necessary to support ongoing research adequately. However, research planning and decisions regarding the deployment of current resources have recognized, of necessity, that further severe financial constraints may fall on agricultural research if the advice tendered to the Secretary of State at the Department of Education and Science by the Advisory Board for the Research Councils is accepted by the Minister: the Board's Forward Look made proposals for a disposition of the Science Budget that would result in a progressive reduction in the share received by the Agricultural Research Council beginning in 1984.

Organizational structure for research. Gradually, the Station's research has become more interdisciplinary in character; laboratory-based investigations involving close interdepartmental collaboration have increased in scope and the complex multifactorial field experiments, begun in the last few years to study the causes of yield variation in major crops, are strongly interdisciplinary. This situation was recognized clearly by last year's Visiting Group, but in the knowledge that several Heads of Department were likely to retire before the end of 1984, the Group commented that a unique opportunity could arise to modify the organizational structure of the Station's senior scientific management in ways that would encourage further interdisciplinary collaboration.

The options for combining research activities into larger groupings (or Divisions) have been assessed carefully by discussion within the Trust Committee and with senior members of the ARC Secretariat, and a plan has been adopted which will lead eventually to the formation of five Divisions: Soils, Crop Protection, Agronomy and Crop Physio-

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logy, Molecular Sciences, and Biomathematics. The new affiliations of staff, previously assigned to the now disbanded Botany and Physics Departments, accord with the proposed divisional plan (see pp. 67 and 173 for further details).

Another organizational change has concerned computing activity at Rothamsted. The Computer Department, using an ICL System-4 mainframe, had provided a computing service for agricultural research institutes in England and Wales, and also partially fulfilled the computing needs of the Agricultural Development and Advisory Service (ADAS). In the knowledge that System-4 must soon be replaced by new equipment, ARC decided, late in 1981, to create an independent Computing Centre to oversee the development of a modern computing network (see last year's *Report*, Part 1, 17). The new ARC Centre, located on the Rothamsted campus, was inaugurated on 1 October and a distinct Rothamsted Computing Unit, whose role is to provide the Station with dedicated advice and undertake collaborative projects with other scientists, officially came into being on the same day (see p. 89).

Weather and crops. The season was variable but generally less difficult than 1981. The drilling of winter cereals in autumn 1981 proceeded without particular difficulties but the major spring sowings were delayed slightly, because rainfall was considerably higher than average in March; however, a relatively dry April enabled sowings to be completed in good conditions. Temperatures at Rothamsted for 8 successive months (February to September) were above the long period means and rainfall, especially heavy in June, provided adequate soil moisture for most crops. The cereal harvest was completed in good time although some difficulty was encountered with lodged crops, particularly barleys and oats. The general pattern of cereal yields was good although the best did not match the peak yields of 1981. Lifting of later potato crops was subject to frequent interruption during a particularly wet October.

Cereals. All wheats were autumn-sown with Avalon and Aquila as the main varieties; Flanders was retained in the longer-term experiments. Generally, yields were slightly lower than in 1981 perhaps attributable to the rapid post-anthesis senescence of flag leaves caused by hot weather prior to anthesis. Foliar diseases were not pronounced but *Fusarium* infection of ears was unusually common, up to 10% being infected. Sharp eyespot (*Rhizoctonia cerealis*) was also more severe. Aphids never attained damaging populations and despite early sowing, barley yellow dwarf virus was infrequent. The best yields of 9·7 t ha^{-1} were obtained with Avalon at Woburn and with Longbow at Rothamsted. For the first time, the multifactorial experiment studying factors causing yield variation in winter wheat included a new test of rotation, which had the largest treatment effect on yield. Wheat following barley developed severe take-all and yielded only 5·0 t ha^{-1}, while after oats an overall yield of 8·2 t ha^{-1} was obtained, with a best treatment yield of 8·8 t ha^{-1}.

Igri remained the standard winter barley variety and, where sown early and well protected against pests and diseases, gave yields in excess of 8 t ha^{-1} at both Rothamsted and, on heavy land, at Woburn. The main spring variety sown was Triumph and some exceptional yields were harvested—up to 7·9 t ha^{-1} at Rothamsted and 8·7 t ha^{-1} at Woburn.

Potatoes. Planting was done in good conditions and completed before the end of April. Initially, establishment and growth were rather slow, but heavy June rains and warm conditions remedied this check. The wet weather predisposed the crop to blight (*Phytophthora infestans*), but this was prevented by four sprays of mancozeb and two of ofurace plus maneb, and yields were good. Even on Broadbalk, where potatoes must be

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lifted early to facilitate the timely entry of wheat, yields of up to 49 t ha^{-1} were recorded; elsewhere at both Rothamsted and Woburn, yields up to 62 t ha^{-1} were obtained.

Field beans. The crop survived the severe winter weather extremely well, but the unusually wet early summer was favourable to the rapid spread of first chocolate spot (*Botrytis* spp.) and then rust (*Uromyces fabae*) in both the winter and spring crops. Control by spraying was prevented after mid-June by lodging of the winter crop and yields were poor, ranging from 2·4 to 3·6 t ha^{-1}. These diseases were controlled reasonably effectively in the spring-sown crops, and with good control of pests and other diseases, yields up to 5·9 t ha^{-1} were recorded, with many in excess of 5 t ha^{-1}.

Sugar beet. The 1982 season was exceptional for this crop and yields were the highest ever recorded. The crop was sown relatively early, and benefited by unusually favourable weather during the subsequent period of seedling establishment and early growth. At Broom's Barn temperatures in April and early May remained consistently above the minimum critical for growth and during 4 consecutive weeks from mid-May onwards were about 4°C above the long-term average; frequent rain during these weeks ensured that the crop was not retarded by lack of water. Leaves expanded rapidly to give almost complete cover by 21 June, when the crop was intercepting 80% of the incident radiation compared with only 30% recorded on the same date in 1981 for a crop treated similarly. Diseases were not prevalent, and in the absence of later water stress, the exceptional sugar yields (expected nationally to reach 8 t sugar ha^{-1}) can be attributed to the very rapid early growth promoting the interception of solar radiation.

Selected research investigations

The Station has continued its broad programme of research to provide a better understanding of the physical, chemical and biological factors governing the interactive behaviour of soils and crops, of the physiological and biochemical response of crops to the external environment or internal controls, and of specific behavioural relationships existing between crop plants and disease and pest organisms; and to develop from this new knowledge better methods for the farmer to manage his soils and plan his arable cultivations and husbandry.

Soils research

The national soil map. The Soil Survey of England and Wales will publish in Spring 1983 a national soil map at a 1:250 000 scale, based mainly on information collected in an intensive field survey lasting 3 years. The production of the map forms a most significant achievement in the Survey's programme, and required the dedication of all staff to the project: since earlier survey information was updated and incorporated, credit also must be extended to some staff who are no longer serving Rothamsted. The map, commissioned by MAFF, seeks to provide a systematic inventory of the soil resources of England and Wales that will be useful for many purposes including agricultural advisory work and land use planning. It will provide information appropriate to national, regional and county issues and, even at farm level, the map will indicate the most likely soil type and the pattern of soil variation.

The map comprises six sheets conforming to ADAS regions with some overlap. A legend covering all six sheets describes the composition, characteristics, land use, and per cent area representation of the 296 soil associations identified. Each regional map has an abbreviated coloured key, and inset small scale maps indicating sheet boundaries

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and the locations of earlier surveys. A bulletin describing each regional map is in preparation and will be published in 1984.

A computerized Soil Information System has been assembled and includes field, laboratory and map unit boundary data and information from 5000 soil pits dug during the national map project. We now must await decisions about the new ARC computing facilities and database software before developing a 'user friendly' method for searching, retrieving and manipulating the soil data forming the system.

Trace elements and heavy metals in soils. There is considerable interest in the possibility that Soil Survey maps may be useful in predicting the levels of trace elements present in particular soils, and the existence of correlations between metal levels and soil series is being tested. In a representative investigation, top soils from ten important soil series in eastern England have been examined. Analyses have shown that the ranges of concentration of metals in different soils overlap considerably, and so identification to soil series can provide little guidance on total metal contents of a soil. However, for some soil series and certain metals only, remarkably good correlations exist between the total content of particular metals and the fraction available by chemical extraction—relationships that may prove valuable in future.

The usefulness of long-term field work again has been demonstrated by the Woburn Market Garden experiment. This received heavy dressings of heavy metal-containing sludges for 20 years between 1942 and 1961, and recent measurements have shown that about 25–35% of the metals originally added are still present in available forms. Very little loss of metals by leaching has occurred, so more than half must be retained by tight chemical bonding. As interest increases in sludge disposal to land, the Woburn site has become especially valuable because now it is probably the oldest and best documented experiment of its type in the world.

Soil moisture stress and wheat growth. The Little Knott rain-shelter facility was used during 1982 to study the effects of the timing and duration of drought on the growth and yield of winter wheat. Early drought depressed straw yield and increased harvest index, and late drought reduced mean grain weight, but neither effect was large. Plants receiving full irrigation from April until mid-July used 40% more water than those plants receiving neither irrigation nor rain during this period, but the grain yield of the irrigated crop (7·6 t ha^{-1}) was only 0·5 t ha^{-1} higher than the unirrigated.

Mycorrhiza and phosphate nutrition of cereals. A 3-year field investigation of the effects of vesicular arbuscular mycorrhiza on the growth and phosphorus response of small grain cereals has shown that yield responses to added mycorrhizal inoculum may be as high as 40% in soils low in phosphate and containing little natural inoculum. Appreciable responses to added mycorrhizal inoculum still were observed when moderate dressings of phosphate were applied, but the responses became very small when this soil had a high content of indigenous mycorrhizal fungi. Barley and wheat responded similarly, as did autumn- or spring-sown crops. Therefore, natural infection of cereal roots by mycorrhizal fungi appears important in their phosphorus nutrition, but it is not essential.

Genetic manipulation of crop species. This programme now has a full complement of staff and, with the benefits deriving from specially-designed laboratories, interesting results are being obtained along several lines of cellular and molecular investigation. Clones of DNA have been identified for many of the major groups of cereal storage proteins. Cell and tissue culture techniques for plant regeneration have been developed and extensively applied; potato plants have been derived from both protoplasts and tissue

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cultures, and wheat plants from callus cultures initiated from immature embryos. Some plants derived by these techniques display substantial variation, both from the original mother plant and among themselves, and the possible usefulness of this variation in plant breeding is being assessed. A number of mutant genotypes of barley have been recognized, and important among these are lines lacking nitrate reductase and alcohol dehydrogenase, and mutants containing both dominant and recessive genes facilitating growth on strongly inhibitory combinations of amino acids or amino acid analogues. These mutant lines are valuable both in the more precise analysis of aspects of the intermediary metabolism of plants and in the provision of readily identifiable markers in systems studying gene transfer.

Much of this work forms part of the more comprehensive ARC genetic manipulation programme, and a close collaboration is maintained with other institutes, particularly the Plant Breeding Institute at Cambridge, with universities at Bath, Cambridge, Nottingham and St Andrews, and with commercial organizations including Shell Research and Rothwell Plant Breeders. Good links already exist with plant molecular biology research in progress in several European laboratories, and two grants recently awarded as part of the EEC-sponsored programme on biomolecular engineering will strengthen collaboration with groups in France and the Netherlands.

Crop pest and disease research

Dispersal of fungal spores. Several investigations in progress seek more refined information about the manner of dispersal of pathogenic fungal spores by wind or rain. In a joint study conducted with the CSIRO Division of Environmental Mechanics in Canberra, a wind tunnel was employed to simulate the dispersal process in turbulent air both above rough surfaces and within a model crop canopy. Diffusion theory, analogous to the theory of molecular diffusion of gases, inadequately describes particle movements within the canopy, and so two alternative theories to describe dispersion in terms of crop and air flow characteristics have been developed. Data from the wind tunnel experiments are being used to test these alternative theories. In one, the trajectories of individual air parcels associated with turbulence can be simulated in three dimensions, and the resulting model successfully depicts spore release in gusts of wind, and relates deposition on surfaces to the instantaneous speed of the spore. Increased understanding of the aerobiology of spore dispersal should facilitate more accurate prediction of patterns of disease development and the adoption of appropriate and timely control measures.

The spread of plant viruses. Winter wheat and barley crops are prone to infection by barley yellow dwarf virus (BYDV), especially if drilled very early. Recent *Reports* have described the development of an Infectivity Index, that indicates the probable need for an autumn protective spray against the aphid vector of the disease. The Index is being adopted increasingly by ADAS for forecasting the incidence of the disease, and in 1982 an Index based on Shardlow, and relevant to the East Midlands, has been calculated for the first time: it differs substantially from that for Rothamsted, and suggests that the threshold index, indicating the need for a control spray, probably will have to be determined separately for each region. Next year, we hope to develop an Infectivity Index based on Broom's Barn and applicable to East Anglia.

Knowledge concerning many factors having an important bearing on the spread of crop viruses is still inadequate; for example, it is not uncommon to find uncertainty about the principal overwintering site of a virus or its main insect vector, or about the range of alternative host plants available to a virus. This situation is encountered with the yellowing viruses of sugar beet. The alternative hosts of beet yellows virus (BYV)

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are considered to be mostly members of the Chenopodiaceae, but the commoner beet mild yellowing virus (BMYV) can infect plants from several families, possibly including oilseed rape. Brassicas are known to be overwintering hosts for *Myzus persicae*, the aphid vector of virus yellows, and the possibility that rape may represent an overwintering site for beet yellowing viruses raises a new and important threat to sugar beet, because the area planted to the rape crop has increased very rapidly in recent years. The sensitive ELISA test, applied to rape crops growing near virus-infected sugar beet seed crops, has given positive results when BMYV antiserum was used. There must then be a presumption that the rape was a host for this virus, although other luteoviruses might give a positive reaction with BMYV antiserum. Whilst further tests are needed to provide an unequivocal identification of the viruses, experiments have already established that *M. persicae* is able to transmit the virus from rape to sugar beet.

Recent collaborative work between the Entomology, Plant Pathology, and Soils and Plant Nutrition Departments has sought to establish X-ray elemental analysis as a technique useful in distinguishing insects originating from different host plants or geographical regions. Results have indicated that a few elements, consistently present in insects in high concentrations, can provide good markers, particularly of the nature of the host plant upon which a polyphagous pest (or virus vector) had developed. Considerably more developmental work is required, but if these early findings are confirmed, this sensitive analytical technique could provide a valuable tool for use in agricultural, veterinary and medical entomology.

Insect pheromones. In the past year, increased emphasis has been given to collaborative work between chemists and biologists on the nature of various insect pheromones and the possibilities for using them in new ways to reduce pest damage. For example, when applied in combination with the aphid alarm pheromone (*E*)-β-farnesene, synthetic pyrethroid insecticides are much more effective against aphids. Also stable involatile adducts of the pheromone can result in a marked diminution of colonization and virus transmission by aphids. It was then fascinating to discover that type B sticky hairs of *Solanum berthaultii*, a wild potato species with a high level of natural immunity to virus infection (*Rothamsted Report for 1979*, Part 1), release the identical sesquiterpene. We believe this to be the first record of a natural defence compound of an aphid having a presumptive role as a natural protective agent elaborated by a plant, i.e. (*E*)-β-farnesene may be classed as an allomone.

Honeybees emit from their Nasonov glands a mixture of seven volatile components forming the Nasonov pheromone and serving to attract other worker bees. A simplified mixture containing only three of the natural pheromonal constituents is still highly effective, and has been tested successfully for field use as a lure to attract swarms into empty hives. A patent on this mixture and its use has been filed, and the relative cheapness of materials suggests that the method may find a widespread application in countries where peasant beekeeping makes a significant contribution to the local agricultural economy.

Combating resistance to insecticides. The development of resistance in insects to insecticides represents a continuing threat to the efficiency of chemical control agents. Build-up of resistance can be rapid as encountered in some housefly populations, on animal farms in Europe, whose resistance to pyrethroids has increased markedly following continuous contact with residues of persistent or frequent exposure to sprays of non-persistent compounds. Recent studies by members of the Insecticides and Fungicides Department, at a farm where previously permethrin had failed because resistance developed within 3 weeks of application, established that the non-persistent bioresmethrin

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gave good control if applied only when fly populations reached a nuisance level; in practice, sprays were applied at intervals of about 2 weeks and excellent control was retained for a year without any indication of the development of resistance. This example has demonstrated that it is possible to devise strategies to combat resistance effectively even in situations where there is a known strong resistance potential.

Electrostatic sprayers. The need to increase the efficacy of pesticide sprays is widely recognized, and has prompted much new research into the design of spraying systems with the object of achieving better deposition of control chemicals on the biological targets. The electrostatically-charged rotary atomizers (APE 80 and 'Jumbo') developed at Rothamsted certainly give considerably increased chemical deposits on plants, including the under surfaces of leaves, and spray drift and soil contamination are reduced. Biological effectiveness is at least as good as and often better than that given by hydraulic systems; dosage rates can be decreased in many instances without loss of biological action, and with a commensurate saving of resources and decreased contamination of the environment. The main technical requirement now is to improve penetration of the crop canopy. Possible methods of achieving this include (i) use of charged deflector bars, (ii) alteration of the orientation of the spray heads to impart a downward component to the spray droplets, (iii) variation of the drop size-charge characteristics by modifying disc speed or voltage or by voltage pulsing, and (iv) air assistance. Modified equipment will be ready for field testing in spring in situations where canopy penetration is essential.

Earthworm production. Last year's *Report* (Part 1, 16) gave a short account of research being undertaken in the Entomology Department to assess the feasibility of earthworms, grown in farm organic wastes, as a new protein source for animal feeding. This year the project has gained momentum. The scientific coverage has been extended by additional collaborative links with ARC institutes and universities, by the introduction of microbiological studies at Rothamsted, and by comparative studies of the reproductive biology and optimum stocking rates of four species of worm. A larger-scale production system is now in use, enabling more extensive livestock feeding trials to be conducted by cooperating organizations, and the utilization of worked wastes especially as composting materials, is being tested extensively. Arrangements have been agreed for a trial of the system under small-scale commercial conditions.

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