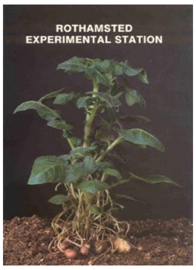
ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1983



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INTRODUCTION

In the UK where £4 billion-worth of crops are grown annually, 10–15% of the potential yield is lost through pests and diseases; globally, the losses are much greater. Crop protection thus occupies, now and for the foreseeable future, a key position in crop production, whether the national emphasis remains on maintaining yields from the present area cultivated, or on increasing production from gradually diminishing land resources. Practices in crop protection must also be cost-effective and have minimal effects on the environment, if they are to remain acceptable to an increasingly sophisticated and influential public.

Against this background, the recent formation of the Crop Protection Division is an important step towards ensuring a forward-looking, coordinated approach towards the changing needs of pest and disease control. The Division, comprising Entomology, Insecticides and Fungicides with their Chemical Liaison Unit, Nematology and Plant Pathology Departments, contains a range of distinguished biologists and chemists, with substantial resources, and is well able to rise to the requirements of research in the subject over the years ahead. The proximity of other Divisions with complementary expertise in field experimentation, crop physiology, and soils will encourage a uniquely broad-based approach.

In the short-term there are exciting prospects for chemical control of many pests and diseases, and for the chemical manipulation of beneficial organisms. In the longer term, work will be directed towards methods that reduce application costs and increase biological effectiveness, to new biodegradable pest control compounds that avoid residual contamination of food or the environment, and to biological agents and

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cultural practices active against the debilitating pests and diseases for which no satisfactory chemical has so far been found. The presence at Rothamsted of a large group concerned with molecular manipulation provides opportunities to look even further ahead into genetically based crop protection mechanisms.

The Division looks forward enthusiastically, confident that it will make major contributions in principle and practice to crop protection in Britain and overseas.

ENTOMOLOGY DEPARTMENT

The Department is well aware of the need for frequent reappraisal of the objectives of applied entomological research, and its own particular role, in a rapidly changing agricultural scene. It has accordingly maintained a careful balance between medium- to long-term basic studies and short-term investigations likely to be incorporated quickly into agricultural practice, and has begun several new and completely innovative investigations.

Insect migration and pest and disease forecasting

The long-established Insect Survey continued to provide valuable information on the occurrence of pest aphids and added to its unique data bank on this most important group of pests. The general level of migrants available to infest crops in an area was again measured by suction traps run by various services, including DAFS, at 23 sites in England, Wales and Scotland. These sample stations were used to provide information to ADAS and others about the risk of crop infestation and virus infection in geographical regions of the country.

The system is constantly being improved by introducing new sampling techniques, recording behaviour to improve forecasting, interpreting population structure to anticipate pesticide resistance, and investigating the differences between fields to make the advice relevant for individual farms. (L. R. Taylor)

Radar detection of aphids. Radar used in studies of pest insect migration has hitherto concentrated on large insects such as locusts and moths. Recently the techniques have been extended to much smaller insects including aphids, and Rothamsted has taken the lead in trying to establish a combined trapping and radar network to monitor aphid movement. 'Vertical-looking' radar is being developed to use alongside suction traps for monitoring aphids at heights up to 500 m. The equipment generates high power, short pulse, X-band emissions operating at a frequency of 9·4 GHz from dual-antennae designed to detect insects in two height-bands from 20 to 100 m and 100 to 500 m. As insects fly over, the returning signals from many heights are sampled and stored. The signal from an individual insect contains information that can reveal its weight and shape, speed and direction of flight, and wing beat frequencies that aid identification.

Radar signals and target identification will be analysed immediately by a dedicated computer which will also control and monitor the radar equipment, and store the information. It is intended to instal up to five radars in the south and east of England over the next few years each linked to Rothamsted. Information will be assessed and collated centrally to give immediate information about insect density and pest movements over a large area. This will significantly improve the monitoring and forecasting ability of the Insect Survey by relating particular outbreaks to their source and to weather likely to encourage their spread. (Bent)

Storing and processing aphid records. The enormous amount of data collected annually, and the unique bank of information on aphid movement, require

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sophisticated recording methods. A new microcomputer system for initial handling of aphid records has operated successfully for two seasons. It is based on a MSI/77 data-logger with barcode reader and a Midas 3HD microcomputer for data validation and the automatic production of the *Aphid Bulletin* (see below), and data analysis for the *Aphid Commentary,* which have to be produced to very tight time schedules. The new system gives good validation and provides maximum time for interpreting the data for advisory purposes.

The main Insect Survey historical database is being transferred from the ICL 470 to the new Rothamsted VAX 750 computer. This will provide faster access as data will be stored on disc rather than magnetic tape. It should also enable the historical and current aphid databases to be integrated with a direct link between the Midas and VAX for data transfer. In the coming season the MSI/77 data-logger will be replaced by an Epson HX-20 microcomputer to increase flexibility and improve the validation of data input and the subsequent speed and efficiency of output for forecasting crop infestation and virus infection. (Woiwod; Rowe and Khasriya, with Clark, Statistics Department, and Summerfield, Computing Unit)

The dissemination of monitoring data for pest warning. Weekly data from the network of suction traps are circulated to the agricultural industry in two forms. The *Aphid Bulletin* (weekly data for 33 aphid species) (*Rothamsted Report for 1983,* Part 2, 301–331) is mailed first class to about 250 individuals and organizations; 200 of these also receive the *Aphid Commentary* (an interpretation for selected species) (see *Rothamsted Report for 1981,* Part 1, 96–97). The *Aphid Commentary* recipients are mainly crop consultants, ADAS advisers, pesticide representatives and farmers. This initial circulation is small, but a recent survey has shown that each recipient of the *Aphid Commentary* makes the information available to an average of 400 farmers, suggesting that a grand total of about 80 000 farmers use it to assist in their own local pest control decisions. This number is due mainly to the audience reached by ADAS and pesticide firms and there may be some overlap between them.

The information goes to all corners of Britain but interest is concentrated in the arable, and particularly cereal-growing, regions of eastern and central England. With the advent of the Epidemics Prediction and Prevention (EPIPRE) technique for small scale, short-term forecasting, interest is turning increasingly towards the factors affecting differences between fields. (Tatchell; Dupuch, Nicklen, S. Parker, Riley, M. S. Taylor and Wood)

Cereal aphids. To examine the between-field variation in cereal aphid numbers, the Rothamsted Insect Survey Cereal Aphid Monitoring Scheme (RISCAMS) was continued for a second year. In 1983, wheat fields were sampled near Rothamsted, Broom's Barn and Writtle on most of the farms examined in 1982, using the same sampling methods (*Rothamsted Report for 1982,* Part 1, 92–93).

The mild winter of 1982/83 increased overwintering survival of cereal aphids, especially *Sitobion avenae* and *Metapolophium festucae* and these attracted the attentions of enough natural enemies in many crops to prevent aphid outbreaks later in the summer.

In some sheltered, early-sown (before 14 October) wheat fields not treated in autumn, aphids (mainly *S. avenae*) reached damaging thresholds (>5 per tiller). Outbreaks only occurred in such fields in Suffolk and in the coastal areas of Essex. None of the fields sampled in the Rothamsted zone had more than three aphids per tiller although almost 30% of them were sprayed with insecticide. Indeed, insecticides were applied, probably unnecessarily, to a much larger area than in 1982. In Essex over half

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the sample fields were sprayed, but the greatest usage of insecticide occurred in northern East Anglia where 77% of sample fields were sprayed at least once. (Dewar; A. Wright)

Population genetics of cereal aphids. Further data in genetic variation between field populations of *S. avenae* is needed to understand their distribution and combat the development of pesticide resistance. To obtain this, samples were collected in 1982 from winter wheat at six sites in the UK, including two of the four previously monitored in 1981, and three in Spain. As in 1981 the samples were surveyed electrophoretically using five enzyme systems representing 13 loci (*Rothamsted Report for 1982,* Part 1, 93–94). Estimates of inter-population genetic heterogeneity showed that there were significant spatial and temporal differences in allele frequency between populations. The spatial differences may reflect genetic drift or localized selection of 'strains' (e.g. to host plant factors), whilst the temporal variation suggests that *S. avenae* populations are either impermanent or that many less fit 'strains' often die out in winter. However, overall genetic distances between populations were small and mostly similar in size, implying that there is sufficient gene flow to prevent regional differentiation into races, etc.

During 1983, Blackberry-grain aphids *Sitobion fragariae* from *Rubus fruticosus* and *Dactylis glomerata* in Hertfordshire and Northamptonshire were surveyed at a single locus (glutamate-oxaloacetate transaminase, GOT) and seven phenotypes identified. These may be useful as markers for investigating gene flow, overwintering strategies and host-related selection in this species. (Loxdale; Brooks and Knight)

Aphid incidence on potato. Large numbers of aphids colonizing potatoes cause direct yield loss due to feeding. The Insect Survey traps provide information which will eventually be used to warn of imminent damage but better understanding of crop populations is required before suction trap data can be fully exploited, and crop monitoring now has this objective.

The 'peach-potato aphid' *Myzus persicae* is probably the main vector of viruses in potatoes in the early stages of growth. Forecasting the time and size of migrations from winter hosts provides warning of the need for, and timing of, control in the seed crop. Knowledge of winter mortality of the aphid is necessary for such a forecast. Cabbages are important winter hosts for this pest in the south-east, where it overwinters most successfully. Most aphids are found on older leaves, which senesce and fall as winter progresses, so to survive, the aphids must move progressively upwards to younger leaves. Survival over this period has been found to be correlated positively with temperature and negatively with leaf surface-wetness but not with rainfall. In the shelter of the leaves rainfall may not directly affect aphid movement, but high surface-wetness and low temperature impeded their escape before leaves fall, so reduce survival. This effect of weather on aphid behaviour causes overwintering mortality at mugh higher temperatures than laboratory studies have indicated, thereby changing expectations for survival used in forecasting crop infestation and virus infection in spring. (Harrington; Cheng Xia-nian)

Elemental analysis of insects. For most insect pests there is no reliable, objective way of deciding what, if any, proportion of a population at a particular place is resident or migrant. However, with the aid of X-ray microanalysis, it may be possible to show that different populations have recognizably different elemental concentrations, i.e. that different populations carry their own natural markers These different elemental combinations are called 'chemoprints'.

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Studies have shown that soil type and host plant both influence chemoprints. In species that feed on a wide range of plants, e.g. cutworms, this means that it is unlikely that chemoprints will define a *geographical* source, though they will differentiate populations and possibly also identify populations from different hosts. In species that feed on one or a small number of related host plants there is a better chance of identifying geographical sources because locality, and soil type, become the major influence on the chemoprint.Geographically-distinct populations of brown plant hopper (bph), a major pest in south-east Asia, have been clearly distinguished by their chemoprints.

Cereal aphids, like bph, have a limited host plant range but present other problems connected with their parthenogenetic mode of reproduction and the presence of both winged forms that move from place to place and wingless forms that do not. Work with three species of cereal aphids, still in its preliminary stages, suggests quite clearly that wingless forms have a remarkably uniform chemoprint but that there is much more variation between the winged forms. This indicates that it may well be possible to differentiate populations from different hosts using the winged forms, but not the wingless. This has been shown to be the case with the bird-cherry aphid, *Rhopalosiphum padi*; winged forms from barley infected with, or free from, BYDV are clearly separable, wingless forms are not. (Bowden; Fox, Minall and Sherlock, with Digby, Statistics Department and Turner, Plant Pathology Department)

The biology and detection of pest midges

Many midge pests are notoriously difficult to control because their biology is often exceedingly complex. New lines of work have begun in 1983 on two pests of current concern.

Pea midge *(Contarinia pisi)*. The pea midge is a sporadic, but locally serious pest of both combining and vining peas in the UK. It causes yield loss by preventing truss formation, but the intensity and timing of attack are unpredictable.

Studies that should provide growers eventually with a monitoring trap (similar to the pea moth trap) for this pest have begun. Preliminary trials have shown that virgin female midges attract large numbers of males to traps placed in emergence sites, i.e. fields in which peas were attacked the previous year, and that both crude and fractionated chemical extracts of virgin females are also very effective for catching males in traps.These results demonstrate the presence of a powerful female sex-pheromone, the identity of which is being investigated.

The pea midge normally has two generations annually; the first emerges from fields (usually wheat) in which peas were grown the previous year, and the second is produced on the current crop. Intensive sampling on two farms in 1983 has shown that only females of the first generation migrate to the current pea crop; males remain at the emergence site, being found only well within the crop canopy (wheat). This pest species is active during the day, and there are strong indications that mating occurs in the early morning, followed later by female migration.

Sex-pheromone traps placed in fields known to have been attacked the previous year should catch male midges immediately on emergence, and offer the opportunity to warn growers in good time of the risk of imminent attack of nearby pea crops by females. A pilot detection system involving virgin female traps will be evaluated in 1984, concurrent with work on optimum trap design, placement and the identification of the pheromone. (Wall; Garthwaite, Morris and Sturgeon, with Pickett and Scudder, Insecticides and Fungicides Department, Mr C. R. Owen, Reading University, Dr J. Blood-Smyth, ADAS Cambridge, and Mr A. Biddle, Processors and Growers Research Organization)

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Oilseed rape pod midge *(Dasyneura brassicae)*. Infestation by this pest causes premature shattering of pods and loss of seed but its ecology and behaviour is poorly understood. An infestation of a commercial crop of winter oilseed rape by the midge was followed from May until harvest. Despite heavy infestation of the crop (12% of pods were split by midge at harvest) few adults were caught by either white sticky traps or yellow water traps and a better method of sampling adults, possibly by pheromone traps, will need to be devised. Mature midge larvae emerged from plants daily from 13 June until just before harvest, with two distinct peaks of emergence in the third week of June and in mid July, clearly reflecting two overlapping generations. Second generation adults emerged 14–19 days after leaving plants as larvae. Cocoons were first found in soil samples on 13 June and numbers increased steadily until harvest. Until 8 July up to half the cocoons contained pupae but thereafter cocoons contained only larvae. Presumably the larvae that pupated emerged as second generation adults whereas those first generation larvae that did not pupate, and all second generation larvae, entered diapause.

Emergence of larvae from pods, of adults from cocoons, and flight activity of adults in the crop all showed marked diel periodicity. Larvae emerged at night and early morning; adults emerged at dawn and until just after sunrise; the two sexes emerged concurrently although male emergence was more prolonged, beginning earlier and continuing later. A suction trap operated at crop height caught male midges mainly between sunrise and noon with a peak at 08.00–09.00 h GMT. Female midges were caught mainly between 08.00 and 20.00 h with maximum numbers between 09.00–10.00 h followed by a steady decline during late morning and afternoon until sunset. (Williams and Martin)

Honeybee management and disease

The unique and vigorous programme on pollination, pheromones and diseases of honeybees has continued.

Pollination of Brussels sprout to produce hybrid seed. Hybrid seed production of Brussels sprout crops depends upon flower-visiting insects moving readily between cultivars to achieve cross-pollination. Observations of honeybees and bumblebees foraging on plots of Brussels sprout in Lincolnshire have shown that about half the bees become conditioned to one or other of the cultivars present, remain faithful to it, and so fail to cross-pollinate; this occurred even in a cage plot with limited forage available. To encourage sufficient movement between cultivars for adequate pollination, plant breeders and growers should select for cross-fertilization cultivars whose flowering periods coincide, which are equally attractive to foraging bees, and between which bees do not readily discriminate. (Free and Williams; Barber, Ferguson, Hadley, Simpkins and Tomkins)

Foraging pheromones. It would often be useful if odours could be applied to flowering crops to increase or decrease their attractiveness to bees; attractants might be useful to enhance pollination, repellants to prevent visits to crops just before insecticidal spraying. Foraging pheromones deposited on flowers by bees might be the source of such materials. It has been demonstrated that honeybees visiting artificial flowers from which they obtain food, deposit on them a substance that attracts other inspecting foragers to land. It was deposited even in the presence of natural or synthetic flower scents. In contrast, when the artificial flowers were unrewarding the foragers deposited a repellant odour that deterred other foragers from landing. This may be the explanation of why bees are less inclined to alight on apple flowers recently visited. (Free and Williams)

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Transfer of pheromone from mature and immature queens. The pheromones of the queen honeybees are immensely important in regulating the behaviour of workers and knowledge of their chemical composition and means of distribution should ultimately provide beekeepers with greater control over colony activities.

Observations have provided strong circumstantial evidence that workers in a queen's court obtain queen pheromone on their antennae, and distribute it through the colony by antennal contact. Workers that had just left the court of a mated or virgin queen were more likely to make reciprocated antennal contact with other workers. This tendency was reinforced when the workers concerned licked the queen in addition to palpating her with their antennae.

The first workers approached by those leaving the court seemed particularly likely to engage in reciprocated antennal contacts. Furthermore, workers even made antennal contact with the excised heads of bees from a queen's court, showing that the presence of the queen's pheromone on the antenna is more important than the worker's behaviour.

Workers from the court, and those they first contacted, also participated in food transfer more than did workers selected at random. Workers that licked a virgin queen subsequently participated in food transfer more than those that palpated her with their antennae only. Within about 5 minutes of leaving the court a worker's participation in all these activities diminished to the level of non-court workers.

Workers that visited queen pupae engaged in antennal contacts; those that visited queen larvae did not. However, when a bee that had visited queen larvae made antennal contact with another worker it rarely initiated the contact, suggesting again the presence on its body of an attractive pheromone obtained from the queen larvae. Workers that had visited queen larvae gave food to other bees much more frequently than they received it, so any pheromone licked from queen larvae could also be distributed through the colony in food. (Free; Ferguson and Simpkins)

***Varroa* and acute paralysis virus infection of honeybees.** The transfer of the mite *Varroa jacobsoni* from its natural host *Apis cerana* (Eastern honeybee) to *Apis mellifera* (European honeybee) in Europe and its spread through most European countries has caused much concern. Recent work suggests that the mite transmits virus diseases of bees. This may help to explain conflicting reports on the effect of mite infestation of individual colonies.

Large amounts of acute paralysis virus (APV) were isolated from samples of dead brood and adult bees sent from *Varroa*-infested colonies in Germany and Russia. Individual bees contained as much virus as those killed by injection of the virus in the laboratory, sufficient to be detected directly by serology. In Britain this virus is normally present only as an unapparent infection of seemingly healthy adult bees and has never been found to be responsible for mortality in nature. In Russia the mite has been shown to transmit the virus from severely infected bees to healthy individuals. It is not known if *Varroa* naturally acts as a vector or on some way affects the inhibitory mechanism which normally suppresses APV multiplication.

The APV isolated from bees from Germany, Russia and Japan was compared with the British type strain. All had the same buoyant density ($1{\cdot}37$ g ml^{-1}) in CsCl and were closely related serologically, although not identical. (Ball; Allen)

Hazards to bees from fungal control agents. Two commercial preparations of the entomopathogenic fungus *Verticillium lecanii,* 'Vertalec' and 'Mycotal', used respectively for control of aphids and whitefly in glasshouses, were tested against honeybees. Bees were fed or sprayed with suspensions of spores at 10× the field application rate

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and maintained in incubators at 25°C, which is optimal for fungal growth but below the temperature of normal colonies. Mortality was not significantly different from control bees when 'Vertalec' was applied but 15% of bees sprayed with 'Mycotal' were killed by mycelial growth in the thorax.

These preparations would be unlikely to be a hazard to bees if applied at the recommended rate for field use. (Ball; Allen)

Integrated control

Work on the development of integrated and biological control has concentrated on determining the impact of natural enemies of aphid populations in winter wheat and on the possibility of using a fungus disease to control aphids directly.

Encouragement of aphid predators. In previous seasons, aphids which had overwintered on early-sown winter cereals were heavily parasitized by Hymenoptera in the spring. Field experiments in 1982 and 1983, involving the release of populations of parasitized aphids on to winter wheat, sown late to avoid natural infestations, showed that such populations in the spring can reduce aphid infestations in summer.

The impact of polyphagous predators on cereal aphids was investigated by undersowing winter wheat with ryegrass. Adult staphylinid beetles and staphylinid and carabid larvae were more abundant and there were fewer aphids in undersown than in control plots. One explanation for this, corroborating results from elsewhere, is that the aphids were controlled when the polyphagous predators were sufficiently numerous.

Organic manuring was shown to be a way of increasing numbers of these predators. In 1983 experimental plots that had received applications of inorganic fertilizer, farmyard manure or sewage cake for six consecutive years were compared. Predatory beetles were more numerous on plots receiving organic matter; beneficial staphylinids in particular increased on plots treated with sewage cake probably encouraged by the general increase of soil-dwelling animals which form an important component of the diet of these predators. The effect of this treatment on aphids remains to be assessed. (Powell; Bardner, Bater, Decker, Modlen and Zhang Zhili)

Aphid diseases. In 1983 experiments were continued to see whether aphid disease, caused by the fungus, *Erynia neoaphidis,* might be used as an alternative to chemical insecticides for control of aphids on winter wheat and spring beans. Applications of the fungus were made on 22 June and 7 July to 2×2 m plots of aphid-infested winter wheat which were caged with nylon screening to exclude predators and parasites thereby ensuring high aphid populations. The introduced fungus killed many more aphids in the early-treated than in the other plots but the difference between treatments in the total proportion of aphids infected (rising to 60–70%) was obscured by another, naturally occurring fungus. Neither fungus prevented the aphid populations from increasing to damaging levels but the weather was exceptionally hot and dry, conditions which limit the effectiveness of these control agents. 1983 also saw the final experiment in a series in which *E. neoaphidis* was tested against black fly *(Aphis fabae)* on spring-sown field beans. The fungus established itself earliest in the plots treated soon after the aphids infested the crop, but it soon colonized aphids in the control plots as well, so that any effect of a later application could not be detected. These results parallel those for a similar trial in 1981 but in 1980 both early and late applications significantly increased mortality.

The results suggest that the fungus will not protect beans and winter wheat adequately from aphid attack, but they emphasize the important natural effect that

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E. neoaphidis and related fungi have on aphid populations, and show that natural mortality can be increased by the early introduction of the fungus into the field. The combined action of natural enemies is often enough to keep aphid numbers below damaging levels, so it is important to identify and avoid, where possible, farming practices which adversely affect natural enemy populations. (Wilding; Brobyn and Mardell)

Control of soil pests

Chemical control of slugs. The important search for effective molluscicides and formulations to kill slugs continued with renewed impetus, and the range of chemicals tested by laboratory bioassay was extended. Several quite unrelated compounds proved toxic, including a number of simple and relatively cheap materials, such as phenols and metal compounds.

The different chemical properties required by poisons intended for ingestion and those designed to penetrate the external skin were confirmed. Efforts have been concentrated on developing control methods based on the latter. The main difficulty encountered was inactivation of test materials by absorption and precipitation by soil. Formulation is required to protect the active material in contact with soil and to allow controlled release of the poison. Novel formulations produced in collaboration with other departments, Government laboratories and private industry have been tested with varying degrees of success. (Henderson; K. Parker, with Briggs, Chemical Liaison Unit, Pickett, Insecticides and Fungicides Department, and Dr H. J. Prosser, Laboratory of the Government Chemist)

Factors influencing the onset and severity of damage to potato tubers were examined in laboratory and field investigations into the feeding behaviour of slugs. In field trials, *Milax budapestensis* was the species most often observed in or near holed tubers, although in controlled tests at least five other species could damage intact tubers. Increasing the amount of alternative food, e.g. haulm and weeds, reduced the damage to tubers. This appeared to be mainly due to the preference of one species, *Deroceras reticulatum,* for green vegetation. Severity of attack was also influenced by variety but not by the age of tubers. (Airey and Henderson)

Ecology and control of pea and bean weevil *(Sitona lineatus)*. Extensive work over many years has established this weevil as a significant pest of field beans and peas, meriting control. The adults are active during the daytime and fly at temperatures above 12·5°C. Nearly all movement into crops is by flight, by sexually immature individuals. This migration begins in late March and reaches a peak in mid April; there is little flight after the crop is infested, and only about 10% adults of the new generation fly from the crop to overwintering sites.

Large predatory carabids probably eat up to 23% of beetles in the late summer, but the greatest mortality (80–90%) occurs between egg-laying and establishment of newly-hatched larvae on root nodules in the spring. Predators at this stage are unimportant and most mortality is caused by difficulties in finding nodules, and competition between larvae.

It is not practicable to predict populations of adults likely to give rise to damaging populations of larvae, because of the difficulties in monitoring adult populations and because of the variable mortality of eggs and young larvae. Crops particularly at risk from damaging attacks are those which are early sown, slow growing, have a low density of plants, occupy large fields, are sited near previous pea or bean crops, or have a combination of these factors. (Bardner; Hamon, with Dr L. Allen-Williams, Hatfield Polytechnic)

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On spring beans the most effective control is given by phorate granules drilled with the seed at rates of 1·7–2·2 kg a.i. ha^{-1}. These treatments are equally effective whether the beans are drilled in wide (53 cm) or narrow (18 cm) rows. Phorate broadcast on the soil and cultivated in before sowing is less effective.

On winter beans adequate protection can be provided by granules of carbofuran or phorate (at similar rates to the above) broadcast on the foliage at the time of adult movement to the crop in mid April and these treatments are also promising on spring beans. Pyrethroid sprays are sometimes effective, but accurate timing is difficult and two sprays may be necessary. The most effective of these various treatments results in mean yield increases of 0·2–0·5 t ha^{-1} or 7–13% and would be economic for most growers. They have little deleterious effect on soil arthropods or on the carabids preying on *Sitona*. Work with peas is less advanced but the effects of treatment are similar. (Bardner; Bater, Fletcher and Lofty, with Griffiths, Insecticides and Fungicides Department)

Earthworms for waste disposal and protein production

This programme, which began in 1980, to develop a system of processing animal wastes with earthworms, with the aim of using them as animal feed protein and the processed material as a plant growth medium for horticulture, has made rapid progress. Many staff in other departments and at other institutes and universities are involved, and early in 1983 a new company, British Earthworm Technology, was set up with backing from the British Technology Group to produce and market worm-processed materials on a profit-sharing basis with farmers and other concerns.

Species and their biology. The programme is based on two temperate compost-dwelling species, *Eisenia foetida* and *Dendrobaena veneta,* one African species *(Eudrilus eugeniae)* and *Perionyx excavatus* from the Philippines. Most of their basic biology has now been worked out and their potential in waste breakdown and protein production assessed. There are clear differences between the species in terms of size, and time to maturity, number of cocoons produced, number of eggs per cocoon and time of hatching. The tropical species are more prolific and grow faster, but have poorer low temperature tolerance than the European ones; the most productive is *E. eugeniae.* For all four species a detailed study of the interactions between temperature and moisture content of the organic wastes in influencing the growth of worms has been made. Tropical species did not do well at temperatures below 10°C and species differed greatly in optimum temperature and moisture requirements. There was evidence of gradual adaptation to temperature. The limits of tolerance to pH, ammonia and salt contents of the wastes have now been established.

All four species were grown in combinations of two or three species together. The presence of one species did not affect the rate of growth of another but one species tended to become dominant. Whilst this could be controlled by changing environmental conditions in favour of a particular species, there was no evidence that a combination of species produced a higher waste/worm conversion ratio than the most productive species alone.

The uptake of heavy metals from wastes was investigated. Levels of copper and zinc in the worms were respectively 0·1 and 0·2 of the concentration in the waste. Cadmium was the only element more concentrated in waste than in worms but it never exceeded 0·76 ppm (Edwards; Ashby, Bryson, Jones and Neale)

Larger-scale production. In collaboration with the National Institute of Agricultural Engineering (NIAE), work has continued on modelling worm populations and

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economics of worm processing. Data for the parameters of the population model developed at NIAE were obtained from various small-scale experiments at Rothamsted and the predictions of the model are being compared with the growth of worm populations in full-scale beds. A preliminary analysis of the economics of waste conversion and worm production by NIAE workers enabled constraints in various systems of waste conversion to be identified and led to suggestions for improving efficiency. (Bardner; Fletcher, Lofty and Neale)

The laboratory studies have been scaled up into worm production in large beds in polythene tunnels. In 10 months, about 80 and 20 t respectively of cattle and pig solids were processed in 120 m^2 of beds. Using a regular top-feeding system, successive layers of fresh solids were applied to a well-stocked bed as the previous layer was consumed. A 1-m deep bed could be processed in 4–6 weeks. A specially designed gantry-type feeding system was installed to improve productivity. Populations of worms in the beds of up to 20 kg m^{-2} were attained.

Well-managed addition of uncomposted wastes allowed the heat generated by composting to be utilized to maintain beds at productive temperatures during the winter. Large numbers of worms produced during the year were harvested from the top layer of waste on to inoculate on-farm pilot systems.

The feasibility of processing wastes throughout the year outdoors was confirmed; in summer, outdoor processing was as rapid as indoors. Changes in characteristics of many wastes such as their moisture holding capacity, chemical form of nutrients and microbial populations were monitored. (Edwards; Fletcher, Russell and Townley)

On-farm work on the breakdown of duck waste in an old duck breeding house at Cherry Valley Farms, Lincolnshire, was expanded. Top and bottom inoculation and different depths of beds (15–50 cm) were compared. Worms worked this material much more slowly than pig or cattle manure and worm populations were lower; shallow beds with minimal addition of water were best. Similar results were obtained with turkey waste on straw at Forge Farms, Diss, Norfolk, and outdoor pig waste beds were also set up at this site. A waste separator was installed, with the help of NIAE, at Oaklands Agricultural College, St Albans and pig and cattle worm beds initiated. (Lofty; Bardner, with Mr J. Richards, Cherry Valley Farms, Mr T. Denholm Smith, Forge Farms, and Mr R. Blossom, Oaklands Agricultural College)

A rapid method of extracting worms from samples of worm-worked wastes using heat was developed. (Mr A. Niederer, Meat Research Institute, New Zealand)

The mechanical worm/waste separator built to a design by NIAE in 1982 was improved by addition of brushes, and a second portable lightweight model built. An entirely new design of a non-labour-intensive, mechanical separator was developed at NIAE. (Edwards with Dr R. Phillips, Mr S. Billington and Mr J. Price, NIAE.

A contract has been signed with Bowaters Paper Company to investigate the potential of the four species in breaking down paper pulp waste. Early studies have shown that all species find paper pulp acceptable and reproduce despite the low nutritional content of the waste (particularly nitrogen). (Edwards; Neale)

Plant growth trials. An extensive investigation of worm-worked waste as a horticultural growing medium was pursued with particular help from Oaklands Agricultural College, Lea Valley EHS and Efford EHS. At Rothamsted, tomatoes, cabbage, cucumbers, lettuce, wheat and radishes were grown with emphasis on the first two. Considerable success was obtained with both pig and cattle worm-worked wastes which gave more consistent and faster seeedling emergence and development than commercially available composts. There was a slight tendency to nitrogen deficiency which was easily corrected. Even better results were obtained with mixes of the worked

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wastes with Kettering loam or peat. The results of steam sterilizing worked wastes was not clear, growth being sometimes better and sometimes slightly poorer.

Many annual ornamentals were grown at Lea Valley EHS and worm-worked cattle waste mixed with peat in the ratios 1:4 and 1:10 produced plants of good quality. Similarly, various shrubs were grown at Efford EHS in mixtures of worm-worked cattle waste and peat in ratios of 1:4 and 1:2 with addition of 1·0, 1·5 and 2·0 kg m^{-3} 'Osmocote'® (18-11-10) slow release fertilizer. The mixes gave at least as good and often better results than the standard peat/sand control potting composts. (Edwards; Burrows, Fletcher and Wilkinson, with Mr J. Farthing, Lea Valley EHS and Mr M. Scott, Efford EHS).

Staff

The Department was greatly saddened by G. Dean's sudden death in June; he will be remembered as an excellent field entomologist who worked on tropical and temperate pests.

Thirteen staff participated in a wide range of international and UK society meetings, and working visits. Particularly notable were C. A. Edwards' visit to various earthworm conferences in Rome, Manila and elsewhere, the presence of a large contingent led by L. R. Taylor at an EEC aphid monitoring meeting in Rennes, R. Bardner's and W. Powell's attendance at a meeting on Integrated Control in Kiel, and Brenda Ball's deep involvement with meetings in Varroasis in Europe. T. Lewis and C. Wall gave papers at the Royal Entomological Society's Symposium on Insect Communication, and many staff contributed to the 10th International Congress of Plant Protection at Brighton.

Mahruk Mama and Sara Huggard resigned; K. P. Allen, Kathryn Parker and Ann Wright were appointed. Fifteen students or visiting workers—U. M. Decker, J. S. Fox, Linda Barber, A. Khasriya, Rosemary Bryson, L. Nicolas, J. Ser, A. F. Niederer, T. Myint, F. Cividanes, R. Mishra, T. Chupa, A. Gareway, K. Budathoki, and Suzi Cristosomo—brought new ideas and interests to the Department. A. W. Ferguson, C. P. Brookes and D. G. Garthwaite were promoted. J. B. Free received Individual Merit Promotion to SPSO and a gold medal from the International Federation of Beekeepers' Association for his book *Bees and Mankind.* L. R. Taylor assumed the Presidency of the British Ecological Society.

INSECTICIDES AND FUNGICIDES DEPARTMENT

Once again this report exemplifies the multidisciplinary nature of the Department's work, which still follows closely the principles of innovative research laid down by a series of distinguished former Heads. The Department therefore welcomes the formation of the new Crop Protection Division and the opportunities it will give for extending this approach by even closer cooperation with colleagues in several disciplines.

The report describes developments in work on relationships between molecular structure and insecticidal activity, exploitation of chemicals controlling insect behaviour, control of soil pests and diseases and behaviour of pesticides in soil and crops, assessment of hazards to beneficial species, resistance of pests and diseases to pesticides and development of electrostatic spray application techniques.

Chemicals for control of pests and diseases

Relationships between molecular structure and insecticidal activity of pyrethroids. At several regions in the molecular structure of pyrethroids, variations produce profound changes in activity; these sites are being systematically examined to provide the most precise definition possible of the characteristics associated with greatest

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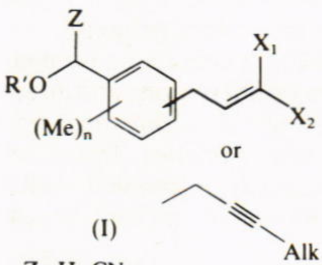
potency in this group of insecticides (cf. last year's *Report,* Part 1, 121). This year the influence of different groups separated by the typical spacing units examined previously have been assessed.

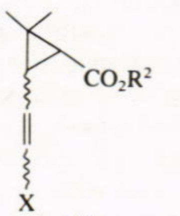
Influence of the side chain of benzyl esters. The present range of synthetic pyrethroids can be considered to have evolved from the discovery of the insecticidal activity of allylbenzyl chrysanthemate, which indicated that the benzyl unit could replace the cyclopentenonyl ring system of allethrin. To examine whether other unsaturated side chains, especially those of the natural cyclopentenolone esters pyrethrin I, cinerin I and jasmolin I, would confer significant activity on benzyl esters, alkenyl and alkynyl benzyl (1R)-*trans* chrysanthemates and (1R)-*cis* dibromosanthemates were synthesized. Because the side chains could be sited at the 3- or at the 4- position on the ring, and the methylene group be substituted or not with α-CN, a wide range of variations was possible (I). Side chains corresponding to that in pyrethrin I ((*Z*)-pentadienyl) and cinerin I ((*Z*)-but-2-enyl) were particularly effective against houseflies and mustard beetles, and superior to that in jasmolin I ((*Z*)-pent-2-enyl). All vinyl compounds (unsaturation conjugated with the ring) were much less active than those with an interposed methylene group (allyl derivatives). α-Cyano groups enhanced the activity of 3-substituted compounds, but almost eliminated activity from 4-substituted analogues. Methyl substituents on the ring were effective only with 3-, and 4-allyl esters without an α-cyano group. A series of halo-substituted allylbenzyl esters was also examined and exceptionally high activity found for 4-(*Z*)-3′-chloro- and 3′-bromo-allyl (1R)-*cis* dibromosanthemates against houseflies but not against mustard beetles. In general, the assays against houseflies and mustard beetles showed that requirements for optimum activity against the two species differed widely, indicating the potential for developing selective insecticides.

Esters of 3-mono-halo and 3-mono-alkoxy-vinyl-2,2-dimethyl-cyclopropane carboxylates. Esters of 3,3-dihalovinyl-2,2-dimethylcyclopropane carboxylates (permethrin, cypermethrin,deltamethrin and related products) are potent insecticides with a range of valuable properties. Related (*E*)- or (*Z*)-mono-bromo, -chloro or -fluoro compounds (II) have now been prepared. Although all had moderate to high insecticidal activity, this was generally less than that of the corresponding 3-(dihalo-vinyl compounds) and did not depend strongly on the configuration (*E*) or (*Z*). Other compounds examined were the (*E*)- and (*Z*)-enol ethers (II). Of these, only the OMe compound was significantly active. These new variations extend the scope of structures available for exmination of species specificity. (Chemical work: Elliott, Janes; Baydar, Johnson, Khambay and Pulman; biological work: Farnham; Adams, Gilmour and Robertson)



(I)

Z=H, CN
X_1, X_2=H, F, Cl, Br, Alkyl
(E and Z forms examined)
side-chain at 3 or 4
Me's at 2 and/or 6



(II)

X=F, Cl, Br, OAlk
(E and Z forms examined)
R=3-phenoxybenzyl or
α-cyano-3-phenoxybenzyl

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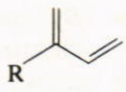
Insect neuroanatomy and the mode of action of insecticides. Mapping ventral nerve cord ganglia in connection with studies of the mode of action of pyrethroids and insect resistance to them, continued. An account of the median neuron cell body groups in the mesothoracic ganglion of the cockroach *Periplaneta americana* (L.) was completed, and further comparative work was done on the nerve fibre tracts and neuron pathways of the pro- and metathoracic ganglia. An examination of the structure of the composite thoracico-abdominal ganglionic mass of the house fly, *Musca domestica* L., was resumed. The main fibre tracts, areas of neuropile and regions of cell bodies were investigated in the three thoracic neuromeres, and interpretation of the more complex structures in the greatly condensed abdominal neuromeres began. (Gregory)

Compounds influencing invertebrate behaviour. This work involves close cooperation with several other departments.

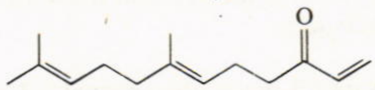
Activity of alarm pheromone analogues. Various analogues of the alarm pheromone have been prepared. Relative to the activity of (*E*)-*β*-farnesene, compounds IIIa–c were inactive, IIId showed 20% activity and IV showed 63% activity. Surprisingly, the trifluorinated compound V was as active as the alarm pheromone, but was more unstable.



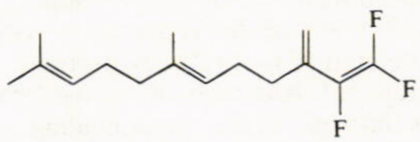
(III)

a: $R{=}CH_3(CH_2)_8\cdot$
b: $R{=}CH_3(CH_2)_{10}\cdot$
c: $R{=}CH_3[C(CH_3){:}CH{\cdot}(CH_2)_2]_3\cdot$
d: $R{=}(CH_3)_2C{:}CH{\cdot}(CH_2)_2\cdot$

(IV)



(V)



Modifying the volatilization rates of pheromones. Existing formulations of pheromones, for example for use in combination with contact pesticides, do not release the pheromone at the desired rates for field use, so work has started on the effect of formulation additives on the rates of volatilization. Single droplet tests with the aphid alarm pheromone, (*E*)-*β*-farnesene, showed that solutions in highly volatile and lipophilic solvents such as hexane and pentane cause best alarm response.

Using the electrostatic sprayer in the field, a formulation containing permethrin as the contact insecticide, hexane as the solvent, the synthetic pheromone and an antistatic agent (shown to be necessary with hexane) was tested against *Aphis fabae* on beans, *Sitobion avenae* on wheat and *Macrosiphum euphorbiae* on potatoes. The alarm effect with the first two species was poor, but *M. euphorbiae* responded well to the pheromone, and with 50 g permethrin ha^{-1} the addition of pheromone caused a significant increase in kill.

The mosquito pheromone (VIa) at 10 $\mu g\ cm^{-2}$ on glass volatilized slowly with a half life of 6 days under laboratory conditions, and the corresponding trifluoroacetyl compound (VIb) more rapidly (half life 1·3 days). Shorter carbon chain analogues (VIc and VId) had shorter half lives (27 h and 2·5 h respectively).

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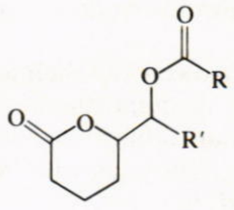


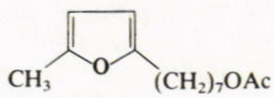
a: $R=CH_3$, $R'=(CH_2)_9CH_3$
b: $R=CF_3$, $R'=(CH_2)_9CH_3$
c: $R=CH_3$, $R'=(CH_2)_5CH_3$
d: $R=CF_3$, $R'=(CH_2)_5CH_3$

(VI)

1,1,2-Trifluoro-(*E*)-*β*-farnesene (V) in hexane applied to glass plates had a half life of about 5 min, but this increased to 16 h if the hexane contained 5% Risella oil. For comparison, permethrin applied in hexane had a half life of 65 days. Deposits of V from hexane solution applied to bean plants fell to 20% of that applied in 20 min but no further losses were observed over the next 3 h, suggesting that part of the deposit is retained by a lipophilic part of the leaf. (With Chemical Liaison Unit)

Inhibition of pheromone activity. The essential oil from hop cones contains (*E*)-*β*-farnesene, yet the crop is colonized by the aphid, *Phorodon humuli,* which is sensitive to this compound. The essential oil had no alarm activity against *Myzus persicae* on Chinese cabbage, and even inhibited the action of exogenous (*E*)-*β*-farnesene. Fractionation of the oil, and examination of the individual sesquiterpene components showed that several were inhibitory, especially *β*-caryophyllene, a major constitutent. It can inhibit 30 times its own concentration of (*E*)-*β*-farnesene, and sufficient is present in the air above hop cones or leaves to account for the natural inhibition. The same inhibition was observed for the response by *Phorodon humuli* on hops and *Lipaphis erysimi* on Chinese cabbage to exogenous (*E*)-*β*-farnesene. The phenomenon may be common, since caryophyllene is a widespread plant component, and could possibly be exploited, for instance to prevent aphid dispersal, so reducing virus transmission and increasing predation.

Pea moth pheromone decomposition products. (*E,E*)-8,10-Dodecadienyl acetate (*E,E*8,10–12:Ac), the sex pheromone of *Cydia nigricana,* both in field-exposed lures and when artificially decomposed, gives rise to a product which inhibits the attraction of male pea moth and of males of the related lucerne moth, *C. medicaginis* Kuzn. (*Rothamsted Report for 1982,* Part 1, 128). Among the photodecomposition products of *E,E*8,10–12:Ac are a furan (VII) and the aldehydes, 8-oxooctyl acetate, and 7-oxoheptyl acetate, none of which are inhibitory. However, small amounts of other 8,10–12:Ac isomers were also detected and shown to be inhibitory. (With Wall, Entomology Department)



(VII)

Synthesis of active 2-acylcyclohexane-1,3-diones from* Ephestia kuehniella *larvae. These compounds and their derivatives are of interest as synthetic and natural products with insecticidal and fungicidal properties. The 16 identified in the larval mandibular glands of *E. kuehniella* (*Rothamsted Report for 1982,* Part 1, 128) were isolated from whole-culture extracts in amounts sufficient for bioassay of their kairomonal activity (see below). Three of these, including one of the most active kairomonal components, 2-(*Z,E*)-hexadeca-12′,14′-dienylcyclohexane-1,3-dione, were synthesized for the first

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time. All previous attempts resulted in isomerization or destruction of the side-chain double bonds.

Behavioural bioassay of the 16 components showed that their activity fell into three distinct groups having high (five components), medium (three components) and low (eight components) kairomonal activity. The four conjugated dienes and 4-hydroxy-2-oleoylcyclohexane-1,3-dione were most active. (Bioassay with Walters.)
(Pickett, Griffiths; Dawson, Greenway, Mudd, Scudder, Smith, M. C., Woodcock)

Seed treatments to control slugs in winter wheat. In collaborative field trials with nine ADAS regions and three other institutes to test experimental seed treatments against slugs in winter wheat, promising results were obtained with two materials. Thus at a site in Kent (Wye, ADAS) methiocarb at 0·1% a.i. per weight of seed and cartap (an analogue of nereistoxin) at 0·1% decreased grain hollowing from 46% to 12% and 17% respectively, and increased yields from 4·9 t ha^{-1} to 7·4 t ha^{-1} and 7·0 t ha^{-1}. The seed treatments were more effective than methiocarb applied as 'Draza' pellets mixed with the seed at a commercial rate (5·9 t ha^{-1} yield).

As a preliminary search for new repellents, slugs were presented with a choice between untreated wheat seeds and seeds treated with ether extracts of plants. Of fifty plants tested, nine prevented seed hollowing (Pickett, Scott; Smith, M. C., Woodcock)

Fungicides and take-all in winter wheat. In the latest of a series of field experiments using soil treatment fungicides, take-all was suppressed significantly by nuarimol harrowed into the seed bed at 1·1 kg a.i. ha^{-1} without the apparent phytotoxic effects of higher application rates.

In another field experiment, drilled for the third successive year to detect residual effects of nuarimol and benomyl applied in the first year, take-all infection was slight in all plots. This suggested that take-all decline was occurring and was not being hampered by either fungicide. This is an important requirement for a soil fungicide used in a sequence of susceptible crops, and contrasts with fumigant treatments which are known to cause resurgence of take-all because of the loss of microbial antagonists. (Bateman)

Uptake and movement of chemicals in plants. Despite the desirability of downward translocation and earlier promise with empirical discoveries, few such pesticides are yet available.This problem has been approached at two levels, the first fundamental (in collaboration with the Chemical Liaison Unit), the second practical.

Direct measurements of mobility. Root uptake from nutrient solution of non-ionized chemicals by rice and the castor oil plant *Ricinus communis*, assessed by RCF (root concentration factor) and TSCF, (transpiration stream concentration factor) was similar to that previously observed in barley, wheat, maize and field bean.

Within a homologous series of naphthoxyalkanoic acids, relative phloem mobility in petioles of *Ricinus communis* (see previous Annual Reports) decreases as the chain length increases. Although this decrease correlates well with increase in lipophilicity, other factors, such as metabolism and pK values, have also been found to be important. Studies with *Ricinus* also allow simultaneous measurements of the chemical concentration in both xylem and phloem sap following uptake of chemical by roots. Concentrations of moderately lipophilic non-ionized chemicals in *Ricinus* were the same in xylem and phloem after 24 h uptake by roots and both fell rapidly after the plants were transferred to nutrient solution without chemical, indicating rapid equilibration of these chemicals between xylem and phloem. Two polar compounds,

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aldicarb sulphone and oxamyl, were present at about twice the concentration in phloem of that in the xylem, and concentrations in phloem declined more slowly than those in xylem.

Measurements have been extended to some weak acids (substituted phenoxyacetic acids, flamprop and maleic hydrazide). Their uptake by roots depended on the pH of the nutrient solution with RCF's, for 2,4-D and 3,5-D of about 20 at pH 4 falling to about 1 at pH 7. The TSCF fell with increasing nutrient solution pH from about 4 at pH 4 to 0·2 at pH 5 and 0·04 at pH 7. Concentrations of weak acids in the phloem of *Ricinus* were up to eight times higher than concentrations in xylem presumably because of an 'ion trap' effect. This occurs because of a pH differential between the phloem (pH 8) and the xylem (pH 6). (Butcher, Chamberlain; White, with Chemical Liaison Unit)

Control of potato-scab by foliar sprays. In glasshouse tests, substituted benzoic acids were sprayed on the foliage of potato plants (cv. Arran Banner) two weeks after potting in soil naturally infested with *Streptomyces scabies,* the cause of common scab; disease severity was assessed about eight weeks later.

Some di- and tri-substituted benzoic acids were very active at 1·6 mM (2,5-dichloro-, 2,5-dibromo-, 2-bromo-3,5-dichloro- and 5-chloro-2-nitro-). A few were slightly active (5-bromo-2-chloro- and 2,5-dimethyl-) but all others tested, including all the dichloro-isomers except 2,5-, were inactive.

In vitro tests of the dichlorobenzoic acids against two isolates of *S. scabies* by the poisoned agar method gave EC50s in the range 10–150 $\mu g\ ml^{-1}$, and the isomers were consistently ranked in the following order of decreasing toxicity: 3,4->3,5->2,4- $\simeq$2,3->2,5->2,6-. Thus, the 2,5- isomer, which alone decreased scab severity as a foliar spray, was one of the least toxic to the causal organism. This suggests that, like 3,5-D, it did not affect the disease directly, but by altering the host response to infection. (Bateman, McIntosh; Chamberlain, Dawson)

Short-term effects of insecticides on beneficial species. Application of the principles of integrated pest control to arable crops requires reliable methods of assessing pesticide effects on beneficial parasites and predators. Effects of demeton-S-methyl and cypermethrin applied to barley in 1982 were therefore measured by visual counts, vacuum samples, pitfall traps and sticky traps. Changes in populations of pest species (aphids) and on relatively abundant beneficial species (spiders and Staphylinidae) were clearly shown. They were not detected in other species because of their apparent insensitivity (Carabidae), small numbers (parasitic Hymenoptera, Chrysopidae) or of inadequate sampling methods (Syrphidae). (Stevenson; Smart, Walters)

Resistance to pesticides

Resistance of insects to insecticides and of diseases to fungicides have much in common, for example patterns of buildup in the field, and biological, biochemical and genetical methods of examining the mechanisms responsible.

Insecticide resistance. The housefly is still used to investigate the fundamental principles of resistance because it is the most suitable species. Such studies are essential to develop models for understanding and controlling the development of insecticide resistance. The practical implications of resistance in the field, in both houseflies and aphids, are also being examined; in the latter the effect of resistance on virus transmission is determined.

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Resistance of houseflies to pyrethroids in the field. Tolerance to bioresmethrin, permethrin, deltamethrin and to natural pyrethrins with and without synergists, and the frequency of *kdr* homozygotes was investigated in 43 strains collected on British pig farms and in one Canadian strain. Although *kdr* was detected in 23 British strains and in the Canadian flies, pyrethroids failed on only 11 of these farms. Regression analysis showed a good relationship between LD50s to pyrethroids, and the frequency of the *kdr* homozygotes and control failure, the first instance in which such a correlation has been established and quantified. Pyrethroids failed when 10% or more of the flies were homozygous for *kdr,* and/or LD50s (μg female^{-1}) exceeded 0·1 (bioresmethrin), 0·12 (permethrin), 0·012 (deltamethrin), 1·1 (pyrethrins). This correlation provides the means of confirming resistance as the cause of control failure in the field. Ongoing work has demonstrated that the influence of pyrethroid resistance genes varies between pyrethroids.

Characterizing acetylcholinesterase in individual houseflies. A spectrophotometer interfaced with a microcomputer to collect and analyse data automatically was used to study the inhibition kinetics of housefly acetylcholinesterase by malaoxon and dichlorvos in the presence of substrate. This system simply and unequivocally identified insecticide-insensitive enzymes from single heads, even when these enzymes were hitherto uncharacterized. As well as identifying individual insects homozygous for a particular form of acetylcholinesterase, the method also recognized heterozygotes because the mixture of enzymes then present gave a heterogeneous response to inhibitors. In the latter case, each component enzyme present could be identified. The technique is valuable for characterizing heterogeneous insect populations collected from the field, for establishing homozygous strains and for more detailed biochemical study.

***Serological characterization of resistance in* Myzus persicae.** The enzyme, carboxylesterase E4, causing cross-resistance to a variety of insecticides was purified from *ca* 50 g of aphids and injected into a rabbit to prepare an antiserum. A variety of serological assays was used to establish the specificity of the antiserum for E4, and to measure the amount of this enzyme in individual aphids; these assays confirmed the quantitative differences in E4 between aphid clones and demonstrated the potential of such assays for characterizing this form of resistance in individual insects collected from the field. (With Govier, Plant Pathology)

Virus transmission by pyrethroid-resistant aphids. The early response of insecticide-susceptible (S), moderately (R_1) or very (R_2) insecticide-resistant *Myzus persicae* to pyrethroids is important in virus control (last year's *Report,* Part 1, 127). When placed on treated potato leaves (0·001% a.i.), fewer R_1 alates flew from the fenvalerate residue (14% after 5 min) than from cypermethrin (37%), permethrin (33%) or deltamethrin (23%). Similarly, fenvalerate was less effective in causing S and R_1 apterae to fall from treated inverted glass plates (<50% in 15 min) than the other compounds (*ca* 90%). Deltamethrin dislodged *ca* 80% of R_2 aphids whereas the others affected only *ca* 20%. Treatment of potato virus Y (PVY)-infected leaves with fenvalerate (0·001% a.i.) diminished transmission by S or R_1 aphids by less than 50% compared with 60% by cypermethrin, 75% by permethrin and 80% by deltamethrin. (With Gibson, Plant Pathology Department) (Sawicki; Cooper, Denholm, Devonshire, Farnham, Gooding, Moores, O'Dell, Rice, Searle, Stribley)

Control of potato virus Y (PVY). Another approach to the control of PVY is associated with the use of electrostatic sprays. The transmission of PVY by aphids can be diminished by many synthetic pyrethroids and also by non-toxic mineral oils. In

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laboratory tests, aphids given access to infected leaves treated with both oil and cypermethrin transmitted PVY less frequently than those given access to leaves treated with oil or cypermethrin alone. In a field trial to exploit this finding cypermethrin (40 g a.i. ha^{-1}) or oil (Sunoco Sunspray 7E, 7 l ha^{-1}) were applied six times at two-weekly intervals either hydraulically in 500 l ha^{-1} or electrostatically in 8·9 l ha^{-1}. The electrostatic sprayers deposited 2–5 times the amount of cypermethrin on the upper parts of the plants at all spray times and similar amounts on the lower leaves to that achieved by the hydraulic sprayer whether the formulations contained oil or not. Correspondingly, the numbers of *Macrosiphum euphorbiae* in late July were less on the electrostatically sprayed plots. Hydraulic application of cypermethrin alone was ineffective. In combination with oil, infestation was decreased from 9·7 aphids per leaf (untreated) to 3·2 (hydraulic) and to 0·6 (electrostatic). Infection with PVY (assessed in early August) showed a similar pattern: unsprayed, 67%; cypermethrin, 47% (hydraulic), 37% (electrostatic): oil, 53% (hydraulic), 28% (electrostatic); combined, 31% (hydraulic), 31% (electrostatic). (Cayley, Chemical Liaison Unit, with Gibson, Plant Pathology)

Fungicide resistance. Work on fungicide resistance in cereal pathogens has been extended following the increasing evidence of problems associated with fungicide use.

***Resistance in eyespot* (Pseudocercosporella herpotrichoides).** Resistance to methyl benzimidazolylcarbamate generating fungicides (MBC) is common in eyespot populations throughout Britain and Northern France. To what extent the population has changed since introduction of these fungicides around 1975 remains uncertain, as untreated sites are now rare. Eyespot populations were characterized from sites at Rothamsted and Woburn where MBC fungicides have never been used, and from commercial sites where use has been frequent. Induction of sporulation directly on lesions, and plating the spores on carbendazim-containing medium, was the simplest and quickest of three ways to monitor resistance (normal growth on potato-dextrose agar containing 1 μg MBC ml^{-1}). Less than 3% of lesions from untreated sites yielded MBC resistant isolates and, as eyespot disease spreads only slowly, this indicates the probable frequency of resistance prior to introduction of these fungicides. Sixty-five per cent of lesions from commercial sites yielded resistant isolates. (Bateman, Hollomon; Li)

***Sensitivity of barley powdery mildew* (Erysiphe graminis f.sp hordei) *to fungicides*.** Testing of isolates continued against fungicides which inhibit sterol biosynthesis. Sensitivity to triadimenol decreased still further during autumn and winter, 1982, but then remained unchanged during the following spring and summer. Cross-resistance patterns were as before (see *Rothamsted Report for 1981* and *1982*), and triadimenol-resistant isolates were not resistant to fenpropimorph or ethirimol. Isolates were obtained for the first time from fenpropimorph-treated barley. Although difficult to maintain, these were no less sensitive in laboratory and greenhouse tests to fenpropimorph than other isolates, but were more sensitive to triadimenol.

Performance of these fungicides varied in two field experiments, but poor mildew control was not correlated with resistance. A strategy in which fungicides with different modes of action (triadimenol, fenpropimorph) were alternated was no better than one using only fungicides with the same mode of action (triadimenol, propiconazole). Triadimenol and triadimefon seemed better on varieties with M1k+M1a$_7$ resistance genes [Keg, Triumph] but significant yield increases were also obtained after treatment of Carnival (M1a$_6$) with triadimefon. (Hollomon; Butters, Clark with ICI and Plant Breeding Institute).

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Mechanism of triadimenol resistance. Six mildew isolates differing in sensitivity to triadimenol took up different amounts of the fungicide, which was not metabolized. The active diastereoisomers (1R2R, 1S2S) were taken up from barley in preference to the inactive isomers (1R2S,1S2R), but the degree of preference varied between isolates. None of these differences was correlated with resistance. Changes in sterols and fatty acids may be related to resistance. Consequently, we have characterized by GC/MS the major sterols in conidia of a triadimenol sensitive isolate. Ergosterol was absent and the main component was ergosta-5,24(28)-dienol. (Hollomon; Butters, with Loeffler, Long Ashton Research Station)

Factors affecting the performance of pesticides

Electrostatic spraying of crops. This technique has potential for greatly improving efficiency and environmental safety of pesticides. Much of the assessment has been done in collaboration with the Chemical Liaison Unit.

Field assessments. Field trials to evaluate the performance of electrostatic sprayers continued, using the Jumbo spray head. The main objectives were to compare the equipment in its charged and uncharged modes, to test modified sprayers against pests and diseases which were difficult to control in 1982, and to make comparisons with other spray equipment.

Herbicides, fungicides and insecticides were applied successfully to winter wheat and winter beans throughout the growing season. For pre-emergence and early post-emergence application of herbicide, results were at least as good as with the hydraulic sprayer, and better than with the uncharged rotary atomizer. For a later post-emergence spray in winter wheat, Zadoks growth stage 30, the electrostatic sprayer deposited twice the amount of herbicide on the winter wheat and only half the amount on low-growing field pansies and so was less effective than the hydraulic sprayer. Surprisingly, eyespot, which infects stem bases of winter wheat, was very effectively controlled by electrostatically applied sprays of 'Sportak alpha' at Zadoks growth stage 31. Hydraulically-applied sprays decreased infection by only 30% but electrostatically-applied treatments gave a 75% reduction. At a later date, dimethoate at one-third the recommended dose gave more effective control of aphids when applied with the electrostatic than with the hydraulic sprayer.

In 1982, control of mildew on spring barley and swedes was not commensurate with the increased fungicide deposits achieved using the electrostatic sprayer. However, this year the standard dose of triadimefon applied by Jumbo spray heads at 1 m spacing gave good control of barley mildew and even at one-quarter of this dose the percentage leaf area infected with mildew was reduced to 25% of that in the untreated control whereas one-quarter doses applied hydraulically only decreased infection to 50%. The same equipment was used in the swede trial to apply nuarimol at the onset of mildew infection, in contrast to 1982 when sprays were applied only after the disease was well established. With these more timely applications all electrostatically applied treatments gave better and more prolonged control than those applied hydraulically.

In conjunction with Broom's Barn and NIAE a range of electrostatic and hydraulic sprayers for applying permethrin to sugar beet was compared. The Electrodyn and APE 80 sprayers gave the greatest deposits on both small and large plants although with large plants most of the deposit was on the outer leaves. On large plants no treatments decreased aphid numbers and on small plants only the Electrodyn and APE 80 sprays gave effective control probably because they were the only two sprayers that deposited droplets on the abaxial leaf surfaces. (Griffiths; Etheridge, Pye & Scott, with Chemical Liaison Unit)

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Control of potato virus Y (PVY) See page 104.

Laboratory assessments. Laboratory tests of oil formulations with APE 80 at 28°C using earthed metal targets to stimulate leaves confirmed earlier field observations on cotton and soybean crops in USA by Arnold and Pye. The ratio of abaxial to adaxial deposit depended on the type and amount of surfactant. Reversal of these ratios when surfactants were absent was due to non-charging of droplets. (Phillips; Etheridge)

Behaviour of pesticides in soil. This work illustrates the value of combining biological and chemical techniques to assess pesticide behaviour.

Biological activity of insecticides in soil. The toxicities to the corn root worm, *Diabrotica balteata,* of a range of organophosphates, carbamates, organochlorines and pyrethroids were measured by topical application, by fumigant action and after uptake from a moist sandy loam. Uptake by fumigant action was important for efficient action in soil except for the pyrethroids where initial experiments with 2,3,4,5,6 pentafluorobenzyl (1*RS*)-*trans* 3-(2,2-dichlorovinyl)-2,2-dimethyl cyclopropane carboxylate, which showed fumigant action, indicated that it was no more efficient than permethrin or deltamethrin which had no fumigant action. (Farnham, Nicholls; Buxton, Church)

Leaching in the field. The movement and degradation of monuron in a silty clay loam was measured in the field at Rothamsted. The experiment was simulated using both Leistra's model and the more empirical model CALF (*Rothamsted Report for 1981,* Part 1, 134). Initially the simulations, which allowed complete equilibration of herbicide between water and soil, predicted too much movement in the period of heavy rain towards the end of the experiment. Attempts to account for this discrepancy were made (1) by using adsorption coefficients larger than those measured in the laboratory, (2) by assuming some rainwater in heavy showers to pass through large channels in the soil directly to the subsoil without contacting the herbicide or (3) by assuming diffusion of herbicide to sites in fine pores or within organic matter where it is available for degradation but not for movement. The last approach fitted the measured distributions most closely. (Nicholls, with Chemical Liaison Unit)

Insect species reared

Homoptera	*Aphis fabae* Scop.; *Lipaphis erysimi* (Kltb.); *Metopolophium dirhodum* (Wlk.); *Myzus persicae* (Sulz.), susceptible and resistant strains; *Rhopalosiphum padi* (L.); *Sitobion avenae* (F.).
Coleoptera	*Diabrotica balteata* LeConte; *Phaedon cochleariae* (F.).
Dictyoptera	*Periplaneta americana* (L.).
Diptera	*Calliphora erythrocephala* (Meig.); *Drosophila melanogaster* Meig.; *Musca domestica* L., various susceptible, resistant and visible mutant strains.
Hymenoptera	*Aphidius matricariae* (Hal.); *Venturia canescens* (Grav.).
Lepidoptera	*Ephestia kuehniella* Zell.; *Plutella xylostella* (L.).
Neuroptera	*Chrysopa carnea* Steph.
also Mollusca	*Deroceras reticulatum* (Müll.).

The Chemical Liaison Unit

The Unit continues to invesigate how pesticides are distributed both immediately after application, and later. For example, distribution studies, coupled with assessment of

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biological effectiveness, indicate the advantages of electrostatic spraying, and the movement of chemicals in crops and soils is being related to chemical structure, which should enable the prediction of pesticide behaviour in the environment from a few easily measured physico-chemical properties. This work necessitates close collaboration with other departments, especially Insecticides and Fungicides, as indicated in the following list of work described elsewhere:

Modifying the volatilization rates of pheromones (Briggs; Chen Qui Fang, with Insecticides and Fungicides)

Uptake and movement of chemicals in plants (Briggs, Bromilow; Chen Qui Fang, Evans and Rigitano, with Insectides and Fungicides)

Behaviour of pesticides in soil (Briggs; Evans, with Insecticides and Fungicides)

Control of potato virus Y (Cayley; with Insecticides and Fungicides, and Plant Pathology)

Potato diseases: gangrene (*Phoma enigma* var. *foveata*) (Cayley; with Plant Pathology)

Nematicides (Bromilow, with Nematology)

Staff of the Department and the Chemical Liaison Unit

M. Elliott relinquished his appointments as Deputy Director and Head of Department in August to return to full-time research. J. H. Stevenson was appointed acting Head pending a new permanent appointment. J. A. Pickett was appointed Head of Department from January 1984.

Three senior members of the Department retired after long and distinguished careers: P. E. Burt (33 years' service), A. J. Arnold (35 years) and A. H. McIntosh (nearly 39 years). They approached their studies from differing disciplines which complemented one another so that jointly they contributed much to knowledge of both the fundamental principles of the action of insecticides and fungicides and to their practical application.

D. N. Butcher transferred to Long Ashton Research Station to work on plant growth regulators. Bernadette S. M. Buxton transferred to the Biochemistry Department. Lorna A. Adams and Caroline Beasant were appointed to temporary posts supported by the BTG.

In the Chemical Liaison Unit, Yvonne Dunne and M. Batchelor left at the termination of their appointments, and R. Lewthwaite was appointed to a temporary post supported by the Potato Marketing Board. G. G. Briggs completed a part-time one year secondment in the Chemicals Synthesis Group of FBC Ltd.

Among visitors welcomed to the Department was Dr U. Wachendorff-Neumann of Bayer, Leverkusen, who came to gain experience of techniques for studying housefly resistance.

M. Elliott was awarded 'La Grande Médaille de la Société Française de Phytiatrie et de Phytopharmacie' in Paris in October. He gave a plenary lecture, by invitation, on The Interaction betweeen Chemistry and Food Production to the Second International Chemistry Conference in Nairobi, 27 June–2 July. He also visited the Pyrethrum Board of Kenya, in Nakura and the International Centre of Insect Physiology and Ecology, Nairobi.

P. Etheridge and F. T. Phillips visited Brazil to investigate the use of citrus pulp baits for control of the leaf-cutting ant *Atta sexdens rubropilosa*. R. M. Sawicki visited Egypt and Sudan as an invited speaker at the International Conference on Environmental Hazards of Agrochemicals in Developing Countries and to consult about resistance

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problems. G. L. Bateman presented a poster at the Fourth International Congress of Plant Pathology, Melbourne.

Staff contributed to numerous scientific meetings and conferences in the United Kingdom, notably the 10th International Congress of Plant Protection in Brighton, giving papers and posters and playing a large part in the organization. Staff were increasingly involved in advisory and consultation work with organizations in the public and private sectors.

NEMATOLOGY DEPARTMENT

Recent progress on two aspects of the Department's work is described in detail. The control of stem nematode is emphasized because, although the problem in field beans is well understood (see Hooper in Part 2 of this *Report*), problems caused by this complex pest in other crops require fresh examination. Work on the effects of nematode infestation on nitrogen fixation by *Rhizobium* in pea roots is nearing completion, and has wider implications for leguminous crops parasitized by nematodes. Other aspects of the Department's work are described briefly.

The terms 'host race' and 'pathotype' are used in this report. Host races are defined as races of a nematode species distinguished by inherited ability or inability to successfully parasitize certain *species* of plant; pathotypes are nematode races distinguished by inherited ability or inability to reproduce on specified *lines* of a host species which embody different genes for resistance. Pathotypes may exist within a host race. Studies of host races and pathotypes are an essential adjunct to the control of plant-parasitic nematodes by crop rotation and resistant cultivars.

Control of stem nematode

Stem nematodes *(Ditylenchus dipsaci)* are damaging seed- and soil-borne pests of many British field crops and ornamentals. Although they have been recognized pests for 125 years, they are still difficult to control. More than 20 'host races' of stem nematode have been recognized by their differing host ranges, although most races can interbreed and the offspring have genetically determined host ranges. One hundred and twenty-nine populations of the principal races have been collected in Britain and Western Europe for study of host ranges and of resistance to infestation.

Crop rotation. Stem nematodes usually have wide host ranges making control by crop rotation difficult and some crops, e.g. broad bean, onion and sugar beet are hosts of many populations.

Of 68 European populations examined, 62 multiplied on broad bean and 37 on sugar beet; most populations also multiplied on onion. Even the more specialized lucerne and clover races may multiply on other plants. All lucerne race populations examined multiplied on broad bean and some on sugar beet. Similarly, some white clover populations multiplied on red clover and some from red clover multiplied on broad bean and on sugar beet. However, none of the lucerne populations multiplied on white or red clover and the red clover populations did not multiply on white clover.

Even when non-host crops are grown, stem nematodes may survive by invading and feeding (but not multiplying) in them. This was observed in resistant oat cultivars and may be a common occurrence in resistant crops. Stem nematodes may also multiply in weeds. Although they are normally shoot parasites, attaching the soft tissues of stems and the mesophyll of leaves, they may feed and reproduce in plant roots, and also on certain soil fungi.

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Nematicides. Onions are very sensitive to stem nematode attack. Damage to young plants is largely prevented when small amounts of aldicarb or oxamyl are applied over the seed furrows at sowing but such treatments do not prevent attacks late in the season, which may cause some bulb rotting in store. In spring-sown onions, placement of half the nematicide in the seed furrows at sowing and half over the rows of plants mid-season was no more effective and less convenient than applying all the nematicide to the seed furrows. In summer-sown onions, however, the split-application technique was sometimes more effective than seed furrow treatment alone (*Annals of Applied Biology* (1979) **93,** 213–220). More than half the UK onion crop is now grown with small amounts of granular nematicide applied to the seed furrows. Aldicarb at 1·5 or 4·5 kg a.i. ha^{-1} applied around the seeds at sowing controlled stem nematode attacks in onions, field beans, peas, Manod and Maris Osprey oats and maize and greatly increased their yields (*Annals of Applied Biology* (1983) **103,** 291–299). In an experiment in 1983, aldicarb in the seed furrows decreased the percentage of susceptible oats suffering 'bloat' disease due to stem nematode attack and greatly improved the growth and yield of the crop.

Field beans are frequently attacked by stem nematodes and the seed is often infested, especially by the 'giant race', which reduces the yield and quality of the subsequent crop. Seed-furrow application of aldicarb or carbofuran promises to allow stem-nematode-free bean seed crops to be grown from heavily infested seed sown in spring. At Rothamsted, field experiments have shown that infestation of spring beans by the giant race, whether seed-, or soil-borne, can be very greatly reduced by seed-furrow application of aldicarb or carbofuran. Similar treatments with dimethoate, phorate, disulfoton, fenamiphos or oxamyl were either less effective or ineffective. Top dressing the rows of plants sometimes enhanced control achieved by seed-furrow treatment alone. In winter beans, the percentage of damaged stems was not decreased by carbofuran, aldicarb, oxamyl, phoxim, pirimiphos-methyl or thiabendazole applied to the seed. Aldicarb or carbofuran as seed-furrow treatments may also be inadequate. Top-dressing the rows of plants in spring with aldicarb, carbofuran or thiabendazole may improve nematode control and grain yield but may not if done in late spring or early summer.

In lucerne (cv. Europe) aldicarb, applied in the seed furrows at sowing and over the rows of plants after each cut, significantly increased herbage yields in the first year by 30% in soil inoculated with lucerne race and by 19% in uninoculated soil. Similar yield increases were obtained in the second year as residual effects from carbofuran applied to the seed furrows in the first year. In the second year, aldicarb or thiabendazole over the rows failed to control infestation of the stems. The stem-nematode-resistant cultivar Vertus was more difficult to establish than Europe and was injured by aldicarb applied to the seed furrows. Vertus yielded about 25% less than Europe in untreated soil in the first year and about as much as as Europe in the second year. Further attempts to control stem nematode in lucerne are being made with electrostatic and hydraulic sprays of different nematicides but the chances of success are poor with available nematicides.

Resistance. The best long-term solution to stem nematode control is the use of agriculturally acceptable cultivars with broad-based and durable resistance to stem nematode increase.

At Rothamsted, the supposedly resistant spring oat Manod was susceptible to oat race stem nematode and Maris Tabard, which was thought susceptible was resistant. The spring oat Milford (S225) and the winter oats Pennal, Peniarth (S238), Panema and Pennant (S227) were also resistant but their outer (basal) leaves often had necrotic

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areas containing many stem nematodes but no eggs. Oats can be susceptible to stem nematode without displaying the usual bloat symptom of the stem bases and the resistance of the winter oat cultivars mentioned may not be as broadly based as supposed (*Annals of Applied Biology* (1983) **103,** 291–299).

Resistance in the lucerne cvs Sverre and Vertus was studied in pots in comparison with the susceptible cv. Europe, using eleven English isolates of lucerne race. Sverre, bred for resistance in Sweden was as susceptible as Europe. About two-thirds of Vertus seedlings were resistant but one-third were susceptible to five of the 11 isolates and resistant or slightly susceptible to the other six isolates. This indicates the presence of at least two pathotypes among the 11 isolates used (*Plant Pathology* (1984) **33,** 31–35). Further evidence of pathotypes within the lucerne race was observed in the resistant lucerne (cv. Europe × Vertus hybrid) which was susceptible in two fields in Dorset.

The existence of several pathotypes within a race is also indicated from the reactions of five resistant red clover cultivars to four isolates of red clover race. The cv. Redhead was susceptible to all four isolates, whereas Quin was susceptible to one and resistant to three isolates, Norseman was susceptible to one of three isolates, Grasslands Pawera was susceptible to two of four isolates, Britta was susceptible to three of four isolates and Sabtoron was resistant to the three isolates against which it was tested.

Although differences in host range between different isolates of a stem nematode race have been recognized for 20 years, their significance in breeding for resistance seems not to have been appreciated. Future breeding for resistance should be against a better sample of populations than that obtained from a single field, as is usually used. The tests must also be conducted over a longer period to see how durable the resistance is. The breakdown of resistance to several stem nematode races as well as to other important nematode pests (p. 116) shows that the gene pool of a plant-parasitic nematode can contain much variation for virulence. (Whitehead, Tite; Fraser, Nichols, Penn)

Observations on the incidence of infestations of the oat race and giant race on field beans on the Rothamsted and Woburn farms since 1965, symptoms on plants, effects on yield, incidence in seed stocks, persistence in soil and control with aldicarb are recorded in Part 2 of this *Report.* (Hooper)

Effects of nematode infestation on *Rhizobium* nodulation of peas. The pea cyst nematode, *Heterodera goettingiana,* is an unusual pest because low population densities, which may persist in the absence of hosts for a considerable time, sometimes cause severe damage to pea crops. Other nematode parasites of legumes, e.g. soybean cyst nematode, *H. glycines,* have been reported to inhibit normal development of *Rhizobium* root nodules. In the field *H. goettingiana* can eliminate *Rhizobium* nodulation of peas completely, typically causing chlorosis, dwarfing, limitation of the number of flowering nodes and early senescence of the plants. Symptoms tend to become more apparent after 6–8 weeks growth and most obvious at commencement of flowering but may appear later in the season.

To investigate the effect of nematode infestation on nodulation in the absence of pathogens, plants were raised in microbiologically defined conditions using a variety of techniques. In experiments with pea plants grown in pots of sterilized soil *H. goettingiana* cysts were added at six rates between zero and 243 cysts per pot. *Rhizobium leguminosarum* strain 1001 was introduced with the cysts or as an additional inoculum. Nodulation was inversely proportional to log number of cysts but was not completely suppressed even at the highest rate. Effects of nematodes on nodulation by *R. leguminosarum* strain 1001 were more conveniently examined using pea plants growing in aseptic culture for shorter periods although then the plant response was less easy to

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measure. Initially plants were grown in a nitrogen-deficient agar medium in flasks but plants could be maintained for only seven weeks and consistent nodulation failed to develop within this time. In later experiments the agar medium was replaced by fine sand containing nutrient solution. Nematode invasion was irregular from both sand and agar but on average 10–15% (maximum 33%) of inoculated surface-sterilized second-stage juveniles developed as females. Fifty to one hundred *H. goettingiana* juveniles per plant were enough to decrease nodulation by about one third of that of uninoculated controls, although the decrease was very variable. Increasing the number of juveniles inoculated did not result in a further decrease in nodulation. Because nodules on cyst nematode infested plants were smaller and more widely distributed on the roots than on those of uninfested plants, nodulation scores for parasitized plants were often relatively high but with smaller numbers of compound nodules. Fewer of the nodules on infested plants were on the tap root and total weight of the nodules was inversely proportional to the nematode inoculum. Leghaemoglobin content of nodules was very variable, particularly in those from infested plants, but nematode infestation decreased leghaemoglobin amounts by about 40%. However, there was on average little difference between infested and uninfested plants.

In the field, crop plants are rarely infested by one nematode species only. The stem nematode *(D. dipsaci)* and the species of root-lesion nematode *Pratylenchus thornei* are both associated with crop losses in peas and their effects on *Rhizobium* nodulation were examined using *in vitro* grown plants, as with *H. goettingiana*. Stem nematode is a foliar parasite but also invaded roots *in vitro*; *P. thornei* is a root endoparasite inducing necrotic lesins in invaded roots. The presence of *P. thornei* and *D. dipsaci* increased nodulation by about one third. There were similar numbers of nodules in the tap root of infested and uninfested plants but fewer of these were compound nodules. As with infestation by *H. goettingiana,* there were many small nodules on the lateral roots, accounting for the greater number on infested root systems. Leghaemoglobin content of nodules from plants infested with *D. dipsai* and *P. thornei* was decreased by a third. The larger nodules from infested plants had less red pigmentation and were often very green, typical of inactive nodules.

Nematode infestation by cyst-, stem- or root-lesion nematodes interfered with nitrogen fixation but apparently by different mechanisms. In all cases the many smaller nodules that developed on fine lateral roots appeared to be a response to nitrogen deficiency caused by the failure of the nodules on the tap root. Cyst nematodes inhibited nodulation so that there were fewer mature nodules while stem and lesion nematodes did not appear to do so and all nematodes were associated with decreased leghaemoglobin content. In the experiments with pea cyst nematode only one generation of the nematode could develop during each experiment and the results suggest that the second-stage juveniles inhibited nodulation in the root zone they invaded but did not prevent nodules forming elsewhere on the roots while they developed. The effect of the nematode in the experiments was therefore probably transient. In the field, invasion by pea cyst nematode juveniles hatching from eggs in the soil would extend over a longer period than in the *in vitro* experiments, and the contrast between absence of nodules in field-grown plants and regeneration of nodules on experimental plants may be due to this difference. Additionally, cysts in field soil are distributed throughout the soil volume and eggs are stimulated to hatch as roots approach the cysts, resulting in a continuous invasion of young roots as they grow. Previous examination of roots from field crops showed continuous nematode invasion from March until July and consequently there would probably be continuous inhibition of nodulation throughout this period. Stem and root-lesion nematodes have shorter generation times than cyst nematodes and their effect on *Rhizobium* nodules observed

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in the *in vitro* experiments may also be more extended in field conditions. A single examination of the effects of other cyst nematodes parasitizing peas and of *H. goettingiana* on soy bean indicate that the effects reported are not specific. Nematodes are ubiquitous and their effects on legume nitrogen fixation may also be widespread. Nematode control may therefore be an important adjunct to the use of *Rhizobium* to reduce the dependency of farming systems on nitrogen fertilizer. (Green; Makin, with Day, Soil Microbiology)

General aspects

Control measures. Because all major nematode pests are soil-borne organisms, their control by chemical agents ('nematicides') requires that the active material be adequately incorporated into the soil. Currently available compounds all require some direct form of appplication and this is often technically difficult while fully effective control, which must limit nematode population increase as well as protecting crop yields, is hard to obtain. The majority of the compounds used as nematicides have a high mammalian toxicity or other undesirable characters, as well as being costly, So, as well as continuing research and development of chemical control measures, it is necessary to investigate control by biological agents and resistant crop cultivars.

Nematicides. The four novel compounds investigated were initially unpromising. Two organophosphate nematicides (FMC 65201 and 67825) increased potato yields by 25 t ha^{-1} (about twice that of untreated controls) on land heavily infested with *Globodera rostochiensis* at Woburn but required four times the amount (11·2 kg a.i. ha^{-1}) of oxamyl needed for the same yield increase. Avermectin B2a (Merck, Sharp and Dohme), an antibiotic with high nematicidal activity *in vitro,* and polygodial, a sesquiterpene extracted from *Polygonum hydropiper* which discourages feeding by insects, failed to control *G. pallida* on potato when incorporated into pots of peaty loam. (Whitehead, Tite; Fraser, Nichols)

Oxamyl at standard rates has failed to control adequately increase of *G. pallida* in irrigated, peaty loam soils at certain sites (*Rothamsted Report for 1982,* Part 1, 157) for reasons unknown at the time. Soil factors (extreme pH, excessive adsorption, microbial decomposition) now appear not to be implicated and satisfactory control has been obtained with these soils in glasshouse tests. Mid-season invasion by juveniles from soil below the zone of nematicide incorporation may account for the poor control. *G. pallida* has a more extended hatching period than *G. rostochiensis* and thus has the potential to behave in this way. Because early invasion is controlled, yield loss will be minimized and cyst nematode increase may at first go unnoticed. However, failure to control this increase will eventually involve yield penalties and this danger appears greater under irrigation. (Whitehead, Tite; Fraser, Nichols, Penn)

Some UK potato producers are growing maincrop potatoes continuously on soils infested with potato cyst nematodes, relying on nematicides to prevent development of damaging population levels. The efficacy of commercial applications of 3·3 kg aldicarb ha^{-1} was studied on two intensive potato farms in Cambridgeshire. On one farm, *G. pallida* was dominant in all nine fields sampled and *G. rostochiensis* was found in only three of them. This was probably the result of successive cropping with Maris Piper, which is resistant to *G. rostochiensis* and susceptible to *G. pallida.* Aldicarb was applied as 10% gypsum granules to the soil surface and incorporated by spike rotavator. Chemical analysis of soil cores taken from three fields just after treatment showed that roughly 50% of the nematicide was in the top 5 cm of the soil, 30% in the 5–10 cm and 20% in the 10–15 cm depth fractions. A more uniform distribution of the nematicide in

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the top 15 cm of the soil could improve nematode control but crude nematode increase for the ten fields sampled before planting and after harvest on the two farms averaged ×2·3 (0·7–5·6). In a three or four-course rotation this would have provided adequate control of long term population increase but for potato monoculture nematode increase should not exceed ×1·0. (Whitehead, Bromilow; Fraser, Nichols)

Work with nematicides as a tool in studies of the effects of nematodes on crop yields is reported in the following pages; the report on Multidisciplinary Agronomy also includes reference to their use.

Biological control agents. Two fungi, *Nematophthora gynophila* and *Verticillium chlamydosporium,* are widespread in cyst nematode infested soils in northern Europe and can prevent populations of *H. avenae* increasing even in cereal monocultures. Work has continued on ways of using these fungal parasites in the management of cyst-nematode pests. Our studies include monitoring changes in *H. avenae* and *H. schachtii* populations in intensive cropping systems in soils containing nematophagous fungi (*Rothamsted Report for 1982,* Part 1, 165) and the introduction of these fungi into soils where they are absent. Changes in *H. avenae* populations and the numbers of *N. gynophila* and *V. chlamydosporium* spores have been followed in microplots containing different soil types at Rothamsted. In general changes in numbers of spores in soil are related to nematode densities but soil texture also appears to have an important effect. In earlier work the sterilant, formaldehyde, was used to suppress soil fungi in studying their effects on nematode populations but the fungicide, captafol, has been used to suppress the fungal activity and resulted in increased multiplication of *H. schachtii.* In a soil from Broom's Barn where *H. schachtii* had failed to increase on sugar beet for 2 years (*Rothamsted Report for 1982,* Part 1, 165) captafol at 60 kg ha^{-1} greatly increased the production of female nematodes on beet in pots. Increased nematode multiplication in treated soil probably was due to the suppression of root-infecting fungi, especially *Cylindrocarpon destructans* that was found in many females and eggs in untreated soil. However, eggs of the nematode were not infected by this fungus *in vitro.* Captafol is being used as an experimental tool to suppress the fungal parasites of cyst nematodes but the effects of agrochemicals on the desirable fungi must be understood, if fungi are to be used as control agents. A number of insecticides, nematicides and fungicides (with the exception of captafol) had little effect on the growth *in vitro* of *C. destructans* and *V. chlamydosporium* at concentrations applied to soil in normal agricultural use. Different isolates of *V. chlamydosporium* vary in their growth *in vitro* and in their ability to colonize the rhizosphere of some crop plants. Eggs in nematode females are more susceptible to parasitism by all isolates than eggs containing second-stage juveniles, i.e. early infection of the female on the root system is likely to have a greater effect on nematode multiplication than when females are mature. The effectiveness of introducing *V. chlamydosporium* into soil for control of cyst nematodes depends on the isolate and method of introduction. Although some isolates significantly reduced nematode multiplication in pots, results have been variable and soil conditions are important in determining the amounts of parasitism. (Kerry; Crump, Hornsey, Irving)

Effects of nematodes on crops

Cyst nematodes and oilseed rape. The brassica cyst nematode *H. cruciferae* and the sugar beet cyst nematode *H. schachtii* both parasitize oilseed rape. As a result of the very large increase in the area of this crop in the last 10 years an increasing area of oilseed rape is being grown on land infested with one or both of these nematodes. Infestation may be severe, because host crops have been grown repeatedly, or may be at a low level maintained either by infrequent cropping with a host or by weed hosts.

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Depending on the rotation in which oilseed rape is grown, crop damage due to cyst nematodes may become obvious either almost immediately or only after a number of years (or not at all on land free of these nematodes). Over the last two years ADAS has reported a number of fields showing damage to oilseed rape by *H. cruciferae*. Rape has such a long growing season that the nematodes may be able to complete three generations before harvest of autumn-sown rape, so the potential for reproduction is greater than for other cyst-forming species on British crops.

An oilseed rape crop growing near Newmarket, sown in September 1982 and suffering overt damage by *H. cruciferae* when inspected in March 1983, was treated with extra nitrogen and the nematicide aldicarb. There was no response to additional nitrogen but a very significant response to aldicarb, with yield increased from 2·15 to 3·19 t ha^{-1}. Such late treatment with nematicide can only have controlled the final generation of the nematode and earlier application might have had a much greater effect. Final nematode populations on control plots were over 120 eggs g^{-1} soil but were only about 25 eggs g^{-1} in the treated plots; the pre-planting population was not assessed. (Evans; Greet, Inge)

Tolerance of cyst nematode attack by potatoes. Potato cultivars can differ in the yield loss they suffer when attacked by potato cyst nematodes and even resistant cultivars may suffer in this through effects of nematode invasion, even though the parasites are unable to complete development. Cultivars (resistant or non-resistant) which suffer a heavy yield loss are referred to as 'intolerant', those that suffer a relatively small loss are 'tolerant'. Plant breeders are seeking to select tolerant lines and at present this depends on field trials on nematode infested sites. Testing on several sites becomes possible only late in the development of a potential new cultivar, by which time much effort has gone into its selection. Unfortunately, it is clear that the environment affects tolerance; a line tolerant at one site may suffer a severe yield loss at another site even though the nematode population densities are similar. Soil-borne factors may be involved. Potato cyst nematodes may interact with the soil-borne fungus *Verticillium dahliae* to produce 'early-dying' disease of potatoes, characterized by leaf yellowing and early senescence. It now seems clear that potato cultivars differ quite markedly in their susceptibility to invasion by *V. dahliae* and this may have a bearing on tolerance. For instance, Maris Anchor seems to be invaded by the fungus even when no nematodes are present, Maris Peer is only invaded if it has alreay been invaded by nematodes and Pentland Javelin is particularly resistant to invasion by *V. dahliae,* even when it has already been invaded by nematodes. Since *V. dahliae* is reported to occur only sporadically, the potential for 'early-dying' disease to develop will also be sporadic even in fields known to be infested with potato cyst nematodes. Potato cultivars which are very susceptible to invasion by *V. dahliae* will therefore yield very poorly where the fungus occurs but may yield as well as non-susceptible cultivars elsewhere, even on nematode-infested land. (Evans; Greet, Inge)

Potato plants that are infested by potato cyst nematodes suffer water stress because their roots are damaged and are less able to extract water from soil. Efficiency of water use is one factor affecting the tolerance of potatoes to cyst nematode attack. Because it is thought that the ability of some plant species to accumulate large concentrations of the stress hormone abscisic acid (ABA) is associated with an ability to tolerate water stress, the interrelations of ABA concentrations, transpiration rate and stomatal resistance were investigated in two potato cultivars. Cara is both resistant and tolerant to *Globodera rostochiensis* whereas Pentland Dell is non-resistant and intolerant. Untreated plants of Cara had nine times more ABA than untreated Pentland Dell, but when the plants were infested with *G. rostochiensis* ABA levels inçeased by 14% in Cara and 28% in Pentland Dell. Plants grown in soil containing less water than the

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controls also contained more ABA and all increases in ABA levels (in both cultivars) were accompanied by increases in stomatal resistance and decreases in transpiration, with the magnitude of these effects greater in Cara than in Pentland Dell. The changes in ABA content in potato cultivars induced by potato cyst nematodes could play a major role in determining the degree of tolerance of individual cultivars to cyst nematode infestation. (Fatemy, Evans; Greet, Inge)

Resistant responses to potato cyst nematodes. Changes in cell morphology observed by light microscopy which occur when resistant potato roots are invaded by potato cyst nematodes were described in *Rothamsted Report for 1982,* Part 1, 160–161. Light microscopy can only identify gross effects, but by using the electron microscope alterations effected in the ultrastructure of cells when the nematodes attempt to establish a feeding site in resistant roots can be seen, and provide a better indication of the function of the changes. Two different types of potato resistant to potato cyst nematodes (*G. rostochiensis* pathotype Ro1, and *G. pallida* pathotypes Pa1 and Pa3) were compared with the response in the susceptible potato *Solanum tuberosum* cv. Désirée. The cultivar Maris Piper with resistance to *G. rostochiensis* Ro1 only, conferred by a single major gene H_1 derived from *S. tuberosum* ssp. *andigena,* was one resistant type; the second possessed polygenically inherited resistance derived from *S. vernei,* effective in varying degrees against *G. rostochiensis* and *G. pallida.* The response of the susceptible host to juvenile invasion involves formation of a multinucleate syncytium with the characteristics of a transfer cell as reported by others, including cytoplasmic changes which suggest enhanced metabolism, and the development of cell wall ingrowths which are believed to provide a much increased surface area for the passage of nutrients into the syncytium. In all resistant clones juveniles enter roots and initiate syncytia but these are different from those formed in the susceptible response, lacking the characteristic changes to the cytoplasm and apparently without cell wall ingrowths. Evidently the syncytial metabolism is much less active. In plants with resistance against *G. rostochiensis* and *G. pallida* derived from *S. vernei* there is inhibition of normal syncytial development only but in plants with the ex *andigena* gene H_1, inoculated with juveniles of pathotype Ro1 there is in addition necrosis of the cells surrounding the sincytium. Apparently different mechanisms of resistance to potato cyst nematodes have evolved in *S. tuberosum* ssp. *andigena* and *S. vernei* and it is known that while the ex *andigena* resistance to Ro1 (based on a single major gene) is fully effective, the ex *vernei* polygenically inherited resistance to *G. pallida* is not. The response of an ex *vernei* clone to an invading *G. pallida* juvenile depends upon the level of resistance responses triggered by the nematode. (Rice, Stone, with Dr B. S. C. Leadbeater, University of Birmingham)

Trichodorid nematodes and barley yield. Poor establishment of cereals in light sandy soils has been associated with root browsing trichodorid nematodes. In an attempt to better define the relationship between numbers of trichodorids and yield loss, several rates of the nematicide oxamyl were used to produce different initial nematode population densities in a sandy-loam soil site in N. Humberside. This had an estimated 3250 *Trichodorus cylindricus,* 470 *T. primitivus* and 380 *Paratrichodorus teres* l^{-1} soil (total=4100 l^{-1}) and a total of 4800 l^{-1} other plant parasitic nematodes at sowing. Winter barley cv. Igri was drilled and oxamyl was applied at drilling at rates of: 0; 0·5 and 1·5 kg a.i. ha^{-1} in-furrow and 5·0 kg a.i. ha^{-1} broadcast. Numbers of all nematodes the following spring were significantly smaller on plots treated with the largest rate of oxamyl than those receiving other treatments. Treatments could be distinguished during much of the growing season and growth appeared to be improved in relation to

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the rate of oxamyl applied but at harvest yields from plots treated with 0·5 kg a.i. oxamyl ha^{-1} were not significantly better than untreated plots. Yields were improved from plots given larger applications: 5·7 t ha^{-1} where 1·5 kg a.i. oxamyl ha^{-1} was applied, and 6·3 t ha^{-1} from plots treated with 5·0 kg a.i. oxamyl ha^{-1}, compared with 5·1 t ha^{-1} from untreated plots. Yields were negatively correlated (P=0·01) with numbers of trichodorid nematodes in spring. Over the range of populations studied, each doubling of trichodorid nematode numbers was related to a yield loss of about 0·8 t ha^{-1}. (Spaull; Mewton)

Nematode biology

Pea cyst nematode development on field beans. *H. goettingiana,* as well as parasitizing peas, also attacks other legumes including field beans, of which it can be a significant pest. Plot experiments to investigate the invasion, development and number of generations of *H. goettingiana* on winter and spring sown field beans showed that second-stage juveniles invade winter beans in October and produce white females in mid-May only four weeks earlier than females from the invasion of spring beans but, unlike the closely related species *H. cruciferae* on autumn-sown oilseed rape (see p. 114), *H. goettingiana* did not produce more than one generation in a growing season October to July although results show that development of the early juvenile stages can continue at temperatures below 4·4°C. The basal temperature of 4·4°C was the determining factor only for the final moult from fourth-stage juvenile to adult; an accumulation of fourth-stage juveniles occurs in the plants until the basal temperature is exceeded. (Perry; Beane)

Taxonomy and morphology

Identification of root-knot species. Species of *Meloidogyne* are the most damaging nematode pests of tropical and sub-tropical crops. There are more than 50 and their taxonomy is complex and identification is difficult. Following a general assessment of the characters used in identification (*Rothamsted Report for 1980,* Part 1, 160) and a detailed treatment of males using characters of the head and stylet, and second-stage juveniles using characters of the tail (*Rothamsted Report for 1981,* Part 1, 169), attention has now turned to the female. Firstly, female stylet characters were analysed (*Rothamsted Report for 1982,* Part 1, 168) and now female size, using measurements and ratios of length, width and neck length, and overall shape, including the presence or absence of a posterior protuberance on which the vulva is situated, have been assessed. There are clear differences in size and shape which are consistent between different species, from small and round *M. exigua* through to very large and elongate *M. coffeicola.* These differences, together with the presence or absence of a posterior protuberance, bear a clear relationship to the position of the female within the root and to the type of gall produced. The use of the perineal pattern, which is the character most commonly relied upon for identification, has been rationalized for all of the 54 currently described species and subspecies in order to establish how the pattern is best used together with other characters, bearing in mind the enormous intraspecific variation exhibited by some in this character. An atttempt has been made to group species according to similarity of pattern type and to emphasize the most important and consistent features. In doing this use has been made of photographs of typical specimens and a schematic diagram representing the major characters for each species. These photographs and diagrams provide a simple basis for identification. A collection of morphological and host-range data, drawings and photographs for all of the 54 currently described species and subspecies has now been completed. (Jepson; Hoole)

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Identification of cyst nematodes. Potato cyst nematodes require to be identified in statutory samples taken from fields as part of the certification process for seed potatoes. A related species, *G. achilleae,* occurs sporadically in the UK as a parasite of the common weed yarrow *(Achillea millefolium)*. It is unimportant in most advisory situations but its potential for confusion with potato cyst nematode is important in relation to statutory sampling because *G. achilleae* is not a potato parasite. *G. achilleae* is particularly difficult to separate from potato cyst nematodes of the species *G. pallida*. However, we have found a clear distinction in the morphology of the vulval basin of females of the two species: those of *G. achilleae* lack the papillae present anteriorly and posteriorly to the vulval slit in *G. pallida*. The difference can be most clearly seen in the scanning electron microscope but is also resolvable in preparations of perineal regions from mature females and newly formed cysts examined by light microscopy. Because the difference can be seen only on specimens in fresh condition, the identification of old cysts from field samples remains difficult and in many cases impossible. The distinction extends to other species of *Globodera*: *G. pallida, G. rostochiensis,* and *G. tabacum* and its subspecies *G. tabacum virginiae* and *G. tabacum solanacearum*; all possess papillae in the vulval basin, parasitize Solanaceae and have their natural distribution in the Americas. *G. achilleae, G. millefolii* and *G. artemisiae* all lack the papillae, parasitize members of the Compositae and are described from the old world palearctic, although *G. achilleae* has also been reported from the USA. The differences in vulval morphology, which may be related to mating behaviour, in host range and in distribution are important biological differences between the two groups of *Globodera*. (Stone; Burrows, with Dr E. Krall, Estonian Institute of Botany and Zoology, Tartu).

Staff and visiting workers

The ODA Plant Nematology Liaison Officer's Unit was closed at the end of March but J. Bridge and S. L. J. Page remain associated with the Department as visiting workers. They now form the CAB tropical plant nematology research and advisory unit with facilities at the Commonwealth Institute of Parasitology but work at Rothamsted on the importance in rice cultivation of a range of nematodes collected from various areas of the world. S. L. J. Page was awarded the Ph.D. degree of London University during the year.

Audrey Shepherd retired after 25 years service in the Nematology Department. Her departure marks the termination of her ultrastructural studies of nematodes, which she brought to a high level of excellence. Terry Williams and Noel Greet also retired, after 20 and 35 years service respectively. All will be missed as colleagues and friends; we wish them well in retirement.

M. Trett, Westfield College, London University joined the Department as a long term visiting worker to investigate changes induced in nematode sense organs by nematicides and Dr K. Wright (University of Toronto), Dr Soledad Verdejo (Inst. Parasitologia 'Lopez-Neyra' de Parasitologia, Granada), Hilary Chitapi (Plant Protection Research Inst., Harare, Zimbabwe) and Isabel Abrantes (Universidad de Coimbra, Portugal) spent extended periods in the Department. There were numerous shorter term visitors from home and overseas, including eight ADAS trainees who received instruction in nematode identification.

A. R. Stone and B. R. Kerry gave papers at the 4th International Congress of Plant Pathology in Melbourne and visited Australian research centres. Kerry also attended the 75th Anniversary Meeting of the American Phytopathological Society in Ames, Iowa. A. G. Whitehead visited several European research centres in connection with collaborative work on stem nematode. During the year members of the Department

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contributed to several scientific meetings in the UK including the 10th International Congress of Plant Protection, the 1st CAB International Nematology Course, the AAB meeting Plant Breeding—An Integrated Discipline and a specialist meeting on plant resistance to nematodes organized for the Linnean Society by Stone.

PLANT PATHOLOGY DEPARTMENT

The Department has been concerned with the increase in the incidence of take-all and the claims for the control of the disease are being investigated. The increase in take-all incidence may be due to enlargement of the area of early-sown winter crops.

The Infectivity Index (II) for barley yellow dwarf virus is providing more information than was previously available for forecasting infection but the results showed that still more local sites are needed. Five more have been established in conjunction with ADAS. The control of aphid-borne viruses by pyrethroids has continued in collaboration with the Insecticides and Fungicides Department (p. 104) as has the investigation of the poor control of gangrene in stored potatoes on farms.

Properties of viruses, virus diseases and virus vectors

Beet mild yellowing virus (BMYV). Tests by immunospecific electron microscopy (ISEM) showed that BMYV, which infects beet but not lettuce, was closely related to an English isolate of beet western yellows virus (BWYV), which infected lettuce but not beet. In further reciprocal tests with an American strain of BWYV, which infects both beet and lettuce, and its antiserum, the American isolate could not be distinguished from BMYV by ISEM tests, nor by enzyme-linked immunosorbent assay (ELISA). ELISA is usually more specific than other serological tests and so has potential value for distinguishing virus strains differing in epidemiological significance but it appears the technique will be of limited value for distinguishing luteoviruses infecting beet. (Govier)

Interference between potyviruses during aphid transmission. Fewer aphids *(Myzus persicae)* transmitted potato virus Y° (PVY°) if, either before or after PVY° acquisition, they had probed on beet mosaic virus (BMV) or PVY^N infected leaves; PVY^N similarly inhibited transmission of BMV. However, transmission of PVY^N was not significantly altered by probing on either PVY° or BMV infected leaves and transmission of BMV was not significantly altered by access to PVY°. (Gibson; Katis)

The effect of post-inoculation treatment with mineral oil on virus infection. Peters and Lebbink (*Virology* (1975) **65,** 574–578) showed that dipping leaves of *Nicotiana glutinosa* previously inoculated with tobacco mosaic virus (TMV) into a mineral oil emulsion significantly decreased the number of TMV lesions produced. A 0·2% emulsion of the mineral oil 'Bayol 52' applied after inoculation reduced the numbers of TMV lesions formed in *Nicotiana tabacum* cvs Judy's Pride (White Burley Type) and Xanthi-nc. Oil treatment reduced the number of lesions most when applied 15 min after TMV inoculation but was ineffective when applied 3 h after inoculation. Leaves rubbed with water were susceptible to TMV infection when dipped into a virus solution and susceptibility also declined with time. This suggests that oil and virus particles gain access to cells by similar mechanisms during dipping.

Treating tobacco protoplasts with 0·2% 'Bayol' following inoculation with TMV reduced virus yield by up to 100% but only when protoplasts were centrifuged through the oil emulsion. The reduction in yield was due to the death of protoplasts. Possibly the reduction in lesion numbers following mineral oil treatment is caused by the oil entering cells damaged by the inoculation process which kills them before the virus can multiply and/or spread. (White; Forde)

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Cereal diseases

Initiation and development of eyespot lesions on wheat. Wheat plants (cv. Armada), exposed amongst infected wheat straw during rain (3·7 mm) collected spores of *Pseudocercosporella herpotrichoides* on their upper and lower leaf surfaces, culms and coleoptiles. These spores were not removed by rain (0·4 mm) the following day. However, this rain realigned many of these needle-shaped spores so that their lengths lay parallel to the anticlinal plant cell walls. After 48 h, 25% of spores in this position had germinated compared with only 8% of others.

Benzimidazole-tolerant isolates of *P. herpotrichoides* (supplied by Dr M. J. Griffin, Bristol) were as pathogenic to wheat seedlings as benzimidazole-sensitive isolates when seedlings were inoculated with filter paper discs impregnated with spores, as described previously (*Rothamsted Report for 1982,* Part 1, 194). Benzimidazole-sensitive isolates showed differences in pathogenicity to adult plants which had been inoculated as seedlings. Isolate pathogenicity was significantly correlated with growth in potato-dextrose broth at approximately 20°C.

Inoculated wheat plants grown individually in polyethylene tubes filled with sand/loam mixture were given different watering regimes at 'booting stage' (Zadoks growth stage 40 to 50). Severe eyespot lesions developed in well-watered plants (root water potential −2·8 bars), whereas in plants which were water stressed (root water potential −13 bars) or watered normally (root water potential −3·4 bars) lesion development was minimal.

In a field experiment, crop growth and disease development were slower than in 1981–82, probably because sowing was on 2 November rather than 1 October. By April 1983 (Zadoks growth stage 21), 45% of the plants were infected, whereas by April 1982 the crop had reached Zadoks growth stage 31 and about 60% of the plants were infected, with some lesions already established on the stems. On 9 August 1983, before harvest, only 30% of main shoots were infected, none severely, compared with 100% infection (44% severe) by harvest in 1982. The difference was probably caused by the dry summer of 1983 which may have increased the death and sloughing off of the outer leaf sheaths, where the fungus is initially contained. (Fitt and Higgins)

Barley yellow mosaic virus (BaYMV). BaYMV was first reported from Britain in 1980 winter barley. Since then infection has been found in several hundred crops including farms nearby but not at Rothamsted or Woburn. Symptoms appear as pale flecks from January onwards which in some cultivars, especially Maris Otter, become necrotic. Symptoms fade as the temperature increases in spring and early summer, but infected plants remain stunted. Barley is the only known host and the vector is the soil-borne fungus *Polymyxa graminis* (*Rothamsted Report for 1981,* Part 1, 190). Spring barley cultivars are very susceptible and in pot tests infected plants of cvs Georgie, Athos and Porthos gave less than half the yield of uninfected plants, mostly because they produced fewer grains per ear. However, symptoms of BaYMV have not been seen on spring-sown barley crops. Probably, drying, warming soils are not conducive to infection by *P. graminis* and, if plants do become infected, symptoms are not clearly expressed because of the warmth. An explanation for the sudden recognition of BaYMV in Britain and coincidentally in other areas of Western Europe may be that, before the practice of sowing barley in the autumn was widely adopted, spring-sown barley was infected and helped to disperse the virus and vector but did not show symptoms and was apparently unaffected itself. With the practice of autumn sowing, the cooling, wetter soils in autumn and winter favoured infection by the vector and the low temperatures in winter and spring encouraged symptom expression.

Infection and damage of winter-sown barley is affected by sowing date and cultivar.

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The earlier crops are sown in the autumn the more likely they are to be infected by BaYMV. Infection in April of the very susceptible cv. Maris Otter was almost 100% when the crop was sown on 2 October but only 30% when sown in the same field a month later, the difference being closely related to infection by the vector *P. graminis*. By April 88% of the roots of October-sown plants but only 30% of November-sown plants showed infection.

However, cv. Sonja sown on 23 September in the same field had only 5% infected shoots in the following April but more than 90% of plants were infected by *P. graminis* and the mean severity of infection (measured on a 0–3 scale) was more than for the most severely infected crop of cv. Maris Otter. There is some evidence to suggest that plants of cv. Sonja most heavily infected with *P. graminis* are the most likely to be infected with BaYMV.

BaYMV-infected and uninfected plants of cv. Maris Otter collected from the October-sown crop and grown to maturity in a glasshouse showed that infection decreased plant height by 25% and grain yield by 15%. There was no effect of infection on tiller number, possibly because plants were collected after tillering was complete, but both grain number (−6·5%) and 1000 grain wt (−8·8%) were significantly decreased. Plants of cv. Sonja collected in the same way from a different crop showed that the effect of infection was greater than on cv. Maris Otter; the decrease in height (−30%) was similar to that for cv. Maris Otter but tiller number (−29%), grain number (−36%), 1000 grain wt (−20%) and grain yield (−49%) were all significantly decreased. (Plumb; R. A. Gutteridge and Lennon)

When mechanically-inoculated plants were placed in a glasshouse or in growth rooms at either 19° or 15° day/10° night, symptoms on cv. Maris Otter developed equally rapidly (to about 100% plants) in all three environments. In the more resistant cv. Sonja, symptoms were less distinct and appeared most rapidly at 19° but final disease incidence was similar in all environments. Few or no symptoms developed on cv. Athene. In experiments using seedlings with three expanded leaves, inoculating the youngest leaf led to the greatest incidence of systemic symptoms. When seedlings with two, three or five leaves were inoculated on the two youngest leaves, disease incidence was greatest in the smallest plants and the effect of plant size was greater on cv. Sonja than on cv. Maris Otter. With further refinements and more knowledge about environmental effects, mechanical inoculation is expected to provide a suitable method for routine testing for cultivar resistance. (Macfarlane and Adams)

Barley yellow dwarf virus (BYDV)

Aphid infectivity and the Infectivity Index (II). Last year (*Rothamsted Report for 1982*, Part 1, 195–196) widespread BYDV infection was forecast in autumn-sown cereals, and crops sown up to the end of September were thought likely to benefit from an aphicide spray. This forecast was largely fulfilled although contradictory results were obtained from winter barley and winter wheat at Rothamsted (see Multidisciplinary Agronomy, p. 24). Infection was not as common as in 1980/81 which had a larger II (195) than in 1982/83 (145). The very large II obtained at Shardlow last year did not, as expected, indicate widespread infection but some crops were infected and many are likely to have benefited from an autumn aphicide treatment. Continued monitoring of infective aphid populations in relation to crop infection should help to define the threshold II for this area more closely.

Because the II provides more information than previously available on the likelihood of infection by BYDV and has given quite valuable forecasts of infection, the number of sites at which the II is obtained was increased this year from four to nine. The results from Rothamsted and Shardlow had shown the need for local forecasts and additional

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infectivity-testing sites were therefore established at Broom's Barn, and in conjunction with ADAS at Leeds, Reading, Starcross and Wye. The results from these sites and those already in operation at the Welsh Plant Breeding Station, Long Ashton Research Station, Shardlow (ADAS) and Rothamsted are collated at Rothamsted and a statement issued for the information services and the Rothamsted *Aphid Commentary* after consultation with virologists and entomologists in ADAS.

Although records are not yet complete there has been little infectivity this year and smaller than usual cereal aphid populations in the Insect Survey traps. The only sites at which infective aphids have been found are Long Ashton (II=29), Shardlow (II—undetermined because of a trap failure), Starcross (II=32) and Rothamsted (II=4). These figures suggest that few crops will benefit from an aphicide spray this autumn. However, a feature of this year has been the detection of infective *S. avenae* at Starcross and Rothamsted. The only previous autumn in which this occurred (1980) was followed by serious BYDV damage but was also accompanied by widespread infectivity in *Rhopalosiphum* spp. The new sites will enable a more accurate picture to be obtained of BYDV epidemiology and results over 2 or 3 years should enable local thresholds to be determined. (Plumb; R. A. Gutteridge and Lennon)

A possible disadvantage of the present method of determining vector infectivity, which depends on feeding aphids on test plants and subsequently recording symptoms of BYDV infection, is that symptoms take from 2–4 weeks to develop. In fact, in most years, this is not a problem as reliable data can be obtained about those crops most at risk before the optimum spraying time, the first two weeks in November. However, any method of speeding up the process or enabling more aphids to be tested from more sites would be an advantage. In autumn 1982 a second suction trap was operated 10 m from the trap used to catch aphids for infectivity testing. The aphids from the second trap were caught alive, identified and then frozen. Subsequently, each aphid was tested using the fluorogenic modification of ELISA (Torrance and Jones, *Annals of Applied Biology* (1982) **101,** 501–509), using the antiserum to the severe strain of BYDV most efficiently transmitted by *Rhopalosiphum padi.* In all, 373 aphids were tested and depending on the criterion used to determine positive reactions 12–47 were considered to be carrying BYDV. When the proportion of positives each week was multiplied by the number of *R. padi* caught in the Insect Survey trap, as is done for the calculation of the II, the resulting figures differed from those of the Index calculated in the usual way but, when plotted on a graph, the lines of the accumulated Indices were almost parallel. A serious reservation about the serological detection of BYDV in aphids is that virus may be detected which the aphid cannot transmit. However, should subsequent years' results show a constant relationship between the Indices obtained by the two methods there may be a possibility of using the serological method at more sites. (Plumb; R. A. Gutteridge and Lennon with Torrance, Harpenden Laboratory, MAFF)

Spring and summer infectivity 1983. After a mild winter, infective *Sitobion avenae* (23 May) and *Metopolophium dirhodum* (23 June) were caught at Rothamsted 2–3 weeks earlier than usual but the first infective *R. padi* (1 July) was four weeks later. Few aphids were infective during the summer and those migrating from ripening cereals were most numerous from 11–25 July when only 2–3% were infective. However, this agrees well with the proportion of infected winter barley (see Multidisciplinary Agronomy p. 31). (Plumb; R. A. Gutteridge and Lennon)

Take-all

Control of take-all: testing the claims. Increased take-all in the last three years again has made the disease a matter for concern where cereals are grown frequently and, not

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unexpectedly, reports claiming control of the disease are receiving publicity. Many of these claims originate in countries with very different farming systems and climates from Britain. Most are based on limited experimentation, usually with artificial inoculum; and few have been critically tested here. Consequently in 1982 we started to investigate experimental designs and procedures for testing putative control agents in the field. Because take-all occurs in patches many small plots of winter wheat were used instead of the traditional small number of large plots. Candidate control agents were applied to approximately 35×35 cm plots arranged in a balanced incomplete block design, with blocks of complementary treatments paired to form a complete replicate and the pairs scattered at random throughout the experimental site. The block-pairs were randomly allocated into three groups. All plants in one group were removed and assessed for take-all in April and those in the second, in June: the remaining block-pairs were used for grain yields and soil infectivity estimates after harvest. The unpredictability of natural epidemics was acknowledged by using two sites differing in soil type and previous cropping. New Zealand field at Rothamsted, a clay-loam with flints, had had severe take-all in a third wheat crop and was sown to a fourth in late October 1982. The Pightle at Woburn is sandy-loam and increased take-all was expected in the second wheat sown early in October 1982.

Grain yields from both sites were similar. In late April 1983 disease ratings in New Zealand were about half those in The Pightle and did not increase subsequently. Between April and June the ratings for The Pightle approximately doubled. Estimating and removing treatment effects allowed comparisons of the random variability of blocks and plots. In The Pightle the small plots seemed to achieve the desired result because they were the least variable areas of disease, whereas in New Zealand, which was exhibiting take-all decline, the block variability was no greater than the variability amongst plots. This suggests that in take-all decline sites the optimum plot size will be bigger because of more evenly-distributed disease. Further comments on the designs are in the report of the Biomathematics Division, (pp. 73–74).

The supposed controls applied as soil drenches in autumn were *Bacillus mycoides* and a coryneform bacterium supplied by Dr R. Campbell of Bristol University and nuarimol and benomyl applied at uneconomically high rates. Benomyl plots and half of the plots treated with bacteria also received a second application in spring. Compared with water-only drenches, both the coryneform bacterium and benomyl increased plant weight temporarily, in April in The Pightle and in June in New Zealand. Significant increases in grain weight were associated with benomyl on The Pightle and nuarimol on New Zealand. Generally benomyl increased yields, whereas the coryneform bacterium applied in autumn and spring was ineffective on The Pightle and decreased yield on New Zealand. All treatments except *B. mycoides* decreased the April take-all rating on The Pightle, but only nuarimol decreased it on New Zealand and this was the only treatment on either site that continued to have a significant effect on disease in June. Nuarimol treatments nearly always caused lighter and shorter plants, lower take-all ratings, fewer infected seminal roots and often fewer infected nodal roots. All treatments had early effects, but only the chemical treatments continued to have significant influences until harvest and these lasting effects did not seem to be related to the control of take-all. This approach will allow controls applied in ways other than drenching to be tested, and is possibly applicable to other diseases caused by soil-borne plant pathogens. (Hornby; Henden with Bateman, Insecticides and Fungicides Department, Brown, Soil Microbiology Department and Payne, Statistics Department)

Winter wheat varieties and take-all. For many years estimates of take-all on the Rothamsted winter wheat variety trials after wheat or barley have shown no consistent

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differences between varieties, so the large differences in take-all and yield between cv. Avalon and cv. Norman grown as second wheats at Saxmundham in 1982 and 1983 were unexpected (see report of the Soils Division, p. 174). At Saxmundham the same varieties were grown for two successive years after beans, i.e. Avalon after Avalon, Norman after Norman, and it seemed possible that the first crop of Avalon provided a better host than Norman for multiplication of the take-all fungus after the bean break, so leaving more inoculum to attack the second crop. Wheat seedling bio-assay (using cv. Flanders) of soil infectivity for take-all after the first wheats in September 1983 supported this view: 40% of seedling roots were infected after Avalon, only 20% after Norman. After both varieties as second wheats 40% of seedling roots were infected. The concept that varieties may differ in their ability to increase small populations of the take-all fungus but yet be equally susceptible to damage by large populations is important and will be further tested at Rothamsted in 1984. (R. J. Gutteridge and Swaby)

Phosphate manuring and take-all. Take-all was assessed in June 1982 and 1983 on selected crops of second winter wheat after beans in the Saxmundham Residual Phosphate experiment. Without fresh P fertilizer, average take-all disease rating (maximum 300) for the 2 years was 160 on P deficient soils (ADAS Index 0) but only 87 on soils with adequate reserves of P (Index 3). Applying 120 kg P_2O_5 ha^{-1} as superphosphate almost eliminated this difference: take-all ratings were 102 and 92 for Index 0 and 3 soils respectively. These results are similar to earlier ones from Rothamsted experiments and confirm the view that farmers growing successive wheats after break crops (and so risking take-all attacks) should ensure that P manuring is adequate. (Slope and R. J. Gutteridge, with P. R. Boulton, Soils and Plant Nutrition Department)

Soil type and take-all. A three year study attempting to relate severity of take-all on winter wheat to within field variations in soils derived from chalky-boulder-clays is described in the report of the Soils Division (p. 182). (Slope; R. J. Gutteridge and Swaby with Catt, Soils and Plant Nutrition Department)

Biodeterioration

***Fusarium* contamination of cereal grains.** The hot weather during grain development and ripening in 1983 was much less favourable for *Fusarium* colonization than the cooler wet weather of 1982. Fewer than ten *Fusarium* colonies were isolated from 100 plated wheat grains, compared with 83 in 1982. In both years *F. culmorum* was predominant, accounting for 57% and 40% of *Fusarium* colonies in 1982 and 1983 respectively. However *F. avenaceum* (12% of isolates 1982) was almost as abundant as *F. culmorum* in 1983. *F. poae* (3% of isolates both years), *F. nivale, F. equiseti* and *F. oxysporum* were also isolated. Lodging greatly increased *Fusarium* contamination, particularly by *F. culmorum,* in both years. (Lacey)

Metabolism of propionate by yeasts and bacteria. Experiments with the preservation of hays containing more than 30% water indicated that bacteria and yeasts were favoured by these very high water contents even in hay treated with up to 3% of propionic acid-based preservatives and tests were made to see whether bacterial or yeast isolates could metabolize propionate as reported for some fungi (*Rothamsted Report for 1979,* Part 1, 125).

Of 30 bacterial isolates from damp, propionate-treated hay tested for their ability to grow on propionate-containing agar, half grew on medium containing 68 mM

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ammonium propionate and seven grew on 83 mM. Four of the most tolerant bacteria and representative isolates of the two predominant yeasts, *Candida guillermondii* var. *guillermondii* and *Hyphopichia burtonii*, were grown in liquid medium containing 27 mM ammonium propionate to determine the rate at which they degraded the propionate. Bacteria degraded propionate slowly, only 5–10% having been metabolized after 4–5 weeks. By contrast, the yeasts had metabolized 90% within 3–4 weeks at 25°C. Tolerance of propionate by yeasts was found to decrease with decreasing availability of water in the medium. (Lacey and Magan)

Diseases of grain legumes

Detection of seed-borne viruses in *Vicia faba* by ELISA and ISEM. In further studies on the detection of broad bean stain virus (BBSV) and broad bean true mosaic virus (BBTMV) in broad bean and field bean seed (*Rothamsted Report for 1982*, Part 1, 200), ELISA proved to be as reliable as ISEM in detecting the viruses in seed lots that gave 1·0–2·5% seedling infection. Seed extracts, prepared from groups of 10 or 25 seeds, in which many particles were detected by ISEM (i.e. >50 particles per field at ×40000) gave A405 values greater than 1·5 (readings taken after 1 h at 20°C) in ELISA, and extracts in which no particles could be detected by ISEM usually gave A405 values less than 0·10. The relationship between ISEM and ELISA results and seedling infection is now being investigated so that the results of tests on seed extracts can be used as a rough guide to the percentage of seeds likely to produce infected seedlings. (Cockbain; Woods and S. E. L. Roberts)

Other work on viruses of grain legumes is reported in Multidisciplinary Agronomy (p. 33).

Viruses of faba bean crops in China. In a survey of autumn-sown faba bean crops in the Nanjing area, Jiangsu Province, in March and April, five viruses were detected, namely broad bean wilt, bean yellow mosaic, broad bean luteo-type, broad bean vein mottle and broad bean spherical (the last three names are provisional). Of these, broad bean wilt virus was the most common and widespread. All except broad bean spherical virus, which has spherical particles *ca* 35 nm in diameter, were readily transmitted by *Aphis craccivora*. The seed- and pollen-borne vicia cryptic virus was detected by ISEM in glasshouse-grown seedlings of three Chinese cultivars. (Cockbain and Woods; with Chen Yong-xuan and Xu Zhi-gong, Nanjing Agricultural College, China)

Bean rust. The study of bean rust (*Uromyces viciae-fabae*) was continued in 1983 (*Rothamsted Report for 1982*, Part 1, 202). Rust pustules were first found on 15 July and the crop defoliated by 2 August, largely it was thought through the effect of the prolonged dry weather. However, plots sprayed twice (18 and 27 July) with maneb+mancozeb or propiconazole yielded 4·08 and 4·76 t ha^{-1} respectively compared with untreated 3·64 (SED 0·219, 24 d.f.). (Lapwood with McEwen and Yeoman, Field Experiments Section)

Other results on diseases of beans are reported under Multidisciplinary Agronomy, p. 33.

Chocolate spot of beans. *Vicia faba* leaves of three ages (5, 7 and 30 days old) were inoculated in laboratory experiments with drops of *Botrytis fabae* spore suspensions at concentrations of 10^6, 10^5, 10^4, 10^3, 10^2 and 10 spores ml^{-1}. The speed and severity of lesion development seemed to increase with increasing leaf age and increasing spore concentration. Concentrations of 10^6 and 10^5 spores ml^{-1} produced aggressive lesions

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on leaves of all ages within 25 h. A concentration of 10^4 spores ml^{-1} produced aggressive lesions on the oldest leaves within 24 h but on the youngest leaves only after 6 days, while a concentration of 10^2 spores ml^{-1} formed aggressive lesions on the oldest and youngest leaves in 12 days and 34 days respectively, when leaves had senesced. Lower concentrations produced few infections and no aggressive lesions. (Bainbridge and Creighton)

Potato diseases

Powdery scab *(Spongospora subterranea)*. To investigate the effects of irrigation frequency on disease incidence, infected seed tubers (cvs Estima and Pentland Crown) were planted in plots at Gleadthorpe EHF. The five irrigation treatments were: (1) 12 mm water applied whenever the calculated soil moisture deficit (SMD) reached 15 mm during the 6 weeks after tuber initiation and thereafter 25 mm applied at 35 mm SMD. (2) 25 mm water applied at 35 mm SMD from early July onwards. (3) 30 mm water applied at 45 mm SMD from early July onwards. (4) 40 mm water applied at 55 mm SMD from early July onwards. (5) None. Common scab was severe on all except the wettest plots [treatment (1)] but there was some indication that the wettest treatment (7·6% tubers infected) had increased powdery scab over the other regimes (average 1·3% tubers infected). (Adams and Lapwood with Gleadthorpe EHF)

Stem canker *(Rhizoctonia solani)*. In 1981, severe stem canker had a severe effect on King Edward. In 1983, effects of stem canker were compared on five early and seven maincrop cultivars using sprouted seed inoculated with cultures of *R. solani* at planting.

Stem canker and shoot and stolon pruning in July were more severe on all early cultivars and on King Edward and Pentland Squire than on other maincrop cultivars and, in August, Ulster Sceptre was the most severely infected, with about 60% stolons infected and Record the least (20% infected). Diseased plants of all cultivars had fewer stems than healthy and fresh weight of haulm and plant height in July were significantly decreased in Maris Peer, Cara, King Edward and Pentland Squire. Numbers and weight of lateral stems in August were increased in Arran Comet, Estima and Cara. Tuber number and weight were decreased in most cultivars in July and August but by harvest in late October yield was significantly less only in King Edward (13%). In all cultivars the proportion of large tubers was increased. The experiment confirmed that infected plants can eventually compensate and suggests that the disease would cause greater losses in crops harvested early than in those grown to maturity. (Hide; Read and Sandison)

***Rhizoctonia* on potatoes and barley.** Following reports that growing potatoes increases the incidence of *Rhizoctonia* infection in the following cereal crop, cultures of *R. solani* from potatoes, *R. cerealis* from wheat and *R. solani* from barley (kindly supplied by Plant Breeding Institute) were grown for six weeks on moist vermiculite that was later added to soil (200 ml m^{-1}) before drilling Triumph spring barley and planting Désirée potatoes in 1983.

Sharp eyespot on barley was increased by *R. cerealis* but not by *R. solani* (potato and barley isolates) but in June *R. solani* from barley had caused severe rotting of crown roots and at harvest decreased grain yield by 6%. On potatoes, *R. solani* (potato isolate) caused severe plant damage and decreased yield by 30% in July. At harvest in September, yield was decreased by 15%. The other isolates did not affect stem canker or haulm growth but the barley isolate caused lesions and damage on roots. Yield was decreased by 30% in July and by 5% in September. (Hide; Read)

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Gangrene *(Phoma exigua* var *foveata)*. Development of gangrene in store is controlled by applying thiabendazole to tubers during or after lifting provided 10–15 g t^{-1} is deposited over the tubers and into wounds. Failure of the treatment to control disease on farms was investigated.

Pentland Javelin tubers, lifted at 3-week intervals from early August to late October from a crop grown from seed with gangrene lesions, were uniformly wounded and treated or not with thiabendazole. Incidence of gangrene after 12 weeks' storage at 5°C increased in successive samples but on all dates thiabendazole gave good control of the disease (mean of five dates, untreated 50% wounds infected; treated 2%). Immersing washed tubers in hypochlorite (2–3% available Cl) before wounding prevented rots developing at most wounds (0·6% infected). Washing alone decreased the disease (17% wounds infected) but was more effective in August than later.

Tubers infested with soil slurries of *P. exigua* var *foveata* at three concentrations were uniformly wounded and sprayed with thiabendazole suspensions at 5, 15 or 40 g t^{-1}. All suspensions decreased the disease but at all levels of inoculum gangrene was controlled better by a mixture of thiabendazole and 2-aminobutane than thiabendazole alone. (Hide; Adams and Read with Cayley, Chemical Liaison Unit)

Potato virus diseases at Rothamsted. When counts were made in early July, plots planted with King Edward seed grown at Rothamsted in 1982 had 0·6% infection with potato virus Y (PVY) but no potato leaf roll (LR). Désirée had 0·1% infection with PVY but no LR and Pentland Crown was not infected with either virus. Aphids *(M. persicae)* were earlier and more numerous than for several years and at the end of July, 0·1% current-season infection with PVY was detected in the King Edward crop for 1984 seed. (Govier)

Aerobiology

Late summer asthma. Seasonal asthma may sometimes occur in atopic subjects during late summer. Symptoms appear as cereal crops start to ripen and cease soon after harvest is completed. Spores of *Cladosporium* and *Alternaria* have been implicated but the frequent occurrence of symptoms at night or following rainfall suggested other possible causes. *Didymella exitialis,* a saprophyte and weak pathogen of cereal crops, often produces very large numbers of airborne ascospores during ripening especially during rain or heavy dew. Cultures of this fungus were extracted and the extracts tested on a group of 16 volunteers from the Rothamsted staff with a history of late summer allergy, four of whom gave positive skin test reactions. These four also reacted to *Alternaria* and three to *Cladosporium.* Bronchial provocation tests with nebulized extracts of *D. exitialis* reproduced asthma in the four skin-test positive subjects who usually exhibited decreased peak expiratory flow when airborne-spore counts on Rothamsted Farm were high. (Lacey; with Cayley, Chemical Liaison Unit and Dr M. G. Harries, Guys Hospital, London)

Staff and visiting workers

E. Lester retired at the end of June. R. D. Woods was appointed acting Head pending a new permanent appointment. R. T. Plumb was apppointed Head of Department from January 1984. O. J. Stedman and D. B. Slope took early retirement after many years of service and A. Bainbridge was seconded to the Chief Scientist's Group, MAFF for three years as Scientific Liaison Officer (Crop Protection). M. Weller was appointed to a temporary position. D. Shaw left and was replaced by Helen Trangmar-Sly (part-time) and Jackie White (part-time); Sharon Hall joined the Potato Group on a PMB award (three

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years). B. Crook took up a three year appointment funded by the Health and Safety Executive. Patricia Roberts transferred to Biochemistry.

J. Lacey was elected Chairman of the Committee on Mycotoxicology of the International Society for Plant Pathology (ISPP) and D. Hornby accepted another term of office as the Chairman of the ISPP Committee on Soil-borne Plant Pathogens.

Visiting scientists during the year included R.Cuero, Universidad del Valle, Cali (Columbia), Dr P. Boiron (Paris) and V. Okoth (Uganda).

Maryse Chabrol obtained the Diplôme d'Etudes Approfondies and Susan Marriott completed her CASE studentship. Karen Prosser, B. Chappell and Anita Longley were sandwich students and Victoria Poole and Deidre Mattison were CASE students.

B. D. L. Fitt, D. Hornby, R. T. Plumb, J. Lacey and C. J. Rawlinson attended the 4th International Congress of Plant Pathology in Australia. R. W. Gibson visited the Department of Agriculture, Northern Ireland to deliver the Distinguished Scholar's Lecture and attended the Virology Conference of European Potato Association in Braunschweig. P. Jones attended a Cryo-ultramicrotomy Workshop in Austria and I. Macfarlane visited Yugoslavia to discuss 'rizomania' disease of sugar beet. R. T. Plumb was invited to South Africa on a Research Fellowship to advise on the future research programme on cereal viruses and was also invited to attend a workshop in Mexico by the International Maize and Wheat Improvement Centre. D. H. Lapwood attended the European Association for Potato Research section meeting in Denmark. C. J. Rawlinson attended the 6th International Rapeseed Congress in Paris and R. F. White participated in a Workshop in Wageningen.

A. J. Cockbain, supported by the British Council and Nanjing Agricultural College, spent four months in China working on viruses of *Vicia faba* and lecturing.

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Entomology Department

General Papers

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