ROTHAMSTED RESEARCH

Report for 1979 - Part 1

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Entomology Department

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Introduction

The 'theme' around which to write an Annual Report for the Entomology Department in 1979 almost chooses itself. In October, the Royal Commission on Environmental Pollution published its seventh Report on 'Agriculture and Pollution', a large section of which was concerned with the use of pesticides, contrasting the immense benefits these have conferred on crop production with their alleged and proven harmful effects to the environment and wildlife.

Aspects of research recommended for greater emphasis by the Commission included

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studies on the factors determining the incidence of pests and diseases, the measurement of economic threshold levels, the development of strategies to delay the onset of resistance to pesticides, and a strong commitment to apply the concepts of integrated control so that the use of insecticides is minimised and their useful life extended. Much of the programme of the Entomology Department is so relevant to, and in sympathy with, the spirit of this document, that it provides an ideal framework within which to set some of the year's work and the future direction of research. Reports on studies in other areas of entomology are held over until next year.

For 10 years the Insect Survey has been collecting basic information on the incidence of agriculturally important aphids, and has now a unique and unrivalled core of knowledge. Progressively, this will permit better interpretation of current data as they are collected and processed, and a major effort will be made to release this rapidly for advisory purposes using modern methods of communication. The Survey data will also provide a geographical basis for other work on resistance, insect-borne viruses and biological control. The offer of EEC funds to the Department and to research institutes in France and Belgium, and the presence of traps in Holland and Denmark, will now extend this monitoring system along the north-west seaboard and through France to the Mediterranean, thereby providing further recognition and incentive for the Survey to build on the scientific leadership it has already established.

In contrast with this national and regional monitoring system, joint work with the Insecticides and Fungicides Department started 6 years ago has led to the sex-attractant monitoring traps for pea moth, widely used by farmers in their fields to time, or even restrict, pesticide sprays. This is the only commercial pheromone monitoring system for a field crop available in this country, a success that has encouraged a wider search for sex attractants to be used in this way, with preliminary results for diamond back moth available this year.

The determination of population thresholds above which serious damage is caused and insecticidal applications are justified has long featured in the Departmental programme, and present efforts are directed towards cereal aphids on wheat, and pea and bean weevils on field beans and peas. In an exceptional season, considerable yield losses in wheat were caused largely by heavy infestations of aphids feeding on the leaves, a situation not previously recognised as important. This emphasises the value of long-term observations on the biology of pests and their interrelationships with weather, crops, new varieties and evolving farming practices. Persistent work over the past 5 years has shown that attacks of pea and bean weevil larvae on the nodules of field beans can produce hitherto unsuspected yield losses comparable with those caused by infestations of the more obvious bean aphids on leaves and stems. Various combinations of insecticides, formulations, rates and times of application are being studied to see which gives the best control with the minimum amount of active ingredient, and therefore with the least environmental impact.

Each year the evidence mounts against the likelihood of finding a chemical to which some pests will not develop resistance; in Britain some local populations of insect species (e.g. houseflies) already resist the potent synthetic pyrethroids marketed for only a few years. Perhaps a disproportionate amount of research has been spent on the search for substitute chemicals to counter this gradually worsening problem, instead of studying the more basic questions of why, how and when infestations develop, so that the pesticides already available can be used to greatest effect and their useful lifetime extended. For these reasons the emphasis of the aphid genetics work in 1979 was moved towards studies of the population structure of cereal aphids, to see whether insecticide resistance was developing, and what biochemical variability occurred between different populations. Another fascinating aspect of this work was the prospect of identifying not only

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parasitized aphids by electrophoresis, but the species of parasite within the host aphid.

A direct danger arising from pesticide use on flowering crops is that bees visiting the crop are killed. Some of the work on honeybee pheromones may lead to ways of manipulating foraging to prevent bee poisoning by pesticides, and at the same time ensure adequate pollination.

The integrated pest control experiment in wheat, started in 1978, gathered momentum as more staff devoted effort to this important, and, in the event, timely new venture. Combinations of pesticides to control soil and general foliar pests, and pirimicarb and entomophagous fungi to control aphids, were compared. As an example of our ignorance of the biology of even common pests, the most numerous parasitoid in 1979 had not previously been recorded from cereal aphids. Joint experiments with the Glasshouse Crops Research Institute and the MAFF Plant Pathology Laboratory, Harpenden on the effect of polyphagous and aphid specific predators on cereal aphids were assisted by the acquisition of a machine for laying polythene barriers around large plots to exclude the predators. The collaborative experiment with six European countries on the integrated control of soil pests in sugar beet, under the sponsorship of the International Organization for Biological Control (IOBC) continued, with encouraging indications that eventually parasites and/or predators of pygmy mangold beetles would build up enough in unsprayed plots to remove the need for insecticides. Studies on interactions between pests, weeds and herbicides form part of this programme, and perhaps this is a topic deserving wider study in more crops.

Any changes in cultural methods are likely to affect the spectrum of pests and beneficial organisms present in field crops, and this has never been demonstrated more clearly than through the studies on the structure and size of earthworm populations in direct-drilled soils. The importance of earthworms in the promotion of root growth in cereals has been confirmed by increased yields from field plots, and as a sequel comparisons have been made of the value of different organic fertilisers for encouraging earthworms.

Clearly, several of the broad topics identified by the Royal Commission as needing greater research input, namely factors affecting pest incidence, threshold levels, resistance and integrated control, already occupy a large part of the departmental programme. Indeed, it is with considerable satisfaction that the Department can claim to have anticipated by several years much of the thinking outlined in the Report, and thus find itself in a position to implement many of the recommendations. The fundamental information gained from physiological and long-term ecological studies is essential for the wise use of insecticides, and as a basis for alternative methods of limiting pest outbreaks. Furthermore, its value will persist long after the current pesticides have ceased to be useful.

Pest detection and evaluation

Aphid monitoring achievements. The value of the Rothamsted monitoring system was first realised with the recognition of *Rhopalosiphum padi* as a potential vector of barley yellow dwarf virus (BYDV), when the enormous size of its autumn aerial populations was recorded in the early 1960s. Since then, the recognition of the early migrations of *Myzus persicae* as the cause of the virus epidemic in Scottish seed potatoes in the early 1970s, the identification of the overwintering survival reservoir of *M. persicae* in the London Basin, the replacement of orchard sampling by Survey samples for detection of the apple-grass aphid and the close correlation between the forecasts for black bean aphid made by host-plant sampling and the aerial Survey samples, have confirmed this value. Recent work on the spatial dynamics of the hop aphid gives the first clear measurements of the distances regularly travelled by an aphid species. This is now being inter-

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preted in relation to aphid control in hops and the risk of spread of insecticide resistance.

After monitoring for 10 years it is possible to compare current aerial populations with long-term averages and thereby assess the risk of serious infestations occurring. This is becoming vital as resistance to both old and new insecticides seems to be developing.

Aphid occurrence. In detail, 1979 was an exceptional year in several ways. In the spring of 1976, at the end of a series of mild winters, 30 out of the 33 aphid species listed in the *Weekly Bulletin* migrated earlier than usual. In the following year, 1977, and again in 1979, 31 of those 33 species migrated later than usual, but the average delay in 1977 was only 4·5 days. However, in 1979, the migration was a record 17·5 days later. In particular *Brevicoryne brassicae* appeared on average 58 days late and *M. persicae* 34 days late over the country as a whole. One cereal aphid, *Rhopalosiphum padi* and the potato aphid *Macrosiphum euphorbiae* were both 26 days late everywhere, whilst *Sitobion avenae* varied between regions but was delayed on average by 33 days. *Metopolophium dirhodum* averaged 15 days late except in the Midlands where it migrated on time, whilst *Aphis fabae* was generally only 9 days late and migrated on time in the Midlands and South-East where economic damage occurred.

Another exceptional circumstance was in the population levels achieved by different species. It was to be expected, with such a late migration caused by high winter mortality and unsuccessful spring migration, that many species would be initially rare. Commercial roses, for example, were more lightly infested with aphids than for many years. *M. persicae* was scarce until the middle of July, but the aerial samples accurately anticipated its appearance on sugar beet as reported subsequently in the Spray Warning Bulletin issued from Broom's Barn. In contrast with the low levels of *M. persicae*, *A. fabae* increased considerably on sugar beet, as expected, resulting in the need for insecticidal control. In July, *S. avenae* was rare enough on cereals for research workers to circulate appeals for specimens from grasses, whilst *R. padi* recovered enough to exceed its average annual population by about 20% and *M. dirhodum* produced record aerial populations in Britain; more than 20 times larger than usual. (L. R. Taylor, French, Woiwod, Tatchell, Harrington, Dupuch, and M. S. Taylor)

Cereal aphids. The huge populations of migrating *M. dirhodum* that plagued eastern and south-eastern England during the summer, leading to 1979 being dubbed 'the year of the greenfly' by the national press, originated from local cereals and not, contrary to popular speculation, from Continental sources.

The first cereal aphid, a *M. dirhodum*, was caught in the 12·2 m tall trap at Rothamsted on 20 May, 2 days before any were found in the field. Colonisation in the field was only detectable using a vacuum sampler, which revealed 1 alate m^{-2} ($\equiv$ 1 per 500 tillers) and no further immigration of this species occurred until mid-June. The value of suction traps for indicating the arrival of immigrants was thus well demonstrated.

Of the other cereal aphid species, there were no *S. avenae* in the trap until two were caught at the end of June when some were also found in the crop. A few *Sitobion fragariae* and *R. padi* were recorded in both trap catches and vacuum samples in early June, but their populations did not increase substantially thereafter, possibly because *S. fragariae* is predominantly a grass-feeding species, whereas *R. padi* prefers seedling cereals.

M. dirhodum was, therefore, the major aphid pest of winter wheat in 1979, and it is instructive to consider what environmental conditions allowed it to build up such large populations when the initial colonisation from roses was so small.

Laboratory measurements of generation time have shown that apterous *M. dirhodum* require about 150 day degrees to develop from birth to maturity (7–8 days at 20°C, with a threshold of 0°C) (Ajayi, personal communication). Between the initial immigra-

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tion of aphids on 20 May and the attainment of peak populations at the end of July seven to eight generations might have been produced, enough to result in very large numbers in the absence of significant mortality.

During June and early July, development of the crop was about 2 weeks later than in previous years due to the very cold winter and cool wet spring, so the aphids had a nutritious food supply for a longer period than usual. Rapid multiplication was further encouraged by 2–3 weeks of warm, dry weather from early July.

Colonisation of shoots within the crop increased from very few in late May (approx. 1 per 500 shoots) to an average of two per shoot at the beginning of July. The even distribution of *M. dirhodum* in the crop was probably enhanced by the production of alates in June which dispersed within and between crops during this period. These alates were not recorded by the 12·2 m suction traps, but they were detected by another trap set at 1·5 m, suggesting that they were flying locally and not migrating long distances.

Alates of many aphid species are usually produced in the summer because of overcrowding and/or poor nutrition but neither of these factors appeared to be operating in 1979. Alates of *M. dirhodum* were first produced in the crop when the population was less than 1 per tiller (mid-June) and when the plants were growing rapidly, just before ears were produced (Zadoks 50–57). This suggests that either this species responded to crowding at very low densities, or that alates were continually produced by apterous parents irrespective of environmental conditions.

The loss of alates from the crop through emigration is normally regarded as a mortality factor, but in 1979 the re-entry of these alates into the crop seemed to be a major factor producing economically damaging populations. Numbers eventually reached over 100 per tiller in some winter wheat crops by the end of July and were responsible for considerable yield losses (up to 14·6%) as indicated by results from one Rothamsted experiment in which aphids were controlled by insecticides.

Yield losses caused by aphids in wheat have previously been thought to be a result of feeding damage to the developing grains during flowering and ear-filling. However, in 1979 the yield loss occurred almost exclusively through the leaves and in particular the flag leaf. Although 1979 must be regarded as an exceptional year, future advice on the control of cereal aphids must take into account the effect on yield loss of extremely high numbers of aphids of whatever species, whether on the leaves or the ears, at later growth stages than flowering. (Dewar)

Moth monitoring with sex attractants

Pea moth. Monitoring and spraying trials were continued to verify the reliability of the traps and of different threshold catches as a guide to spraying dates. As a result, the prospects for developing a warning service based on catches obtained on individual farms and regional meteorological forecasts are being investigated. (Macaulay, with Mr. B. Emmett and Mr. J. Cochran, ADAS, and Mr. A. J. Biddle, Processors and Growers Research Organisation)

To further the understanding of how pheromone traps function and moths respond to them, interactions between traps (*Rothamsted Report for 1977*, Part 1, 94 and *for 1978*, Part 1, 88–89) were investigated in more detail. The type of interaction is dependent on the number of traps, the attractant and dose. This was demonstrated in trap configurations aligned with the wind, with an inter-trap distance of 50 m. This spacing, which is well within the range of attraction of traps containing 100 μg (E,E)-8,10-dodecadien-1-yl acetate *Rothamsted Report for 1977*, Part 1, 94), has now been shown to be within the range of attraction of traps containing 1000 μg of (E)-10-dodecen-1-yl acetate. The latter, which is used in commercially available pea moth monitoring traps, is a much

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weaker attractant than (E,E)-8,10-dodecadien-1-yl acetate and yet significant trap interactions exist at a spacing of 50 m.

The consistent results of the last 3 years have posed fundamental questions about pheromone dispersal from point sources and the orientation behaviour of male moths to them. (Wall, with Perry, Statistics Department)

Diamond back moth. Following the success with pea moth, possible sex attractants for diamond back moth, (Z)-11-hexadecenol and (Z)-11-hexadecenyl acetate, and (Z)-9-tetradecenyl formate were synthesised, and several formulations tested at nine sites in the Eastern counties and Humberside from June to September (see Report of the Insecticides and Fungicides Department p. 117). Preliminary results were encouraging. Moths were caught at all sites and in most places catches were greatest in late July, with a maximum weekly catch of 124 on the Lincolnshire coast. At an inland site in Suffolk 93 moths were caught in 1 week in mid-August, whereas at a Bedfordshire site, much further inland, only 32 moths were caught throughout the season. These catches were obtained in a season when light traps at Rothamsted and on Humberside caught unusually few moths. (Macaulay, with Pickett, Insecticides and Fungicides Department, with Mr. P. F. Parmenter, Birds Eye Foods Ltd.)

Control of *Sitona* on field beans and peas. Work reported previously has shown that substantial increases in spring-sown field beans can be obtained if *Sitona* larvae attacking the root nodules are controlled. Because of the late spring in 1979, emergence of spring-sown beans coincided with weather suitable for the flight of adults from their winter quarters so most pea and bean crops were seriously attacked by adults. Larval populations reached their peak in mid-July, but were only moderate at four to eight larvae per root, so there must have been heavy mortality between the initial immigration of adults and larval sampling.

Methods for controlling *Sitona* attack on spring beans were tested on plots large enough for harvesting (Table 1). The standard treatment was aldicarb applied as granules

TABLE 1

Control of Sitona

	Larvae per root (Log n+1)	Yield (t ha^{-1})
No insecticide	0·733	4·16
Aldicarb 10 kg a.i. ha^{-1} broadcast and cultivated in	0·190	4·89
Carbofuran granules to furrows 2·24 kg a.i. ha^{-1}	0	4·61
Phorate granules to furrows 2.24 kg a.i. ha^{-1}	0	4·40
Phorate as seed treatment 0·75 kg a.i. ha^{-1}	0·048	4·16
Permethrin spray 0·15 kg a.i. ha^{-1} applied to foliage in mid-May	0·311	4·44
SED	0·0694	0·165

at the very high rate of 10 kg a.i. ha^{-1}, and cultivated into the soil before sowing. This is uneconomic, but has given excellent control of *Sitona* in a series of experiments on factors affecting the yield of beans. Every treatment controlled larvae well, and all except the phorate seed treatment increased yields, though significant increases (P=0·05) from the mean of the untreated plots were only obtained with the aldicarb and carbofuran treatments. Beans produce notoriously erratic yields, so more experiments are needed to determine whether the range of yield responses obtained with furrow treatments of systemic insecticide granules, or with foliage applications of pyrethroids, will justify the cost of control.

In laboratory tests, sprays containing 0·05% a.i. permethrin (about equivalent to

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field dosages) killed all the *Sitona* adults when applied directly on to the insects or when taken up from a residual deposit on glass. Residual deposits of permethrin on bean leaves killed few adult *Sitona* but did protect the leaves from being eaten even at 1/10–1/30 of the normal dose, suggesting that the anti-feeding effect may be important in the field.

Investigations continued on the effects of *Sitona* on the yields of autumn-sown (winter) beans. In 1978, controlling *Sitona* had no measurable effect on yield, but in 1979, the number of *Sitona* larvae per root on untreated plots was 8·4 compared with 5 the previous year. A permethrin spray applied in mid-May decreased larval numbers by 67% and increased yields by 15%. *Sitona* can therefore affect the yield of both spring and winter beans, an important point since the proportion of winter beans grown is increasing. (Bardner and Fletcher, with Griffiths and Woodcock, Insecticides and Fungicides Department)

Leafless peas also gave increased yields when *Sitona* was controlled. Aldicarb at 10 kg a.i. ha^{-1} cultivated into the soil before sowing improved yield by 6–20% (mean 15·3%). An investigation into the effects of *Sitona* on conventional dry-harvested peas compared soil application of phorate granules and foliage sprays of permethrin or triazophos. All insecticides increased yields by 4–5%, but differences were not significant. (Bardner and Fletcher, with Mr. A. J. Biddle, Processors and Growers Research Organisation)

Side effects of insecticides

Genetic variability of aphid populations and insecticide resistance. Increasing concern over damaging infestations, spraying and possible insecticide resistance led to a change of emphasis in the aphid genetics work towards studies on population structure. In most years, *S. avenae* is a major pest of cereals in the UK and while no resistance has yet been detected in this species (*Rothamsted Report for 1979*, Part 1, 116), it is being studied to assess the genetic variability within national populations. Biochemical and chromosomal markers are being used to provide information on the persistence of given genotypes in the field so that control can be planned should insecticide tolerant forms arise.

The biochemical variability within *S. avenae* populations is being monitored by analysis of the isozyme patterns of 16 soluble enzymes using slab polyacrylamide gel electrophoretic systems developed this year. During the summer, samples of populations of *S. avenae* were collected throughout the UK and these are being examined for biochemical polymorphism between clones maintained in constant environments.

The genetic population structure could best be studied by analysing the isozyme patterns of aphids collected directly from the field, but this is problematical because *S. avenae* is difficult to separate morphometrically from the less-agriculturally important species *S. fragariae*, and many individual aphids collected from the field are parasitised by hymenopterous primary and secondary parasitoids. Solutions to these problems have been sought with considerable success.

Using a range of enzyme systems, electrophoresis has shown that the two *Sitobion* species may be distinguished from each other by the absence of peptidase isozymes PEP-1 and -3 in *S. fragariae*. Similarly, parasitisation of *S. avenae* by its main parasitoid *Aphidius uzbekistanicus* may be detected by characteristic isozyme bands in 11 out of the 16 enzyme systems examined; parasitised individuals are thus easily distinguishable using electrophoretic techniques.

In addition, efforts have been made to characterise biochemically the influence of parasitisation by other parasitoids on the isozyme patterns of *S. avenae*. The banding patterns of the adults of only five primary braconid parasitoids have been examined so far, but as they can be distinguished electrophoretically from one another, it seems

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possible that the approach can be extended to detect parasitisation of cereal aphids by these species. (Loxdale, with Mr. P. Castanera and Miss K. Nowak)

Pheromonal manipulation of honeybee behaviour. Records of honeybee poisoning are cited elsewhere in the Report of the Insecticides and Fungicides Department, p. 117, but much of the basic work on honeybee pheromones has as its eventual practical objective the regulation of colony reproduction and behaviour, and the directing of foragers to crops requiring pollination. Achievement of these aims would diminish the number of incidents of bee poisoning by pesticides, and greatly enhance the certainty of adequate pollination.

The secretion of the Nasonov gland of the worker honeybee contains a volatile pheromone which is attractive to foraging honeybees. The components have been identified as (Z)-citral, (E)-citral, nerol, geraniol, nerolic acid, geranic acid and (E,E)-farnesol, and quantified (*Rothamsted Reports for 1977*, Part 1, 146 and *for 1978*, Part 1, 136.). This year, work continued on the regulation of the composition of the pheromone during scenting (see Report of the Insecticides and Fungicides Department p. 117).

A technique was devised for recording electro-antennographic (EAG) responses of honeybees to the Nasonov components, using excised antennae, and serial dilutions (10^{-2}–10^{-3} μg) of each component were tested on the antennae of workers. Responses to the (E)- isomers, (E)-citral, geraniol and geranic acid were consistently greater than to the corresponding (Z)- isomers, (Z)-citral, nerol and nerolic acid. Each component separately, also elicited a response from virgin- and mated-queen and drone antennae. The ability of queens and drones to smell the Nasonov pheromone may enable them to fly with an airborne swarm. Worker and queen antennae give greatest responses to (E)-citral and geranic acid. The greater sensitivity of the antennal receptors to these two components is interesting because a specific enzyme in the Nasonov gland has been shown to oxidise geraniol to (E)-citral and geranic acid (*Rothamsted Reports for 1978*, Part 1, 137, and *for 1979*, Part 1, p. 117). These two components were also more attractive than the others to foraging honeybees.

The EAG responses of worker, queen and drone antennae to extracts of excised Nasonov glands or filter paper wipes of glands, and to a synthetic mixture containing the same amounts of the identified components, were compared. Responses to the natural pheromone were consistently slightly greater than to the synthetic mixture, and the reasons for this are being investigated. However, despite this difference at the antennal receptor level, in a behavioural bioassay, the synthetic mixture was as active in attracting foragers as the natural pheromone.

Preliminary attempts to attract honeybees to flowering plants, using a synthetic Nasonov mixture, gave promising results. (Williams, with Pickett, Insecticides and Fungicides Department)

Studies on queen pheromones extended the investigations into factors stimulating reproduction and foraging. It has been noted that a vigorous mated queen receives more antennal touches and licking from workers than a virgin queen. This may reflect differences in the quality and quantity of pheromone produced; old failing queens produced an intermediate response. A bioassay, based on the attractiveness of a stationary queen to workers in the comb, has been developed. Various, as yet unidentified, components of the queen's mandibular gland have been shown to be important, but the two major components of the queen's mandibular glands ((E)-9-oxo-2-decenoic acid and (E)-9-hydroxy-2-decenoic acid) have little or no effect.

Attempts have been made to discover how queen pheromone is distributed among the worker bees. Extensive observations of the behaviour of individuals in the 'courts' surrounding queens demonstrated that bees which touched the queen with their antennae

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had an increased tendency, during the following few minutes, to move over the comb surface, make antennal contact with other bases, and arouse interest from the recipients. This suggests that queen pheromone may be distributed on the surface of workers' antennae.

Preliminary investigations into the effects of incorporating an alarm pheromone into insecticidal sprays to repel foragers gave encouraging results. (Free and Ferguson, with Mr. M. Winder)

Integrated control and cultural practices

Pests of winter wheat. Winter wheat was used in 1978–79 instead of the spring wheat used in the initial 1978 experiment. Treatments, similar to those of the previous year, compared untreated plots with (i) a combination of pesticides (metaldehyde, aldicarb, pirimicarb, omethoate) to control soil and foliar pests, (ii) pirimicarb applied as a spray at the beginning of flowering to control aphids, and (iii) biological control of aphids by the release of *Metopolophium dirhodum* and *Sitobion avenae* infected with an entomophagous fungus, *Entomophthora aphidis*.

An extensive sampling programme was designed to cover all likely pests and beneficial organisms. Populations of many of the pests (slugs, stem borers, soil pests, blossom midges) were low. In the dry weather following drilling, bran baited traps on all the plots failed to attract any slugs until after germination and even following substantial rain only ten slugs were taken in seven nights of trapping. As expected from national observations, the principal pest present in the crop was the aphid, *Metopolophium dirhodum*.

Despite the low numbers of *M. dirhodum* in June (<1 per shoot) and virtually no *S. avenae*, pirimicarb was applied at the end of June when the crop began to flower. Within 2 days of spraying, the aphid populations in the treated plots had fallen by 89% compared with those in the untreated plots. However, the insecticide did not persist long (about 5 days) and the treated plots were rapidly recolonised by aphids from adjacent untreated areas. A maximum of about 35 aphids per shoot occurred by mid-July in all the plots, after which numbers declined to zero by the second week of August.

Cereal aphids were infected with the fungus, *E. aphidis*, in the laboratory and about 12 infected *M. dirhodum* and 14 *S. avenae* per m^2 were distributed in the 'biological control' plots on 21 June. Subsequently, the proportion of *M. dirhodum* infected in the untreated plots corresponded closely with those in the *Entomophthora*-treated plots. By early August up to 85% of aphids were infected. In the untreated plots most aphids were infected with *E. planchoniana*, which appeared during early July from natural sources and infected a steadily increasing proportion of aphids in successive weeks. This species also infected many aphids in the treated plots. However, *E. aphidis* was also important; although it infected few aphids in the treated plots during the dry 4-week period after its application, it multiplied very quickly after rain in late July. If it had remained damp for longer the introduced *E. aphidis* may well have prevented the aphids from reaching the large numbers attained in late July. *E. planchoniana*, although apparently less dependent on moist conditions than *E. aphidis*, probably would also have caused heavy mortality earlier had the weather been moister. Data from further years are required to determine whether *Entomophthora* introduced into the crop can diminish cereal aphid populations earlier in their development than occurs naturally.

Few aphid specific predators were found during the weekly surveys, and they were unlikely to have had any significant influence on the development of the aphid population. However, two species of syrphid flies, *Syrphus vitripennis* and *Platycheirus clypeatus* were reared from winter wheat in England for the first time.

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There were few aphid parasitoid mummies found in the weekly surveys. Random collections of cereal aphid mummies throughout the summer disclosed five species of primary parasitoids and five species of hyperparasites, of which *Aphidius uzbekistanicus* (Aphidiidae) (71%) and *Phaenoglyphis* sp. (Cynipidae) (51%) were the most numerous.

However, a sixth species of primary parasitoid reared from live aphid samples (*Toxares deltiger* Haliday) had not been recorded previously from cereal aphids. In laboratory cultures, aphids attacked by this species usually left the plant before dying, perhaps explaining the absence of this parasitoid from the field mummy collections.

There were no significant differences in crop yield between these treatments. (Powell, Dean, Dewar, Wilding, Bardner, Fletcher, Lofty, Edwards and Stephenson)

A further assessment of the importance of carabid and staphylinid beetles as predators of cereal aphids was made. Duplicate experiments were set up at Rothamsted and at North Farm, Sussex, to compare the effects on cereal aphid populations of killing all polyphagous predators in plots enclosed by a polythene barrier by using a surface-application of fonofos, with trapping to remove all carabid beetles, and with control plots in which the polyphagous predators were undisturbed.

M. dirhodum was the most numerous aphid in 1979 whereas *S. avenae* had been the dominant species in 1978, and aphid immigration was later than in previous years. Thus, a clear distinction between early and late predation by polyphagous predators, sought by erecting barriers in March, April or May as in 1978, was difficult to show. Presumably, because the predominant aphid species was different and invasion delayed, even late predation became important and there was an inverse correlation between numbers of polyphagous predators and cereal aphids even when barriers were not erected until May. Whereas the relationships between numbers of aphids and polyphagous predators were strongly inverse, those between aphids and aphid-specific predators were positive, demonstrating the dependence of the more specific predators on a limited food source. (Edwards and Lofty, with Dr. K. Sunderland, Glasshouse Crops Research Institute and Mr. K. S. George, MAFF Plant Pathology Laboratory, Harpenden)

Pests of sugar-beet seedlings. The collaborative experiment of the Integrated Control of Soil Pests Working Group of the IOBC/WPRS was continued for the fourth and final year. This joint study with Broom's Barn and six other countries (Ireland, Belgium, France, West Germany, Switzerland and The Netherlands) compared the effects of various agronomic practices on plant populations, organic matter breakdown and yield. The particular aim of the experiment has been the assessment of rotations, herbicide and insecticide use on the incidence and extent of seedling pest damage. Data remain to be analysed but it seems clear that growing continuous sugar beet did not cause any major pest problem other than an increase in pygmy mangold beetles (*Atomaria linearis*), and there were indications that the increased infestations of this pest began to decline possibly because populations of its parasites and/or predators were becoming established. When no herbicides were used weed problems rarely arose and although populations of soil-inhabiting invertebrates tended to increase with more weeds the animals were less concentrated in the sugar beet rows than when herbicides were used. Moreover, populations of both pests and their predators were larger when no herbicides were used. Of the five insecticides tested, aldicarb controlled soil-inhabiting pests most effectively but it was also more harmful to the beneficial organisms. With the exception of *Atomaria*, soil-inhabiting seedling pests did not cause very large losses. (Edwards and Bater, with Dunning and Thornhill, Broom's Barn)

Experiments on the distribution of the entomophilic nematode, *Neoaplectana* sp., to control seedling pests, continued to show promise.

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Natural enemies of *Sitona*. Factors responsible for limiting the natural increase of *Sitona* have received little attention so far. Examination of the soil around bean roots infested by *Sitona* larvae has shown that larvae of carabids and staphylinids are frequently found with many mymarid wasps, which were possibly egg parasites. Many adult carabid beetles were found in bean fields, most commonly in August, when the new generation of *Sitona* adults was emerging. In laboratory tests, large carabids such as *Pterostichus melanarius* and *P. madida* killed and ate adult *Sitona*, and smaller species such as *Agonum dorsale* and *Bembidion lampros* also ate *Sitona* eggs. Effective methods for controlling adult *Sitona* should not harm these useful predators. Sprays of permethrin did not make the soil toxic to carabids, although individuals exposed on the soil surface may be killed by direct contact with spray droplets. (Bardner and Fletcher)

Direct drilling and earthworms. In March, a survey of invertebrate populations in seven direct drilled fields and seven ploughed fields was made on Lee Farm, Sussex. The average number of all earthworm species (Table 2) was larger in direct drilled fields (range 51·5–109·5 m^{-2}) than in ploughed fields (range 16·0–48·0 m^{-2}). The deep-burrowing species (*Lumbricus terrestris* and *Allolobophora longa*) were encouraged by direct-drilling much more than the shallow-living species, *A. chlorotica* and *A. caliginosa*, confirming results from field experiments. The data from the survey also showed a steady increase in populations of earthworms the longer the fields had been direct drilled.

TABLE 2

Average numbers of earthworms m^{-2} *(mean of seven fields, assessed by formalin method)*

	Direct drilled	Ploughed
Lumbricus terrestris	34·4	6·8
Allolobophora longa	11·0	3·1
Allolobophora chlorotica	25·9	11·3
Allolobophora caliginosa	11·5	10·9
Total	72·8	32·1

In another study, five ADAS experiments that had been direct drilled for at least 5 years were used to examine the effects on root growth of inoculating the soil with earthworms. Just before sowing, one of each of three pairs of plots (3 m × 3 m) at each site was inoculated with 250 *L. terrestris* and 250 *A. longa*. The growth of winter cereals was monitored throughout the following season, and samples for assessments of root growth and yields were taken from the centre of each plot. At all sites inoculated plots had better germination, more tillers, taller plants and a greater yield than uninoculated ones.

Thus, in many soils, earthworms are undoubtedly beneficial to the growth of direct drilled cereals, so all practices that are harmful to worms, such as the use of carbendazim fungicides, should be kept to a minimum.

Similarly, repeated strawburning, now studied over 4 years, decreased populations, particularly of *L. terrestris*, mainly because it diminished organic matter in the soil.

With similar aims new work was started in 1979 to assess the effects of fertilisers on earthworm populations. These increased when organic fertilisers such as farmyard manure, fish meal, sewage sludge and animal slurries were applied. Large doses of 'ammonium' nitrogen decreased populations significantly, but some nitrogenous fertilisers, particularly 'Nitro-Chalk' increased populations of most species except at excessive doses; lime also favoured their increase. Continuous cereals and leys increased

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earthworm populations much more than rotations involving root crops, legumes or fodder crops. (Edwards and Lofty)

Staff

The Department was pleased to host an IOBC Meeting on Soil Fauna and Cereal Pests, arranged in March by R. Bardner. Nine members of the Department attended three different IOBC Meetings in Wadenswil, Vienna and Colmar, several to present papers or chair sessions. N. Wilding participated in a workshop on integrated control in cereals at Gembloux and a meeting on fungal pathogens in Paris. C. Wall visited the University of Leiden to plan cooperative work on pheromone trap spacing.

C. A. Edwards attended the International Congress of Plant Protection in Washington and presented guest lectures at nine US State Universities. He was Rapporteur at the FAO Panel on Pesticides in the Environment in Rome and a UK delegate to the USSR under an Anglo-Soviet cooperative scheme on environmental pollution.

L. R. Taylor gave an invitation lecture at a Symposium on 'Movement of Lepidoptera in the South-Eastern USA' held in N. Carolina.

G. Dean visited Thailand in June for ODA to investigate the Bombay locust (*Patanga succincta*) attacking maize.

Staff were well represented at the AAB meeting on Advances in Crop Production and Protection held at Reading in September, when I. F. Henderson, R. Bardner, R. A. French and M. Dupuch contributed papers, and at the 1979 British Crop Protecton Conference at Brighton, to which R. Bardner, C. A. Edwards and T. Lewis contributed.

J. B. Free was elected chairman of the newly formed British Section of the International Union for the Study of Social Insects. C. Wall retired as convenor of the AAB Entomology group.

Ingrid H. Williams, H. Loxdale and J. E. Bater were promoted. Anne Cameron, Alison Pickard, Janice Browning, Susan Jones and Valerie Humphreys resigned and D. D. Burke completed his research studentship. W. Powell, G. M. Tatchell, M. S. Taylor, N. Morris, Amanda Modlen, Deborah Wood and Sara Huggard joined the permanent staff, and R. Harrington took up a 3-year research grant for the Potato Marketing Board. I. F. Chisholm joined the Department on a 3-year Biet Scholarship to study thrips. Patricia Roberts transferred to the Plant Pathology Department and was replaced by Margaret Pearson.

A. C. Green, Fiona Wilson, Lynn Whittle and Fiona Todd worked as sandwich students and Mr. Khan and Mr. Saleem each visited the Department for 2 months at the request of the British Council. Professor Yoshikazu Inukai, from Tenshi College, Japan, also visited the Department for a similar period to study earthworms.

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