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Entomology Department

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Introduction

The broad objective of the Department's work is to find ways of limiting pest damage to crops by minimal use of insecticides allied to appropriate cultural, biological and behavioural manipulation of populations of pest and beneficial organisms. Details of current work on pest detection and crop loss evaluation, the side effects of insecticides, integrated control and cultural practices, were described in last year's *Report*. However, underlying these obviously applied studies is a programme of more fundamental work, essential to an understanding of the biological processes involved in the interrelationships between

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insects of the same and different species, their host plants, and other organisms. This *Report*, therefore, focuses on the more basic topics covered within the Department.

Plant damage and pathogens

Most sucking insects can damage plants directly, some perhaps cause wounds through which fungal or bacterial pathogens gain access, and others transmit plant viruses. Feeding mechanisms and insect/host/pathogen relationships are being studied in thrips and aphids feeding on cereals.

Thrips, suspected of reducing germination in barley and wheat, have unique mouthparts whose functioning is poorly understood. New techniques have been developed to study their feeding habits. Another general problem with sucking insects is whether they prefer healthy or diseased plants and how their growth rate and fecundity are affected by the health of their host. Studies on the interrelationships between cereal aphids and virus and fungal infection of cereals are shedding understanding on this complex topic.

Thrips feeding mechanisms. Scanning electron microscopy has been used to examine the external morphology of the head capsule of larval, pupal and adult *Limothrips cerealium*, as well as the internal mandibular and maxillary stylets, which were displayed either by partial ashing with a Nanotech Plasma Prep P100 or by dissection. The feeding positions of larvae and adults have also been examined by immersing feeding individuals into liquid nitrogen. The stylets of some of these thrips dislodged from the leaf surface had penetrated 25μm into the plant.

A viewing chamber was devised to film the exploration, probing and feeding movements of adult and larval thrips feeding on sucrose solution through a transparent PVC membrane. The translucent cuticle of the larvae made it possible to record the muscular pumping of feeding individuals. The inflow of liquid during ingestion was traced by the movement of polystyrene latex particles added to the sucrose solution.

Thrips fed through the PVC membrane on sucrose labelled with either ^{32}P or ^{14}C each imbibed about 0·015 μl in 24 h. They have been shown to regurgitate labelled fluid into plant tissue, and by using Ilford Nuclear Research Emulsion 14 their feeding sites have been identified. Preliminary results indicate that they feed more on the rachis and lateral florets than on the grain. (Chisholm and Lewis, with Evans, Plant Pathology Department, Doncaster and Seymour, Nematology Department, Smith, Soils and Plant Nutrition Department, and Pocock, Botany Department)

Aphid/virus/fungal interrelationships. Field experiments in 1979 showed that significantly larger populations of *Metopolophium dirhodum* developed on barley yellow dwarf virus (BYDV)-infected winter wheat (Flanders) and oats (Panema) than on the surrounding healthy plants (80 and 152% more respectively at peak infestation). Similarly, significantly more *Sitobion avenae* were recorded in 1980 on BYDV-infected winter wheat (Flanders), oats (Panema) and barley (Maris Otter) (83, 230 and 168% more respectively at peak infestation).

When simultaneously presented with a choice of targets in a laboratory flight chamber, more *M. dirhodum* and *S. avenae* alighted ($P<0·05$–$P<0·001$) on the leaves of BYDV-infected oats and barley than on those of healthy plants. Infected leaves on oats were bright yellow to orange, and on barley bright yellow.

Laboratory and field studies showed that while BYDV infection of wheat (Highbury), oats (Manod) and barley (Julia) significantly increased the size of adult aphids ($P<0·05$, $P<0·01$ and $P<0·01$ respectively) and fecundity ($P<0·001$, $P<0·001$ and $P<0·05$ respectively) of *S. avenae*, it did not affect *M. dirhodum*. The discrepancies between the

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numbers of *M. dirhodum* on healthy and BYDV-infected plants in the field may therefore be due to the greater initial attraction of infected leaves to immigrating alates; increased fecundity due to virus infection is an important additional factor for *S. avenae*.

In two seasons experiments in which aphids (and therefore honeydew) were excluded from the ears, significantly more *Cladosporium* sooty mould developed on the ears of BYDV-infected winter wheat (Flanders) than on those of healthy ones ($P < 0{\cdot}05$ in both years). This suggests that BYDV predisposes the plant to infection by the fungus, possibly by inducing physiological changes which render the infected plant more susceptible to fungal attack.

The role of aphid honeydew in the infection of cereals by *Cladosporium* was investigated in the field in 1980. In the absence of BYDV infection, plants infested by honeydew-producing *S. avenae* had more *Cladosporium* on the ears than did uninfected ones, but the difference was not statistically significant, probably because there were few aphids.

Laboratory measurements showed that individual *S. avenae* and *M. dirhodum* excreted significantly less honeydew (18% after 5 days for *S. avenae* and 41% after 9 days for *M. dirhodum*) on BYDV-infected than on healthy spring wheat (Highbury). *M. dirhodum* similarly produced 29% less honeydew after 10 days on diseased spring barley (Julia) plants than on healthy ones. Any increase in the amount of honeydew on virus-infected plants compared to healthy ones in the field would therefore be due to the presence of more aphids on the former. (Ajayi and Dewar)

Insect pathogens

The prospects of eventually being able to use insect pathogens reliably and consistently for pest control depend on an appreciation of their biological and physicochemical properties, and their transmissibility and infectivity in relation to weather. A substantial proportion of all known non-occluded viruses of insects have been identified in the Department from bees, and work on these viruses and other bee pathogens has continued. Studies on the effect of weather on the spread of aphid fungal diseases has progressed.

Bee viruses in Britain. A survey of apparently healthy bee colonies within 45 km of Rothamsted has shown that adult bee populations are infected with several viruses, of which black queen-cell, sacbrood and filamentous viruses are the commonest, sometimes occurring in 90–100% of colonies. Cloudy wing virus, bee virus Y, chronic bee-paralysis and acute bee paralysis viruses were all detected in about 20% of colonies. Bee virus X and slow paralysis viruses were the least common.

Bee virus Y, black queen-cell virus and filamentous virus were almost invariably associated with the microsporidian *Nosema apis* in the same individuals. They hardly ever occurred independently of *N. apis*, but were not always in bees infected with this parasite. They thus appear to be helped by *N. apis* either to infect bees or to multiply in them, although black queen-cell and filamentous viruses, at least, multiply in a variety of tissues other than the mid-gut, to which *N. apis* is limited. These three viruses provide the only known examples of an association between viruses and microsporidia. The great physicochemical dissimilarities and serological unrelatedness of the viruses suggest that the effect of *N. apis* on the susceptibility of bees to virus infections is fundamental, and that similar associations between microsporidia and viruses may be expected to occur in other insect species.

An examination of nearly 200 samples of adult bees from all parts of England and Wales indicated that all the viruses found locally also occur throughout Britain to a similar extent and that they have the same relationships with *N. apis*. The occurrence of black queen-cell, filamentous virus and bee virus Y vary seasonally, coinciding with

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the abundance of *N. apis*, with peak infection in late spring or early summer. Sacbrood and acute bee-paralysis viruses also vary seasonally, with most infection during the summer. No seasonal fluctuations were detected in the incidence of the other viruses. (Bailey and Ball)

Filamentous virus. A satisfactory method was developed of purifying this virus from samples of dead adult bees collected in the field. The virus is an enveloped flexuous rod (3000×40 nm) containing double stranded DNA of molecular weight 12×10^6 and about 12 proteins of molecular weights 13 000–70 000, approximately equally distributed between the envelope and the nucleocapsid. (Bailey, with Carpenter and Woods, Plant Pathology Department)

Chronic bee paralysis virus. A particle 17 nm in diameter is associated with chronic paralysis virus. The amount of associate particle that multiplies in bees is negatively correlated with both the absolute amount of paralysis virus that multiplies and the relative amount of the longest, most infective particles of the virus. The relationships are the same as, or analogous to, those between satellite or defective particles or RNAs and their helper viruses of animals and plants, and provide the first evidence of satellitism in insects. The associate particle multiplies much more in queens than in workers and this may reflect innate defence mechanisms against paralysis, which would seem more important in queens than workers. Considerable variations were observed between the amounts of associate particle that multiplied in individual queens. They are probably a result of the genetic differences known to exist between strains of bee in their resistance to paralysis. (Bailey and Ball)

Viruses in bees from abroad. Several common British viruses were detected in dead individuals of *Apis mellifera* sent to Rothamsted from abroad. They included: bee virus Y from Australia and Canada; filamentous virus from Japan and New Zealand; cloudy wing virus from Australia and Egypt; acute bee paralysis virus from Belize and the USSR; black queen-cell virus from Holland, Canada and California and chronic bee paralysis virus from New Zealand and California.

Two viruses were detected in samples of dead adults of *A. mellifera* from abroad; Kashmir bee virus from Australia and Arkansas bee virus from California. They have never been detected in Britain. Laboratory tests established that Kashmir bee virus is readily transmissible by contact between live adult bees but it is not transmissible in food.

The sample containing Arkansas bee virus was the first field sample containing substantial amounts of the virus and the first from anywhere other than Arkansas in which the virus was detected at all. (Bailey)

Reports from elsewhere have suggested that Arkansas bee virus multiplies in plants, and as it was originally isolated from pollen collected by bees there seemed to be a possibility that it is a plant virus. However, using serum-activated electron microscope grids, no virus particles were detected in inoculated or tip leaves of plants (*Nicotiana clevelandii* and *Chenopodium amaranticolor*) 2–4 weeks after inoculation with purified virus preparations that were highly infective to bees. (Bailey and Govier, Plant Pathology Department)

A strain of sacbrood virus was isolated from specimens of *Apis cerana* from Northern Thailand. Serologically distinguishable from sacbrood virus from *A. melliferas* it also has some physicochemical differences especially a higher average molecular weight of its three proteins, and the propensity to aggregate in low salt concentrations and to produce empty particles in the presence of Mg^{2+}. (Bailey, with Carpenter and Woods, Plant Pathology Department)

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Infectivity of *Erynia neoaphidis* conidia for aphids. Aphids are infected by fungi of the family Entomophthoraceae by conidia that germinate readily only in free water or in saturated air. In dryer conditions on inert surfaces, they lose their ability to germinate in less than 12 h, suggesting that dry weather would quickly arrest the spread of fungi in an aphid population. However, no investigations have been made on the survival of conidia on leaf surfaces.

This was tested by inoculating the lower surfaces of detached bean leaves with conidia of *Erynia neoaphidis* (=*Entomophthora aphidis*) from infected aphids and incubating the leaves at a range of humidities. The infectivity of these inocula for pea aphids, *Acyrthosiphon pisum*, diminished with time but some persisted at 100% r.h. for 16 days, when tests ceased, 10 days at 60% r. h. and 8 days at 20% r. h. The infectivity of conidia on leaves of growing plants in the field during July 1980 similarly diminished with time, but some infectivity remained after 15 days, when tests ceased, except on leaves in very exposed positions. These inocula may have been washed from the plants by rain or destroyed by sunlight. The results show that conidia can persist on plants as a source of infection for much longer than had been previously realised and suggest that leaf surfaces are more favourable than inert surfaces to conidial survival. (Wilding and Brobyn)

Iso-enzyme typing

Characteristic iso-enzyme banding patterns obtainable for insect and plant tissue by polyacrylamide gel electrophoresis are being used to study the genetic variability of aphid populations and grasses. In the grain aphid, *S. avenae*, the persistence and movement of specific genotypes is being investigated by monitoring enzyme-isozyme and chromosomal polymorphism within British populations (*Rothamsted Report for 1979*, Part 1, 85); this may incidentally reveal resistance to insecticides should it occur (*Rothamsted Report for 1979*, Part 1, 116).

Some Italian ryegrasses (*Lolium multiflorum*) are particularly susceptible to stem-boring fly larvae but a few are much more tolerant. The genetic basis of this resistance, and a way of identifying it easily and quickly, is also being sought using this technique.

Genetic variability of aphid populations. In 1979, 53, and in 1980, 44, clones of *S. avenae* collected throughout the UK were established under constant environmental conditions. Since *S. avenae* rarely produces sexual forms, thereby limiting genetic crosses, assignment of isozyme bands to alleles/loci is necessarily arbitrary. Of 32 isozyme bands examined (representing 15 enzymes), 13 were monomorphic and 19 polymorphic. (Loci were defined as polymorphic when the frequency of the most common allele in a population was not greater than 0·95.) Frequency differences were found to exist between mobility variants for each polymorphic isozyme examined, categorised as allelic forms. Only two of the polymorphic isozymes showed homozygous/heterozygous patterns characterising monomeric proteins, consisting of slow and fast bands for homozygotes and both bands for heterozygotes respectively.

The statistic 'average heterozygosity H' most often employed as a measure of genetic variability in population studies of sexually reproducing animals was not calculated due to the low overall level of heterozygosity detected. Instead a less precise measure of genetic variability, P, the proportion of polymorphic loci in a population, was determined to give $P=19/32=0{\cdot}59$ or 59%. This value is not as high as that reported for some animals, but is higher than the average of 42% calculated from other surveys of many animal and plant species.

The relative lack of heterozygosity is consistent with *S. avenae* being predominantly anholocyclic (parthenogenetic), while the high level of polymorphism suggests that

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sexual reproduction is not necessary to maintain extensive isozyme variability within field populations for this aphid.

Now that extensive biochemical polymorphism has been detected within the national aphid population, regional populations will be examined to determine two statistics; the genetic identity (I) of populations and the genetic distance (D) between them. Thereafter gene frequency changes within and between populations and values of the two statistics will be monitored. (Loxdale)

Insect-resistant grasses. Differences in susceptibility to insect damage between the commonly sown agricultural grasses have been demonstrated in field and glasshouse experiments. The most serious damage is caused by larvae of the frit-fly complex (Chloropidae) to ryegrasses. Damage to Italian ryegrass (*L. multiflorum*) cultivars was particularly severe and greatly reduced their persistence in the field. In field sowings only a few plants survived more than 3 years, but when protected by insecticidal treatments, many of the original plants persisted for four or more years. The genetic basis of these intravarietal differences is being studied by monitoring the survival of individual spaced plants of *L. multiflorum* (cv. RvP) in the field. Five hundred plants were glasshouse-grown from individual seeds and characterised on their esterase iso-enzyme banding patterns by polyacrylamide gel electrophoresis of macerated leaves and stems. They were transplanted outdoors on 29 July; all established, and differences in vigour are already apparent. (Henderson, with Mr R. O. Clements, GRI)

Pheromones

The intensive studies of pheromones in honeybees are beginning to produce tangible results, some with commercial potential for swarm reclamation and perhaps the control of colony aggression. Further work on pea moth pheromones in the field has suggested that artificial sources may attract moths over great distances.

Electroantennography and alarm pheromones of honeybees. Electroantennography (EAG) has not hitherto been used in honeybee pheromone research. A technique has now been devised for recording EAG responses of honeybees to pheromones, using excised antennae. It has been invaluable in the identification of an important new component of the alarm pheromone. EAG evidence suggested that the natural Nasonov extract was often contaminated. To investigate these contaminants, an extract of worker honeybees was fractionated by liquid chromatography and each fraction giving peaks on the gas chromatograph was examined by EAG. Only one fraction produced a significant EAG response, and activity was attributed using gas chromatography/mass spectrometry (GC/MS) to (Z)-11-eicosen-1-ol (*see* Insecticides and Fungicides Department Report).

Examination of extracts from parts of honeybees by GC showed that (Z)-11-eicosen-1-ol was produced in the dorsal anterior region of the sting, associated with the quadrate plates. Isopentyl acetate, known to be a major component of the sting alarm pheromone, originated from the same place.

The behavioural role of (Z)-11-eicosen-1-ol was assessed by a bioassay for alarm activity. Chemicals were presented on both moving and stationary lures at the hive entrance, because, although bees are attracted to and congregate around an introduced sting or isopentyl acetate on a stationary object, they need the additional stimulus of movement to attack. When tested alone on moving lures, (Z)-11-eicosen-1-ol, like isopentyl acetate, elicited stinging and together these two compounds were as active as the natural pheromone from the sting. On stationary lures, (Z)-11-eicosen-1-ol prolonged the effectiveness of isopentyl acetate. (Z)-11-eicosen-1-ol is therefore a synergist of

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isopentyl acetate, active in alarm behaviour of the honeybee. (Williams and Martin, with Pickett, Insecticides and Fungicides Department)

Honeybee pheromones involved in clustering and attracting swarms. Queen and Nasonov pheromones responsible for clustering were investigated by applying synthetic components to porous polyethylene blocks contained in small cylindrical double-walled cages suspended from the arms of a roundabout, and noting on which of the cages queenless bees clustered.

Both queen and Nasonov pheromone components were necessary for cluster formation. Clusters formed on cages containing synthetic Nasonov pheromone plus either or both of the two major components of the queen's mandibular gland pheromone, (E)-9-oxo-2-decenoic acid (9O2) and (E)-9-hydroxy-2-decenoic acid (9H2). Nasonov plus 9O2 was initially preferred probably because of the latter's greater volatility, although the greater persistence of 9H2 helped to prolong clustering once it had occurred. The addition of 9H2 to 9O2 inexplicably reduced its attractiveness. Bees preferred to cluster around the crushed head or mandibular glands of a queen rather than on equivalent amounts of 9O2 and 9H2, or 9O2 alone, so there are probably other components in the mandibular glands.

The seven components of the Nasonov pheromone are more attractive to clustering bees when presented in equal proportions than in the naturally occurring proportions. The attractiveness of the synthetic pheromone was diminished only when one of the following three components was removed: (E)-citral, nerolic acid, geraniol. A mixture of these three components in equal proportions was as effective as all seven components in equal proportions.

Such a 'lure' would be of great benefit to attract swarms, and lures composed of cheap commercial components made unoccupied hives more attractive to caged and free honeybee swarms. (Free, Ferguson and Williams, with Pickett, Insecticides and Fungicides Department)

Nasonov exposure at hive entrance. Worker bees that have been temporarily lost or denied access to their colony, expose their Nasonov glands, release pheromone at the hive entrance and disperse it by fanning. Odours of empty comb, purified beeswax, honey, pollen, propolis, a living queen, living drones and workers, and inert material on which workers had walked inside the hive, elicit this behaviour. The total odour of a foreign colony also induced worker bees to expose their Nasonov glands but this was less effective than the odour of their own colony.

Odours of recently killed drones and workers, and worker brood were not effective. 9H2 induced Nasonov pheromone release but 9O2 did not. Thus, the relative effects of these two compounds in inducing clustering and Nasonov release were reversed, indicating that they are differentially effective in different behavioural contexts.

Nasonov pheromone readily released Nasonov gland exposure by foragers when presented at the hive entrance, which helps to explain the rapid increase in the proportion of scenting bees that occurs as they cluster. However, earlier experiments showed that it failed to do so at food sources so the behavioural response to this pheromone differs in different situations. (Free and Ferguson)

Orientation to pheromone traps by pea moths. The interactions between traps (*Rothamsted Report for 1977*, Part 1, 94, *for 1978*, Part 1, 88–89, and *for 1979*, Part 1, 83) have been investigated to provide more information on moth behaviour.

In pairs of traps, each containing 100 μg (E,E)-8,10-dodecadien-1-yl acetate (E,E8, 10-12:Ac), the upwind trap usually caught more moths than the downwind trap at spacings of 25–200 m. With three traps spaced in a line at 25, 50 or 100 m the upwind

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trap caught more moths than the sum of the other two. In lines of five traps spaced at 25 or 100 m the upwind and downwind traps caught more moths than the other three. The number of traps in a line had a greater effect on the profile of catches than the spacing between the traps, and the range of attraction of pea moth traps containing 100 μg of this natural pheromone (*Rothamsted Report for 1979*, Part 1, 117) may be in excess of 400 m.

The effects of different doses of the two attractants, E,E8,10-12:Ac and (E)-10-dodecen-1-yl acetate (E10-12:Ac) on the interactions in lines of three traps spaced at 50 m were also investigated. When the traps each contained E10-12:Ac (1 or 10 mg) the upwind trap did not catch more moths than the other two. Changing the dose of E,E8,10-12:Ac had a marked effect on the catch profile. At a dose of 100 μg the upwind trap caught more moths than the other two, but at a dose of 1 μg a profile similar to that for E10-12:Ac was obtained. Thus, in order to obtain a profile of catches in which the upwind trap in a line of three interacting traps catches more than the others, the traps must contain a relatively high dose of the natural pheromone, E,E8,10-12:Ac.

The efficiency with which traps caught moths approaching within 1 m was affected by the attractant rather than the dose. Traps containing E,E8,10-12:Ac were almost twice as efficient as those containing E10-12:Ac, suggesting that the former is a better close-range attractant. (Wall, with Perry, Statistics Department)

Observations of the attraction of male pea moths to vegetation which had been in the immediate vicinity of pheromone traps, and subsequent chemical analyses, indicated that leaves of wheat can absorb sufficient pheromone during 3 h to remain attractive for at least 1 h after removal of the traps. (Wall and Sturgeon, with Greenway, Insecticides and Fungicides Department, and Perry, Statistics Department)

Elemental analysis of insects and plants

Two new studies based on various X-ray spectroscopic and spectrophotometric techniques, of considerable potential for tracing the origin of migrant pests and the sources of trace elements in plants, have begun to yield results.

Elemental analysis of insects. Work has begun on the use of chemoprints in studies of migration (*Rothamsted Report for 1978*, Part 1, 90 and 295), using both wavelength-dispersive and energy-dispersive X-ray techniques. Wavelength-dispersive analysis is being used for *Agrotis segetum* and *Noctua pronuba*. Analyses for 16 elements have been done on many individuals reared on ten soil–plant combinations and on an artificial rearing medium over a range of temperatures. The data are being processed and analysed.

Because individuals of some species of interest are too small to provide enough material for wavelength-dispersive analysis, it is necessary to use energy-dispersive techniques. Investigations using this technique have begun on wheat bulb fly collected from emergence cages on Great Harpenden and Stackyard and on two species of *Culicoides* reared on the same artificial medium at the Animal Virus Research Institute, Pirbright. Analyses for ten elements have been done on many individuals. Preliminary multivariate analysis has been encouraging and suggests further analyses which will be done. In particular the analyses showed differences in preparatory techniques and indicated the preferred method. *Culicoides* was chosen for investigation because individuals are even smaller than aphids and because material was available from stocks with limited genetic and environmental differences. It has been shown that individual *Culicoides* can be chemoprinted so that it should be possible to use the same techniques for individual aphids. (Bowden and Sherlock, with Brown, Soils and Plant Nutrition Department, Turner, Plant Pathology Department, and Digby, Statistics Department)

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Using pollen collecting bees to sample for metals. Pollen loads have been trapped from honeybee colonies in locations known to be contaminated by, or relatively free of, soil-borne heavy metals. The relative amounts of copper, lead, zinc and manganese in the pollen approximated to that found in the soil, indicating that pollen could be used as a method of sampling at least some elements of environmental interest. Thus pollen collecting bees could be used to prospect for metals, and to detect the presence of abnormal mineral contents which might be detrimental to crop plant and human health. (Free and Williams, with Dr R. J. F. H. Pinsent, Royal College of General Practitioners, and Dr A. Townshend, Mr N. S. Basi and Dr C. L. Graham, Department of Chemistry, University of Birmingham)

Pest forecasting

The large amount of data collected over the years by the Rothamsted Insect Survey is gradually being analysed and interpreted to forecast pest arrival on crops. During the year, important progress has been made with two aphids, *Aphis fabae* on beans and *Phorodon humuli* on hops. Somewhat unexpectedly, light trap catches of adult wheat bulb fly in late summer have also been shown to be effective for forecasting egg numbers in autumn.

Aphid forecasting. For 10 years colleagues at Imperial College, in ADAS, and at other universities and institutes have been collecting data on ground populations of *A. fabae* from its overwintering host *Euonymus europaeus* (spindle tree) and from field bean crops. The plant samples can now be compared with aerial samples collected by Rothamsted and the forecast for damage based on both aerial and plant samples compared with the actual damage caused.

The first forecast of likely crop infestations the following spring can be made from the autumn (September/October) aerial migration of aphids, and it accounts for 28% of the variance in infestations between crops in different years and regions. The second forecast, based on egg counts on spindle (December), which are made by about 11 entomologists at over 300 sites, accounts for 54% of the variance; the spring winged nymph-sample, similarly obtained, also accounts for 54%, and the spring migration aerial sample (RIS) accounts for 64% of the variance.

Converted to forecast warnings, these produce about 90% correct warnings in 9 of the 10 years, by either method. The labour-intensive spindle sample gives more local detail and up to 2 weeks forewarning in spring. Both methods failed partially in 1 year for unknown reasons, but combined, the increasing accuracy through the winter makes an excellent forecast possible. The aerial system could be improved by refining the timing limits for samples in relation to crop condition, and by weighting the autumn migration for distribution of overwintering hosts. Analysis suggests that the greatest errors are in damage assessment and the smallest in the aerial sample. Perhaps ground sampling may eventually become unnecessary.

Similar combined efforts to sample other crops and overwintering hosts would enable the aerial sampling system for other aphid pests to be validated. (Taylor, Woiwod and Fletcher, with Professor M. J. Way and Dr M. E. Cammell, Imperial College, University of London)

A forecast of the timing of the beginning and end of the migration of *P. humuli* to hops has been developed for the two major hop-growing regions of Britain, using Rothamsted suction trap data from Wye and Rosemaund. The production on *Prunus* of alatae that will migrate to hops occurs in response to changes in food quality, the older leaves favouring their production. Terminal buds are produced on *Prunus* during the latter part

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of June after which no new leaves are produced so the remaining population of *P. humuli* produces alatae. The time of terminal bud production is partly dependent on weather; when it is warm and dry they are produced earlier than when it is cool and moist.

The forecast depends on finding the best correlation between the dates of the beginning and end of the migration, as indicated by suction trap catches, and various meteorological factors, using a computer program developed at Wye College. To minimise chance correlations, only simultaneous correlations with the same meteorological factor at both sites ($P<0{\cdot}01$) were included. The forecast only uses correlations explicable in terms of the insects' and plants' biology.

The beginning of the migration in late May or early June is negatively correlated with the mean air temperature at the end of March and beginning of April when eggs hatch and the fundatrix generation of *P. humuli* develops on its primary host. The earlier and more rapidly this occurs, the sooner will the first alate funatrigenie be produced. The end of migration in July or early August is negatively correlated with the mean temperature during the middle of June, and there is also perhaps a positive correlation with rainfall during May and June, corresponding with the timing of terminal bud production on *Prunus*, and hence a late production.

The forecast of the beginning of the migration is accurate to within 2 or 3 days of the expected date, and the end of the migration generally to within 10 days. (Tatchell, with Dr G. K. Goldwin and Dr G. G. Thomas, Wye College, London Unit)

Dipterous stem borers of cereals. Monitoring of wheat bulb fly with light traps (*Bulletin of Entomological Research* (1969), **69**, 129–139) has continued. The numbers of mature, dispersing females trapped to 21 August 1980 provided an accurate forecast of egg numbers present in September, e.g. for Broadbalk a forecast of 2·9 M eggs ha^{-1} compared with the actual 3·1 M eggs ha^{-1}. There is a significant correlation between numbers of females trapped at Rothamsted and numbers of eggs in the Eastern Region of ADAS (Norfolk, Suffolk, Essex, Hertfordshire, Bedfordshire and Cambridgeshire.) A forecast of the regional average numbers (which is an average for a very wide range of soils and previous cropping history) was only moderate, being 30% greater than the actual average ha^{-1}, but for a more restricted category of numbers in fallows the forecast was much improved (3·03 M ha^{-1} compared with 2·87 M ha^{-1} actual). The correlation between Rothamsted trap catches and egg numbers in Eastern Region arises presumably either because mature females disperse much more widely than thought, or because some environmental factor(s) affect regional adult populations uniformly and simultaneously, or some combination of these. Chemoprint studies may help towards an explanation. Discussions are proceeding with ADAS Eastern Region entomologists to investigate further the possible use of light traps to forecast regional egg numbers.

Recently there has been a marked increase in attack by *Opomyza* spp. on winter wheat. A preliminary analysis of light trap data accumulated over the past 10 years at Rothamsted suggests that light traps could be used to monitor *Opomyza*. The period when it would be necessary to monitor *Opomyza* follows immediately the critical period for wheat bulb fly (July and August) so, given appropriate position of light traps, both pests could be monitored at the same sites. (Bowden, with Eastern Region wheat bulb fly data provided by Mr F. E. Maskell, ADAS, Cambridge)

Light trapping. A model has been developed which describes the functioning of a light trap in terms of trap illumination and background illumination. It is a good description of catches in traps with different light sources but similar background illumination and of catches in traps with the same light source but different background illumination. The model provides a basis for adjusting light trap catches to allow for variation in

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background illumination caused by moonlight or by latitudinal variation in illumination, and also for the direct comparison of catches at different light sources and between light traps and suction traps. (Bowden)

Earthworms and organic matter

The importance of earthworms for incorporating organic matter in soil in direct-drilled crops was confirmed in a further series of experiments. Knowledge of earthworm taxonomy, biology and ecology revealed by these studies over the last 8 years has led to good prospects of using earthworms to convert farm animal wastes into friable, nutrient-rich and odourless composts at the same time producing large amounts of high quality protein for stock and fish food. The potential for converting farm, and even human, waste into an immense resource for stock food production presents an exciting challenge. There seem no reasons why earthworm protein production from a wide range of organic wastes should not be commercially attractive on a farm or industrial scale.

Earthworms and direct drilling. Further surveys on populations of earthworms in eight direct drilled and eight ploughed fields at Lee Farm, Sussex, confirmed that populations are continuing to build up.

The inoculation experiments on five ADAS sites that have been direct drilled for at least 6 years were repeated for a second year. Plots were inoculated at three population levels of 28, 56 and 84 *Lumbricus terrestris* m^{-2} and an equal number of *Allolobophora longa* m^{-2}, and the effects of these introductions on wheat growth were compared with the growth of uninoculated plots. In all sites, the wheat in the inoculated plots germinated better, tillered more, was taller and yielded significantly more at all levels of inoculation. However, there were few significant responses between the different levels of inoculation, although there were obvious tendencies to better growth in the plots containing most worms.

These studies over 3 years have proved that for the five soil types studied, all of which had poor natural earthworm populations, inoculation of earthworms increased root growth and yield of cereal crops considerably. In such continuously direct drilled crops earthworm activity is beneficial and should be encouraged. To do this an earthworm management programme was devised involving minimal straw-burning, optimal pH, use of suitable fertilisers, avoidance of harmful pesticides and addition of organic matter. The relative importance of these factors was assessed and the addition of organic matter was shown to be the most important.

As a result an extensive programme was begun to investigate the influence of farmyard manure, sewage cake and sludge, cattle and pig solids, sludges and slurries on earthworm populations in the field. This involved setting up three new field experiments at Rothamsted on grass and cereals with two levels of different forms of organic matter, assessment of populations in the 'Broadbalk' wheat experiment, a complex experiment organised by the Water Research Centre, Stevenage, and two experiments by the Thames Water Authority. These experiments confirmed that all forms of human and animal waste applied at up to 150 t dry matter ha^{-1} increased earthworm populations, the increase

TABLE 1

Earthworms and organic matter

(18 months after application)

Treatment	No. worms m^{-2}	Wt worms m^{-2} (g)
Control	111	14·4
FYM (200 kg N ha^{-1})	221	37·2
Sewage cake (200 kg N ha^{-1})	308	44·8

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being dose dependent. However, at single doses above this, the effect began to decline and doses as high as 400 t ha^{-1} had little benefit. Sewage waste was usually more effective than animal wastes. (Edwards and Lofty)

Earthworms for waste disposal and protein production. Work was extended to investigate the possibilities of breeding large numbers of earthworms from organic waste. The programme was begun originally to produce worms to add to direct drilled sites, but it was expanded with special funds from MAFF, with the aim of producing cheap protein for pig, cattle, poultry, fish or even pet feed at the same time converting the organic waste into a useful fertiliser rich in available mineral nutrients. Earthworms contain 60–70% high grade protein and provide adequate vitamins. Several species, especially *Eisenia foetida*, breed rapidly in organic waste reaching maturity after 7–8 weeks and thereafter producing 2–3 cocoons weekly, each containing two or more eggs.

Laboratory experiments have shown that these worms will breed rapidly in pig and cattle solids, in pig waste composted with straw and other materials, or in mixtures of the pig sludge and solids produced by the NIAE integrated piggery project. Production of 1 kg worms from 10 kg of waste was readily achieved and further experimentation should improve this. The worms grew best at 20–25°C, pH from 5 to 7 and moisture contents from 70 to 80%. It is essential that the waste be kept aerobic. These worms are extremely common in trickling filter beds at local sewage works. Large-scale breeding has been started at Rothamsted using pig wastes, cattle wastes, horse manure and sewage products. Work is under way to produce worms from the compost produced from pig waste in the process patented by Dr C. J. Gray and Dr A. J. Biddlestone at Birmingham University. Experiments using earthworms as a source of protein for fish farming are in progress in collaboration with Dr A. G. Tacon of the University of Stirling. Collaborative work on the use of cattle waste to produce earthworms has started at Bore Place Farm (Commonwork Enterprises), Edenbridge, Kent.

It is hoped that most of the basic biological studies will be completed in 1981. Mechanical methods of separating the worms from pig and other waste are already available and it is planned to improve these and engineer farm scale methods of breeding worms from pig manure so that all the supplementary protein needed for a herd of pigs could be generated from their own waste. It may also be possible to lessen odour from piggeries by passing vent gases through earthworm casts which are an effective deódorant. (Edwards and Lofty, with Dr R. Q. Hepherd, National Institute of Agricultural Engineering)

Staff

The Department was pleased to host an EEC Meeting in November on 'Integrated and Biological Control of Cereal Pests'. Other European links included N. Wilding's visit to Institut Pasteur, Paris, to discuss the use of fungi for aphid control, and C. Wall's attendance at a joint meeting of the European Chemoreception Research Organisation and the International Symposium on 'Olfaction and Taste in the Netherlands'. C. A. Edwards visited Brussels at the invitation of the EEC to formulate ecotoxicological methods for earthworms for forthcoming legislation, lectured at the Freie Universität in Berlin and was Rapporteur at an FAO meeting in Rome on 'The Environmental Effects of Tsetse Control'.

T. Lewis and J. B. Free attended the XVI International Congress of Entomology, Kyoto, Japan, and the latter attended the 2nd International Conference on Apiculture in Tropical Climates, in Delhi, giving papers elsewhere in India, and a symposium on 'The Study of Social insects in the Tropics' in Mexico. I. H. Williams also attended the Delhi conference, and with J. B. Free an international symposium of biosystematics of

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social insects in Paris. C. A. Edwards gave the lead address at a symposium at Michigan, USA, on the 'Role of Earthworms in Stabilisation of Organic Waste Residues' and lectured at Delaware and Purdue Universities.

In Britain, L. Bailey, C. A. Edwards, J. B. Free, T. Lewis, W. Powell and Ingrid Williams contributed to various Society and ADAS meetings.

Professor R. Hartenstein, of the State University of New York, Syracuse, visited the Department in November and December, and Dr Astrid Lop-Holmin, Uppsala University, in October. Captain K. Win and Mr E. M. Naasi were based in the Department while studying beekeeping for 9 months, and Dr Nour el Din Farghaly Hamad came to study moth diversity.

The Department was saddened by the death of Dr Margaret G. Jones who still unofficially helped to identify beneficial insects. Several long-standing staff, J. W. Stephenson, R. Welch and A. Whiting, retired and Carole A. Lowther, Margaret Pearson and R. Moore resigned. Hilda R. Goddard and Christine Moule joined the staff. R. Elspeth Neale and G. C. Goats came as Ph.D. students and Wendy Barrow completed her studies. W. Airey, I. J. Tarr, Angela Cleaver and A. Martin worked as sandwich course students, and T. Butt and J. Graham as CASE students.

I. P. Woiwod and A. P. Martin were promoted.

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