ROTHAMSTED RESEARCH

Rothamsted Report for 1963

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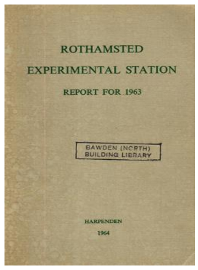

Entomology Department

C. G. Johnson

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ENTOMOLOGY DEPARTMENT

C. G. JOHNSON

R. Bardner was appointed to the Department and Dr. L. V. Knutson of Cornell University, Mr. M. F. Ryan, an Agricultural Institute (Republic of Ireland) Scholar and Mrs. M. G. Jones joined us as visiting members.

J. W. Stephenson attended the 15th International Symposium on Crop Protection in Ghent, Belgium in May; C. G. Johnson, L. R. Taylor and T. Lewis attended the 3rd International Biometeorological Congress at Pau, France, in September; C. G. Johnson was a member of a working group of the International Biological Programme which met in Paris in December. El Iman El Khidir was awarded the Ph.D. Degree of London University and has returned to the University of Khartoum.

Soil Fauna

The breakdown of leaf tissue in the soil. Rothamsted Report for 1962 described studies of the effect of the feeding of soil arthropods and earthworms on the breakdown of leaf material. One of the methods used to assess the rate of this breakdown was to estimate the proportion of the leaf area that disappeared in a given time. Done visually at first, the results have been checked against photometric measurements of the areas of leaf eaten. Both methods give similar results, although the visual method tends to give slightly greater estimates of the amounts eaten. The agreement between loss of area and loss of dry weight was good; progressive dry-weight losses on the same individual leaf can therefore be estimated.

In general, both in old pasture kept fallow and in the litter layer of woodland soils, 95% of the beech-leaf discs disappeared in 12 months when earthworms were allowed access to them; only 50% disappeared when worms were excluded (by keeping discs in nylon bags), but soil arthropods fed on the discs. Equivalent values for oak leaves were 100% and 65%. Leaves picked from trees in August and September disappeared more slowly than those picked at other times of the year. Some other leaves disappeared more rapidly in both soils; for example, three-quarters of lettuce leaves disappeared in 2 weeks, though some remained after 7 weeks, and more than half of beet-leaf tissue had gone in 5 weeks and almost all in 9 weeks. It took 9 weeks for half of the elm-leaf tissue to disappear, and less than 5% remained after 8 months, when only 60% of the ash-leaf had been eaten. (Heath, Edwards and Arnold)

An interesting fact described in last year's report was the different rates at which leaves grown on sunny or shady sides of trees were broken down; this has been further studied. Oak leaves that had been in the middle of the litter layer for 2 months were divided into two groups; one most, and one least attacked by soil animals. Samples of each group were ground and extracted with 50% methanol, and chromatograms of the extracts showed that leaves of both groups (compared with freshly fallen senescent leaves)

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had lost flavonoid compounds and possibly esters of cinnamic acid, e.g., chlorogenic acid. The leaves least attacked contained more ellagic acid, petrol-soluble compounds and polyphenols than those most attacked. Increases in these substances are apparently correlated with increased unpalatability of leaves to soil animals. (Heath, with Bloomfield and King of the Pedology Department)

The slightly quicker disappearance of oak than of beech leaves, found in all experiments, suggests that (apart from differences in palatability to soil animals) the micro-organisms in the soil may digest the leaf tissue at different rates. Cultures of soil micro-organisms and of the micro-organisms inside the animals' alimentary tracts were not obtainable, so the digestibility of weathered oak and beech leaves to the organisms from the rumens of sheep was measured *in vitro*; oak was about twice as digestible as beech. (Heath, with Dr. J. M. A. Tilley of the Grassland Research Institute, Hurley)

The side-effects of toxic chemicals in the soil on arthropods and earthworms. The experiment on Highfield (*Rothamsted Report* for 1962, p. 156) on the long-term effects of a single dose of DDT at 6, 20 and 60 lb a.i./acre and aldrin at 4 lb a.i./acre continues, with the plots kept fallow. By August 1963 the amounts of insecticide remaining, from treatments begun in May 1961, were still large; there was no significant loss of DDT in plots treated with 6 lb a.i./acre, but about 50% of the amount applied had disappeared from plots treated with 60 lb a.i./acre. The plots treated with aldrin at 4 lb a.i./acre had lost about 50% of the total insecticide, and three-quarters of that remaining had turned into dieldrin.

Residues of insecticides were extracted from the soil with a mixture of hexane and acetone, and estimated by gas–liquid chromatography. The column was composed of 2·5% silicone elastomer E301 and 0·25% epikote 1001 on celite (Goodwin *et al.* (1961), *Analyst*, **86**, 697). Detection was by electron capture. The method was satisfactory for aldrin and dieldrin, but with DDT there was background interference at the necessary higher column temperature. The DDT applied at 6 lb a.i./acre was also estimated colorimetrically by the Schechter Haller method, and the results agreed with those obtained by gas–liquid chromatography. (Edwards with Jeffs, of the Insecticides and Fungicides Department)

Springtails in the DDT-treated plots have continued to increase in numbers; onychiurid Collembola are also gradually becoming more numerous because of the prolonged fallowing; isotomid Collembola are, however, becoming fewer. In each of the three seasons, 1961, 1962 and 1963, following the treatment with insecticides, most Collembola occurred between August and October. The effect of DDT on the predatory mesostigmatic mites was still considerable, and in plots treated with aldrin there were still very few of these mites; the long period of fallow has caused the predatory mites gradually to become fewer. The oribatid mites and larvae of Diptera, abundant when the experiment began, have now almost disappeared. (Edwards and Arnold)

An experiment at Levington Research Station, made by courtesy of Messrs Fisons Fertilisers Ltd., studied the effects of continued annual

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application of aldrin at 1 or 2 lb a.i./acre on soil animals. It began in 1959, and although the insecticide at first diminished numbers of arthropods, there has been little further diminution between 1962 and 1963, although the total quantity of aldrin put on during the experiment is 7 lb a.i./acre. Aldrin is apparently destroyed in the soil more rapidly than it is being added.

Experiments to study how aldrin (at 2 lb a.i./acre) and "Telodrin" (at $\frac{1}{4}$, $\frac{1}{2}$ and $\frac{3}{4}$ lb a.i./acre) affect populations of soil animals on different types of soil are being made in the Fens and in Kent by courtesy of the Shell Chemical Company, Woodstock. The effects at these amounts were small in peat soils but considerable in the first season in mineral soils, though they did not persist into the second season.

In collaboration with Mr. J. D. Fryer, Agricultural Research Council, Weed Research Organisation, a long-term study was begun on the effects on soil animals of herbicides applied in spring and autumn. The herbicides are tri-allate, a volatile, persistent carbamate; MCPA, a phenoxyacetic growth regulator; and simazine, a tri-azine. These were applied at 3 lb a.i./acre, and linuron, substituted urea, at 4·5 lb a.i./acre. Tri-allate, MCPA and linuron had no significant effect on numbers of soil animals in the first year of treatment, but simazine greatly lessened the numbers of mites, springtails, millipedes, enchytraeid worms and the larvae of Diptera and Coleoptera. Effects were still detectable 3 months after applying simazine. (Edwards and Arnold)

The effects of menazon on soil arthropods and earthworms were studied in field experiments done in collaboration with Imperial Chemical Industries, Jealotts Hill, and in laboratory tests. In 1962 menazon was applied to fallow plots and to plots sown with sugar beet on a light, sandy loam soil at Newbury, Berks. With untreated fallow and cropped plots the experiment was set out in a 4 × 4 Latin square. Menazon was applied to the treated plots as 5% granules to give 2 lb menazon/acre and was worked into the soil just before the sugar beet was sown. The arthropod population was estimated 2, 4, 8, 16 and 32 weeks after treatment, by taking soil samples from each plot and extracting the arthropods by a standard flotation method. The only significant effect attributable to the menazon was fewer onychiurid Collembola 2 weeks after treatment. No difference between treated and untreated plots was detected subsequently.

In 1963 the effect on soil arthropods of menazon applied at 2, 4 and 8 lb/acre was tested at 5 sites representing differing soil types, viz. clay loam, silty clay loam (2 sites), clay with flints and coarse sand. Soil samples to estimate the arthropod population were taken 4 weeks and 26 weeks after treatment. Four weeks after treatment the only significant effects attributable to menazon were as follows:

Effect	Menazon treatment	Site
Decrease in isotomid Collembola	8 lb/acre	Coarse sand
	4 lb/acre	Coarse sand
	8 lb/acre	Clay loam
Increase in onychiurid Collembola	8 lb/acre	Clay loam
	4 lb/acre	Silty clay loam

Samples taken 26 weeks after treatment are not yet all examined. (Raw and Lofty with Imperial Chemical Industries, Jealotts Hill)

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Laboratory tests lasting 3 months showed that activity of the earthworms *Lumbricus terrestris*, *Allolobophora caliginosa* and *A. chlorotica* was unaffected by 10 mg of 5% menazon granules in 500 g of soil (equivalent to 2 lb menazon/acre). Activity of *A. caliginosa* was unaffected by 100 and 1,000 mg of 5% menazon granules in 500 g of soil, but reproduction as judged by numbers of cocoons seemed to be lessened. Reproduction of *A. chlorotica* seemed to be lessened by 10 mg of 5% menazon granules in 500 g of soil. (Raw and Lofty)

The accumulation of residues of chlorinated hydrocarbon insecticides in soil invertebrates. When chlordane and heptachlor are applied to soil in amounts used to control soil-borne pests they kill earthworms also. However, other related compounds, such as BHC, DDT, aldrin and dieldrin, are thought to be harmless to earthworms, but it has been suggested that they might accumulate in the worms, and eventually harm any animals, such as birds, that eat them. The extent to which such insecticides accumulate in worms, and other soil invertebrates, is therefore being studied. Results, so far, show that for two fields at Rothamsted where aldrinised fertiliser was applied some years ago the concentration of dieldrin (a breakdown product of aldrin) in the earthworms was several times greater than in the soil itself, but that this concentration differed in different species of worm. (Raw)

The recolonisation of sterilised soil by invertebrates. Insecticides kill many soil invertebrates that may help to maintain soil fertility; therefore it is necessary to know how soil sterilised by such treatments becomes recolonised. Soil fumigants are useful in such work, because they are used against eelworms and they are not persistent. Therefore though the soil animals are killed, the soil itself does not remain lethal for long, and recolonisation is unhindered by previous treatment.

In September 1962 plots 8 ft × 8 ft were sterilised with "DD" mixture at 800 lb/acre and by "Vapam" at 600 lb/acre, on a site fallow for the two preceding years (*Rothamsted Report* for 1962). Some plots were isolated from the surrounding soil by polythene barriers round the perimeters rising about 1 ft above and going down 1 ft below the soil surface. One year after sterilising the soil species of Collembola possessing a springing organ and adapted to jump (especially some isotomids and entomobryids) had recolonised both the plots with and without the barriers, and in both were more than twice as numerous as they had been just before the soil was sterilised. Immature forms of some flying insects (e.g., larvae of Diptera) occurred in similar numbers both in the unsterilised and the sterilised plots, both with and without barriers; this was apparently caused by flying insects ovipositing more or less equally in all plots.

There are many soil-inhabiting arthropods, such as symphylids, diplopods and chilopods, which neither jump nor fly, and some Collembola (onychiurids) without a springing organ and unable to jump as well as those with one. These, and other wingless arthropods, had not invaded the DD-treated plots surrounded by polythene, but they had invaded the edges of the unenclosed plots.

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With some other plots the soil was removed to a depth of 1 ft, heat sterilised and then replaced, in plots with and without polythene barriers. As with the fumigated plots, the Collembola with springing organs re-colonised the sterilised soil rapidly in both enclosed and unenclosed plots; 1 month after sterilisation they were found 2 ft within the edges. However, there were twice as many Collembola in the unenclosed as in the enclosed plots, averaging 16·7 and 8·8 per sample respectively. Collembola were always more numerous round the edges than in the centre of the plots, and there were more near the surface than deeper down. Isotomids liberated on the centre of a tray of moist soil in the laboratory also thinned out from the source, with more in the surface than in the deeper soil. These facts suggest that the Collembola invaded the plots through the air. To test this suggestion, traps were placed at different heights above ground level, namely, water trays at 30 and 60 cm high and sticky traps at different heights up to 100 cm. More oribatid mites and Collembola were caught in the lower traps, but the higher traps caught some. There were two population maxima for Collembola (isotomids, entomobryids and sminthurids) in the soil; one in May and June and another, twice as great, in October and November. The greatest abundance of Collembola on the aerial traps coincided with these. About three times more Collembola and oribatid mites were trapped in the air over grass than over bare soil, and the species caught were the same as those that most rapidly invaded the sterilised plots. (Buahin and Edwards)

The control of soil pests. To supplement experiments on the chemical control of wireworms done on Claycroft field at Rothamsted with the Insecticides Department (*Rothamsted Report* for 1962, p. 157), one was done at Bourne, in collaboration with the National Agricultural Advisory Service, Shardlow Hall, in a field of fen soil, ploughed up from old grass in spring 1963 and cropped with spring wheat (Jufy I).

The treatments tested were:

Aldrin spray	3 lb active ingredient/acre
BHC seed dressing (standard)	Seed treated at 2 oz/bushel with a dressing containing 20% isomer, i.e., 1·2 oz active ingredient/acre
BHC seed dressing (high rate)	Seed treated at 2 oz/bushel with a dressing containing 60% isomer, i.e., 3·6 oz active ingredient/acre
Dieldrin seed dressing	Seed treated at 70 oz/bushel with a dressing containing 60% dieldrin, i.e., 7·9 lb active ingredient/acre
Untreated seed	"Agrosan" only

The standard BHC seed dressing did not significantly increase yield (21·2 cwt/acre), but the treble high rate and the dieldrin seed dressing gave 24·2 and 25·6 cwt/acre respectively, significantly more than the control plots (18·6 cwt/acre). Spraying with aldrin also increased yield to 23·5 cwt/acre, but this was not statistically significant.

Soil samples taken after harvest to estimate the effect of the treatments on the wireworm population showed that all the treatments lessened the wireworm population significantly, but that the dieldrin seed dressing did so significantly more than the other treatments. The performance of the

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treble-rate BHC seed dressing, which increased yield more than did the aldrin spray, is particularly noteworthy. (Raw and Lofty)

However, now that the use of chlorinated hydrocarbons is more restricted than formerly, other seed-dressings and soil insecticides with less persistence must be studied. An experiment was started in New Zealand field to study the direct and residual effects of various organo-phosphorus compounds, as alternatives to chlorinated hydrocarbons for controlling wireworms in wheat. (Raw and Griffiths of Insecticides and Fungicides Department) The effect on other soil animals will also be studied. (Edwards and Raw)

Ten herbicides were tested in the laboratory for molluscicidal properties (*Rothamsted Report* for 1962, p. 157) and two (triazines) showed promise. These are now being tested in the field in collaboration with Messrs Fisons Pest Control Ltd. The results of these tests are being analysed. Other, cultural, methods of controlling slugs are also under test. For example, some farmers assert that slug damage is lessened when winter wheat is grown in compacted soil. Laboratory tests in which soil was compacted, to simulate the effects of rolling, showed that damage to wheat seeds by *Agriolimax reticulatus* was 14–40% less than damage to seeds in "unrolled" soil. Damage to leaves of seedlings, however, was greater after compacting, but this may have been caused by the laboratory conditions. A field trial on the effects of rolling is now in progress. (Stephenson)

Some types of plastic sheet used for cages are toxic to slugs (*Rothamsted Report* for 1962, p. 158). The main toxic ingredient of cellulose nitrate sheet was identified as the plasticiser, camphor. Other plastics, such as cellulose acetate, contained molluscicidal dyes and phthalate plasticisers. However, polyvinyl chloride sheet produced no detectable harmful effects on slugs and is considered to be a suitable substitute for the cellulose polymer plastic sheets for use where toxic effects cannot be allowed. (Newell)

The biology of soil-inhabiting pests

Slugs. In 1962 the distribution of slugs in potato fields was studied at the Experimental Husbandry Farm, Terrington, Norfolk, in collaboration with the National Agricultural Advisory Service, (Eastern Province). Potato baits in the furrows suffered more damage than those in the ridges, and this was taken to indicate more slugs in furrows than in ridges. However, the presence of the crop potatoes may have lessened damage to baits in the ridges, and the experiment was repeated in ridges and furrows without plants. Paired potato baits at 6 in. and 15 in. below the surface were used. In 1963 the early spring was drier and the rain in spring and early summer was greater, but fell more evenly over the period than in 1962. Consequently, in 1963 the furrows became moister than in 1962. Nevertheless, damage by *Arion hortensis* was distributed in much the same way as in 1962; more slugs attacked baits in the furrows than in the ridges, indicating more slugs in the furrows. The slugs, however, were deeper down in 1963, probably because of the very cold weather. The dominant species was again *A. hortensis*, though *Milax sowerbyi* was also abundant in the autumn of 1962. Slug damage to winter wheat and potatoes is being surveyed to see if it is affected by cultural practice. (Stephenson)

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It is difficult when studying slug populations to measure the numbers of slugs in a given area, for the number of slugs seen on the surface at any time depends not only on the total population but also on its activity. "Population" and "activity" must therefore be distinguished and assessed separately; this is difficult, for there is no standard method of extracting all the slugs from a given area. One way to attempt an analysis is to collect all the slugs as they appear, hour by hour, and to repeat this collection on successive nights until no more appear. This was done on plots isolated with polythene barriers; *A. reticulatus*, (the most abundant species) were on the surface in greatest numbers at 23.00 h in August, and it took seven successive nights to collect all the adults. On any one night, therefore, only a small proportion of the total population comes to the surface and the problem is to know how this proportion changes and what the unseen slugs are doing.

The activity of *A. reticulatus* on the surface was studied in detail in an enclosed microplot, using a time-lapse mechanism on a ciné camera with a fast electronic flash-discharge tube for illuminating the surface. The film, made in collaboration with C. C. Doncaster, Nematology Department, is being analysed to obtain speeds and duration of movement, proportions copulating and many behavioural characters not seen before.

Another method of studying activity and of estimating the total population is by marking a known number of slugs, setting them free in a population and then estimating the total numbers in the area by the proportions of marked and unmarked slugs recaptured. Slugs are not easy to mark, but this was done by feeding them on lettuce made radioactive with ^{32}P. Experiments are now in progress to show how far and how fast marked slugs move, and to estimate the total population and the amount of activity. Neither *A. hortensis* nor *Agriolimax reticulatus* moved more than 3 ft from the release point in one night, but some *M. budapestensis* moved up to 9 ft. Of the slugs released, 16 of 17 *M. budapestensis*, 14 of 16 *A. reticulatus* and 13 of 18 *A. hortensis* were recovered over a 6-day period by using metaldehyde–bran bait under a 9-in.-diameter seed-pan with one trap every 4 sq. ft. Using 500 marked *A. reticulatus*, a release–recapture experiment was started on a field with a large natural slug population. (Newell)

Some slugs and snails are attacked by sciomyzid flies whose larvae parasitise or prey on them. The slug-killing larvae of *Tetanocera elata* and *Euthycera chaerophylli* were studied. The first and second instar larvae of *T. elata* are specific to *Agriolimax* species and feed on the mucus under the mantle, causing no harm. During the third instar, however, the larvae prey on and kill species of slugs belonging to several genera and this is being studied. (Knutson and Stephenson)

Wireworms. Wireworms are still important pests in spite of modern insecticides. They take up to 4 or 5 years to complete their development to the adult stage, and the adults apparently do not disperse far. Therefore in arable fields the food of the larvae may change from year to year as different crops are grown, and the diet of the adults may be restricted to a particular crop. The effect such feeding on different crops, such as wheat, potatoes, carrot, lucerne and field beans, may have an important bearing not

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only on the development of the larvae and the reproduction of the adults but also on the capacity to disperse. This is being studied in the laboratory, with larvae reared on different foods at different temperatures, and by caging newly emerged adults on differing food plants and measuring their fecundity and flight ability. Larvae fed on wheat or carrots increased in fresh weight faster than larvae fed on potatoes or lucerne, which increased faster than larvae fed on field beans. However, gain in fresh weight is not a good indication of growth, because larvae fed on potatoes can gain in fresh weight without increasing in dry weight. For many insects moulting indicates growth, but wireworms can and do moult without growing. *Agriotes sputator* usually has 7 or 8 growth stages before it pupates, and these can be distinguished by counting the cuticular teeth round the opening of the spiracles. A similar method for distinguishing the growth stages of *A. obscurus* is being sought. Then it will be possible to distinguish between moulting and growth in these two species and to analyse the effect of food supply on them. (Sriharan)

The wheat-bulb fly. The wheat on section II of Broadbalk (first year after fallow) was heavily infested with wheat-bulb fly in 1963. Growth was retarded by the severe winter, and when damage was assessed in late April plants were still in the single-shoot stage, and so were being killed by the infesting wheat-bulb fly larvae. Damage was much greater on some plots than others. On plots 10, 11, 12 and 14, 60–70% of plants were infested and there were fewer than 4 undamaged plants per foot of drill (these plots were ploughed in later), whereas on plots 2, 3, 5, 7, 13 and 15 fewer than 40% of plants were infested and there were more than 6 undamaged plants per foot of drill. Corresponding differences in plot infestation and damage have been observed in other years, and possible causes are being investigated. Earlier work suggests that the differences are not caused by more eggs being laid in some plots than others. Soil samples, taken in September when egg-laying had ended, showed that there were about 3 million eggs/acre in section Va of Broadbalk, which was fallowed in 1963. Similar infestations were found in fallowed land in Great Harpenden I and the Kitchen Garden in New Zealand field. The area in Great Harpenden is being cropped with wheat in strips alternating with fallow, for long-term study of fluctuations in wheat-bulb fly populations. The Kitchen Garden, where carabid and staphylinid beetles, which may prey on wheat-bulb fly eggs, were numerous is being cropped with wheat to study predators of the immature stages of wheat-bulb fly. (Raw, Lofty and Ryan)

Swift moths. Catches of *Hepialus lupulinus* (The Garden Swift) in light traps were analysed in relation to temperature, and showed a flight threshold of about 8° C. Larvae were bred to maturity in a single season on carrot at 15° C. Larvae of *H. humuli* (The Ghost Swift) have 12 instars except at temperatures around 20° C, when there may be additional moults. (Edwards)

The effect of insect attack on the growth and yield of crops. Damage to crops by insects is often unmistakable, but not always so; for it can be

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insidious and may be the unsuspected cause of considerable crop losses. It is a curious fact that in agricultural entomology much time and effort is spent studying the pests themselves but comparatively little in studying their relations with the growing plant, especially the way in which pest population of different sizes affect the growth and yield of the plants at different stages in their development. Yet such a study is very necessary if more rational control methods are to be developed. Crop loss is a reaction within a quantitative ecological system, and much insect ecology now studied as pure entomology would gain in force if associated with studies on yield.

We have therefore started to study the effects of insect attack on growth and yield and how pest populations of different sizes affect the plants in different stages of growth. (Bardner) Several crop and insect relationships were studied in small-scale field and pot experiments. The progress of the attack and the response of plants to it was followed in detail week by week, using growth-analysis techniques wherever possible. At this stage crops and insects were chosen for suitability for experimental work rather than their economic importance. Insect numbers were varied by differences in sowing date, by the use of cages or by infesting plants by hand. Unless it was essential, insecticides were not used to keep control plants insect-free, as these materials may stimulate or depress plant growth and may affect fungi, or other insects parasitic on the plants, and so produce spurious results. (see Slope and Bardner, *Rothamsted Report* for 1963)

Root crops present rather different problems than seed crops, so both are being studied. A convenient experimental system is the relation of growth and yield of radishes to attack by flea-beetles. The dry weight of radish roots is a rough measure of the amount of food produced by the photosynthesis in the leaves in excess of that required for growth and respiration. Adult flea-beetles eat holes in the leaves, and so might be expected to lessen their efficiency and hence the dry weight of the roots. The radish variety, French Breakfast, was grown in small plots in the field with sowings at three intervals in the spring, and at three intervals in late summer; this exposed plants to attack by the overwintering and summer generation of adult beetles. The number of feeding holes in the leaves the number plants per plot, the number of leaves, their area, and the fresh and dry weights of the leaves and the roots were assessed. Cages were used in the spring to produce different degrees of infestation, but not in the summer, when the plots were sampled at intervals throughout growth. The cages had a big effect on the growth of the plants, and a further complication of the spring experiment was the possibility of underground attack by the larvae. The summer generation overwinters before reproducing, so this experiment was free from these disadvantages. The summer experiment showed a relationship between damage and yield, the logarithm of the dry weight of the roots being inversely and linearly proportional to the logarithm of the number of holes per sq. cm of leaf area. The slope of the line relating these two measurements was independent of the time of sowing or sampling. Attack by adult flea-beetles also lessens the proportion of the total dry matter of the plants stored in the roots, food reserves being used to replace damaged leaf tissue. The inter-relationship of damage and various measurements of plant growth is still being examined.

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The seed-bearing crops studied were cereals and the pest leatherjackets (*Tipula* sp.). When grass is ploughed and cereals planted leatherjackets often cause serious damage by severing the shoots at ground level. Accurate estimates of leatherjacket numbers are difficult to get, and the size of population that can be tolerated without serious loss in yield is uncertain. To investigate this, plots of 7 ft square were sown with Proctor barley, surrounded with a barrier of polythene sheet partly buried in the soil, and infested with leatherjackets artificially, but the experiment was sown too late, and failed. It was repeated in 12-in. clay pots, with barley sown at 15 seeds/pot, the equivalent of 2 bu/acre, and leatherjackets at 0, 5, 10 and 20/pot, the equivalent of 0, 0·5, 1 and 2 million/acre. The experiment was ended 91 days after sowing because of an attack by aphids, just before the ears developed. At this stage all treatments had the same number of surviving stems per plant, showing that the plants had not responded to attack by production of new shoots, as they often do when attacked by stem borers, but the mean numbers of stems per pot judged able to bear ears were 30, 33, 18 and 15 respectively.

Cabbage aphids are important pests of biennial brassica seed crops, though not on mustard species, which are annuals, and ripen before migratory aphids are common. However, Trowse mustard (*Brassica juncea*) is a convenient plant to study the effect of sucking insects on seed yield, for it is largely self-pollinated, and the flowering can be easily controlled by altering day length, so making possible experiments in illuminated glasshouses in the winter. Some small outdoor experiments were done, and also a small pot experiment in which plants were infested with aphids 21, 28 and 40 days after sowing, corresponding with the time when the plants had the inflorescence just appearing, were in full flower and had the first pods appearing. Mean yields in grams of seed per plant 98 days after sowing were 57, 100 and 201 respectively, to be compared with 277 for plants kept aphid-free. The uninfested plants had slightly more pods and seeds, but the main effect of aphid feeding was to lessen the individual weight of the seeds. Infested plants had more racemes, perhaps because damage to the growing points stimulated side branches to develop. (Bardner)

The relation between various symptoms caused by swede midge (*Contarinia nasturtii*) and the yield of swedes was studied in 1962 by caging swedes with midges under fine-nylon-mesh 6-ft cages. Yields from infested plants differed greatly between themselves and from controls, but the caged plants, though with much more leaf, gave smaller roots than those grown in the open.

In 1963 the experiment was repeated, but some uncaged plants were infested by confining midges to them in small plastic 3 in. $\times$ 2 in. cylinders topped with nylon mesh. These were kept over the seedlings for only about 3 days, when the plants were allowed to grow normally; the development of symptoms was followed carefully, and each swede was weighed at harvest. The table shows that loss of yield was associated with all symptoms, but most with "many neck" and "cabbage top". Swede midge is obviously a serious potential pest, particularly on late-sown swedes, but more information is needed about natural infestations to assess its

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economic importance. (Edwards and Arnold with Mrs. H. M. Bardner of Plant Pathology Laboratory, Ministry of Agriculture, Fisheries and Food)

Yield of swedes related to symptoms of swede midge attack

	Percentage of attacked plants showing symptoms		Mean yield, in oz, of attacked plants with symptoms	
	Caged	Uncaged	Caged	Uncaged
Some symptoms	100	100	2·0	4·9
Crumpled-leaf	94·3	96·5	1·9	4·5
Swollen-petiole	94·3	55·5	1·9	3·5
Many-neck	90·2	55·5	2·0	3·4
Cabbage-top	61·5	52·0	1·6	4·0
Unattacked	0	0	5·5	7·6

Insect Dispersal and Migration

The daily flight periodicity of insects. The extent to which insects are disseminated by air currents depends partly on the time of day most of them fly, and so on their chances of being wafted upwards by convection or turbulence. Those that fly when the air is relatively still, as in the early morning, evening or night, are probably less prone to wind-borne travel than those flying in daytime. Various species have a wide range of flight periodicities, and over the last few years the disc-dropping suction trap (sometimes modified with a flexible inlet to sample inaccessible habitats) has enabled a catalogue to be compiled of the periodicities of about 400 species from a very wide range of habitats. It would, of course, take many years to make a comprehensive survey in which most families were well represented. As it is, about 500,000 insects have been counted and identified from a total catch of about 5 millions.

In all, 45 sites have now been sampled: wheat, oat, potato, kale, bean and pyrethrum crops and watercress beds; allotments, gardens and orchards; moorland, marsh, pasture and mown grass; ditches, drains, sewage filter beds and compost heaps; lake, pond, stream and river banks; pines, oaks, beech, elms, mixed woodland and evergreen scrub. Some of these sites were sampled repeatedly at different seasons, some continuously from spring to autumn; sometimes samples were taken in every month of the year. Some results are surprising. For example, the Nematocera were the commonest group in all agricultural settings, but were relatively rare in the ancient woodland at Ashridge. This may indicate an effect of agricultural practice on the faunal composition. Many Nematocera feed on decaying vegetation and indeed help in litter breakdown (p. 146), but some are serious pests. Another point of direct agricultural interest is the rarity of insect pests compared with other species. Perusal of the final lists of 400 species confirms earlier impressions that pest insects are only a small part of the total numbers in the air and tend to be restricted in seasonal time of appearance.

Heteroptera were especially rare. Many agricultural pests belong to this Order, and special efforts were therefore made to survey it thoroughly. It happened repeatedly, however, that a trap placed near an infested source failed to get a useful catch. This is probably because their flight is mainly migratory and occupies such a very short period of adult life that the migrating population is too sparse for the trap to detect.

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The original intention was to try to distinguish periodic flight behaviour patterns between major taxonomic groups, but it was often necessary to identify even to species, because quite closely related species may fly at different times. This is more obvious in some Orders than in others, and it may be a characteristic of some Orders or families.

Some relationships are obvious without much analysis. Predators tend to fly all through the daylight hours with fairly constant population density. Insects associated with fungi often fly at dawn and dusk, those associated with vegetable breakdown often only at dusk. The same species rarely fly as much by both day and night, except for White flies (Aleyrodidae), some Ceratopogonidae and moths. For example, females of a leaf-mining moth flew mainly by day and the males mainly by night, raising several curious problems. Light is the most important factor determining time of flight, and there is no evidence that intrinsic (endogenous) flight mechanisms control flight periodicity. The tendency for day fliers to be darker in colour than night fliers in most Nematocera was confirmed, and one species or another is in flight in every hour of the day and night. (Lewis and Taylor)

The weather and mass flights of Thysanoptera. The mechanisms responsible for mass migration of aphids analysed some years ago, showed aphids develop at a lower temperature than they fly. Therefore a period of low temperature allows new alatae to accumulate and when a warm day comes they fly off *en masse*. A similar system operates with thrips. Most species of thrips fly during a few weeks each year. Within this period some fly each day, but on some summer days there are sudden mass flights that can be spectacular where the breeding population is large. Daily trap catches of six common species, collected over five years, showed that the mass flights occurred when temperatures rose above the flight threshold after migrants had accumulated on plants at temperatures too low for flight. Similarly in spring when it was too cold to fly, overwintering females becoming flight-mature accumulated until it was warm enough for them all to take off together. (Lewis)

The weather most suitable for flight was determined by analysis of meteorological factors during flight periods, using data from radio-sonde soundings, synoptic charts and Stevenson screens. Most mass flights of the common species of grass and cereal thrips occurred in sunny, settled weather with slight convection, and a maximum temperature of at least 20° C. (Lewis with Mr. G. W. Hurst of the Meteorological Office (M.O. 7c)) Overwintering *L. cerealium* kept at 5°, 10°, 15° C. and outdoor temperatures were sampled at approximately monthly intervals, and their flight muscles sectioned and examined. Even though many specimens seemed unable to fly during the winter, there was no evidence that the flight muscles had degenerated.

Insect migration in Great Britain in 1963. For many years now records have been made by many amateur entomologists all over Britain of the occurrence of migrant Lepidoptera, and these records have been compiled at Rothamsted and published. This is more than a record of odd events

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and may now become part of the framework of an organisation which measures the general flux of insects in the air over Northern Europe and even farther afield. This development has been made more possible by the active co-operation of Mr. G. W. Hurst of the Meteorological Office (M.O. 7c) and by developing a network of light and suction traps in different places in the United Kingdom.

Long-distance migrations of Lepidoptera. In 1962 there was an unprecedented record of an invasion by the African Army Worm, *Laphygma exigua*, into southern England. The Meteorological Office provided the back-cast of wind at the time of this invasion, and it is now clear that these insects started their journey from the west coast of Morocco and were carried over the Atlantic on winds which brought them to Britain, where they arrived after 4 days continuous flight, and even to Holland. This example was clear because of the many that landed; but now this system has been demonstrated, other similar occurrences, less noticeable by themselves, can be detected. Thus, this moth appeared suddenly in February 1952, and again in 1958, when back-casts of wind showed that it came from the Azores. In June 1947 it was again traced back, but to an origin in Spain.

This kind of analysis was also made with *Utethesia pulchella* (the Crimson Speckled Footman) in August and September 1961 and *Itame brunneata* (the Rannoch Looper) in June 1960; the former was traced to N.W. Spain and the latter to Western Germany. Numerous other examples exist in the records of the past years and are being studied. It is now possible to see that what have been regarded as exceptional and curious events are part of a common, widespread and general flow of insect populations wafting in many directions in the air over Europe. We intend to explore this and to incorporate it into a general system of migration and dispersal not confined to Lepidoptera. (French)

Insect migration records. 1963 was another poor year for the commoner species of immigrant Lepidoptera; both *Vanessa cardui* L. (the Painted Lady) and *Vanessa atalanta* L. (the Red Admiral) were below average abundance. The Clouded Yellow (*Colias crocea* Fourc.) was very rare, as also was *Macroglossum stellatarum* L. (the Humming Bird Hawk-moth). Their rarity seems to reflect the scarcity of arrivals in the spring and the summer weather which discouraged breeding here. Although *Plusia gamma* L. (the Silver Y moth) was not very abundant, it was just above average; about half the year's total came in September, but without the large immigration on, or about, 24 September this moth would have been rather rare.

After the record numbers of *Laphygma exigua* Hübn. (the Small Mottled Willow) in 1962, it is interesting that very few were recorded in 1963; apparently this moth is unable to establish itself in the British Isles.

In a year of general scarcity, more *Hippotion celerio* L. (the Silver-striped Hawk-moth) were recorded than in any year since 1885. This moth arrived here on 26 October, possibly in association with *Nycterosea obstipata* Fabr. (the Gem) and *Rhodometra sacraria* (the Vestal). It is hoped that a study of the winds at the time of arrival will indicate the origin and path traversed by these immigrants. (French)

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Cardington trap catches. The preliminary sorting and counting of the catches from the suction traps used in 1955 at Cardington, on the ground, on the towers and on the balloons, was completed to Orders and with some Orders to families. The next step is to divide these groups even further and then to submit them to specialists for final identification. The meteorological data collected at different heights in relation to the numbers of insects flying at different levels are also being analysed. (Johnson and French)

Aphid Studies

Studies on root-feeding aphids. Work continued on two root-feeding aphids, *Rhopalosiphoninus latysiphon* Davids and *R. staphyleae* (Koch.), particularly to study their dispersal.

The growth of *R. latysiphon* colonies on the roots of potato plants on a small plot was measured to see whether spread from one plant to another is by alatae or apterae. Infested (*c.* 30–150 apterae per tuber) and non-infested potatoes were planted at the beginning of May, but only 3 of 10 previously infested plants lifted in mid-July had colonies on the roots, and adult alatae or alate nymphs were not found. Plants lifted in mid-August or September were aphid-free, and alatae were not trapped in cages enclosing other plants that had had heavy infestations of the tubers at planting. The reason for failure of the colonies to develop is not known, for the potato variety used, Majestic, is a suitable host for *R. latysiphon*, and the soil was heavy and moist, conditions apparently suitable for the development of this aphid. Nevertheless, plants grown from infested tubers yielded 17% less weight of tubers than those from clean tubers when lifted in August, but yield from previously clean and infested tubers was not significantly different in September. (Cockbain)

Tests were made to see if *R. latysiphon* apterae transmit potato viruses from infected to healthy tubers, for this aphid often infests tubers in clamps and chitting houses, and the spread of virus in these situations could be important. Potato virus Y was not transmitted by aphids fed on shoots of infected tubers for 1 minute, nor leaf virus after an acquisition feed of 4 days; however, tubers may not have been a good source of leaf roll virus, for *Myzus persicae*, an efficient vector, also failed to transmit from them. Potato virus A was transmitted by aphids fed on infected tubers for 1 minute, and *R. latysiphon* seems only slightly less efficient than *M. persicae* as a vector. (Cockbain, with Gibbs, Plant Pathology Department)

Winged and wingless forms of the mangold clamp aphid, *R. staphyleae*, transmitted sugar-beet yellows virus but not sugar-beet mosaic virus. *R. staphyleae* seems as efficient as *A. fabae* in transmitting yellows, though less so than *M. persicae*. (Cockbain with Heathcote, Broom's Barn Experimental Station)

Transmission of viruses in relation to the behaviour and physiology of aphids. Previous workers have shown that sugar-beet yellows virus is transmitted more readily by wingless than by winged forms of *Aphis fabae* and *Myzus persicae*, but our results suggest that the two forms do not differ in their intrinsic ability to transmit. Winged forms are more restless and often

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feed for only brief periods, but after similar feeding times on infected plants they transmitted as often as did wingless forms. Individuals fed on infected plants for 5 minutes did not transmit and few were infective after feeding for 30–60 minutes.

Wingless forms kept from feeding and at various temperatures up to 30° C for 4 hours after their infection feed, all transmitted equally often. Winged ones transmitted as readily after a 4-hour flight as after a 15-minute one. Some winged *M. persicae* remained infective longer than apterae, but most individuals of both ceased to be infective within 2 days of leaving infected plants. Most winged individuals ceased to fly 3–5 days after the final ecdysis because their flight muscles autolysed. (Cockbain, with Heathcote, Broom's Barn Experimental Station)

Growth and reproduction of *Aphis fabae* in relation to the amount of plant sap ingested. As described in our Report for 1962, the food ingested by *Aphis fabae* and its use for growth and reproduction are being studied to provide information for comparing and analysing the suitability of different plants and different parts of the same plant for nourishing aphids. Aphids fed on two varieties of broad bean plants ingested the same amounts of sap from both, while developing and as adults; but their fecundity differed on the two varieties, even when they fed on the young leaves at the crown of the plant. When fed on very young, folded leaflets and on the growing point (their favoured feeding places) the unexpected result was obtained that fecundity was lessened and became similar on the two varieties. Fecundity thus seems to depend on the quality and not on the quantity of food ingested, and this different quality occurs very soon in the growth of young leaves. Total amounts of nitrogen acquired from the plants by the aphids and the amounts used by them in growing and reproducing are being studied. (Banks and Macaulay)

The Biology of Aphid Predators

The feeding, growth and reproduction of Coccinellidae in relation to the accumulation of food reserves. Some Coccinellidae overwinter as adults, and the success with which they do so, and therefore the number that survive to prey on aphids in the spring, probably depends on the amount of fat and glycogen these adults have accumulated during their larval development. When coccinellids were reared from larvae to adult by feeding them on aphids (*A. fabae*) adults reared in the warm had more fat and glycogen than those reared in the cool, because in the warm they ate more of the aphids they killed.

The fat and glycogen in overwintering, new adults of known age of three species reared from larvae during the summer are also being measured and related to the beetles' powers of survival and to the growth of the gonads. It is evident that the rate at which reserves are used and the degree of gonad development affect the flight powers and migration of these beetles in the spring. As hibernating adult beetles may feed on honeydew and nectar, the effects of these diets on food reserves, survival and gonad development are also being studied. (El Hariri)

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