ROTHAMSTED RESEARCH

Report for 1964

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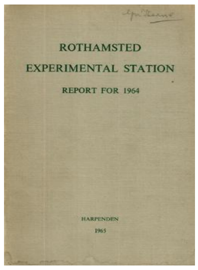

Entomology Department

C. G. Johnson

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ENTOMOLOGY DEPARTMENT

C. G. JOHNSON

E. Judenko joined the department with a grant from the Ministry of Overseas Development. Mr. A. Youdeowei (Cocoa Research Institute of Nigeria) and Mr. T. Rygg (Norwegian Plant Protection Institute) joined as visiting members. L. R. Taylor was awarded a National Science Foundation Senior Research Scientist Fellowship to work at Kansas State University for a year.

F. Raw, C. A. Edwards and R. Lofty attended the 8th International Congress of Soil Science, Bucharest. C. A. Edwards gave a course of seminars, by invitation, at Purdue University, Indiana, U.S.A. The 12th International Congress of Entomology, in London, was attended by most members of the department, and, with the Insecticides and Bee Departments, we were hosts to the Congress on 11 July. C. G. Johnson was a delegate to the 8th Commonwealth Entomological Conference in London. The department showed its work at a Research Day in the Royal Institution.

The Effect of Pest Attack on the Growth and Yield of Plants and Crops

The work on how pests affect the growth of plants and the yield of crops (*Rothamsted Report* for 1963) developed in two main directions; comparisons of methods of assessing damage and loss of yield, and studies of the physiological and ecological causes of loss. Assessing damage is less simple than it may seem, for each pest and crop has its own special difficulties. Also, work on mechanism of loss is tentative, partly because too little is known about how to assess losses and partly because the incidence of insect attack is not predictable, so elaborate field experiments may fail. In developing the subject, such failures must be regarded as experience in methodology.

The need for making a special study of factors determining yield losses is evident from much of our past work, in which losses are not those that might be expected from the extent of pest infestation. The study of insect abundance and factors affecting population changes is fundamental in pest biology, and rightly is a main branch of agricultural entomology, but numbers of pests are not all important. For example, studies of wheat-bulb fly on Broadbalk show that factors affecting plant vigour can be more important than insect numbers. Again, with tipulids, the total infestation in a crop may matter less than how this population is distributed; for when attack is concentrated in patches it can be devastating, but harmless when evenly distributed, and uninjured plants can compensate for damage to their neighbours.

Frit fly on oats. Stemborers are important wherever cereal crops are grown, and there is need to compare and standardise methods of assessing

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damage and loss; frit fly on oats is therefore being studied primarily for its methodological value. The yields of two sets of plants, one attacked and one unattacked, were compared, in 1964, by three different methods. The percentage germination of the grain was assessed by the official seed-testing station for England and Wales, Cambridge, and the grain samples were valued commercially by Messrs. Heygate and Sons, Ltd., Bugbrooke, Northampton.

Plants whose main stems and tillers were attacked were compared with unattacked plants in the same crop. By the 39th day after sowing (with Planet) 33% of plants were attacked in main stem and tiller, and yields from 118 pairs of these and controls were compared. The coefficient of harmfulness, the difference between the weight of grain from attacked and unattacked plants expressed as a percentage of the weight from the unattacked, was 75%; as the crop had 33% of injured plants, the loss of grain from the crop was 25%.

The actual yield/acre was estimated at 20·02 cwt, and the potential yield, in the absence of the pest, at 26·60 cwt, giving an estimated loss of 6·58 cwt/acre. None of the grain was of value for seed or for milling, probably because it was sown so late, but the quality was affected by attack and individual grains from attacked plants weighed about 10% less. In these experiments the effects of compensatory growth were not fully accounted for.

Four categories of plants were distinguished in an experiment with potted plants and possessed features shown in Table 1.

TABLE 1

Effect of frit fly (tiller generation) on yield of oats

Category	No. of plants	Average weight grain (gm)	Coefficient of harmfulness	% of grain injured	% germination	Price (for livestock) (/cwt)
I: Shoots uninjured	62	2·53	—	35	65	18*s.*
II: Tillers only injured	40	2·29	—	24	61	17*s.*
III: Main stems and tillers injured	15	1·20	—	—	73	17*s.*
IV: All infested plants	55	2·00	21%	—	—	—

Average weight of grain significantly different between all categories except I and II

Two plots were caged in May soon after the first adult frit fly appeared: one cage was artificially infested in July, the other left uninfested. This experiment dealt only with the generation of frit fly attacking the grain. Plants were categorised and possessed features shown in Table 2.

TABLE 2

Effect of frit fly (panicle generation) on yield of oats

Category	% grain injured	Weight of 1,000 grains (gm)	% germination	Price/cwt For livestock	Price/cwt Seed
I: Caged: uninfested	1	25·8	98	19*s.*	22*s.* 6*d.*
II: Caged: infested artificially	67	25·1	61	19*s.*	0
III: Uncaged plants in the crop	49	22·1	62	19*s.*	0

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The above methods assess the effects of attack of main stem, tiller and main stem, and grain. Results are too few yet for a strict comparison of methods. Nevertheless, assessing yield by comparing naturally attacked and unattacked plants in a crop seems to be the most useful, not only because it is near to agricultural practice but also because it allows commercial losses in any particular field to be assessed. (Judenko)

Losses to potatoes by aphid attack. The effects on potatoes of aphid-transmitted viruses have tended to overshadow the injury that aphids can cause directly when they feed on the plant and foul it with honeydew. Nevertheless, such losses can be large, as they were in 1963, when infestations, especially of *Aphis rhamni*, Koch, killed the haulms of many crops prematurely, and spraying some commercial crops with insecticides increased yield of tubers by as much as 28%. Although such severe attacks may be uncommon, their prevention is obviously worthwhile. As the problem has been neglected in Britain, the relationships between numbers of potato aphids, plant injury and loss of yield are now being studied.

As often happens, a year of unusual aphid abundance was followed by one with few aphids, and spraying with menazon, introduced as an extra treatment into a long-term experiment on the control of potato blight, did not increase yield in 1964. The effects of *Aphis rhamni* on yield were studied by infesting Majestic potatoes grown under fine-mesh nylon cages at various times during the growing season. Yield was studied in relation to plant growth, the development of aphid populations and the duration and intensity of the aphid attack. The largest infestation developed from aphids introduced on 22 June and caused a 26% loss of yield. Plants were too few to be harvested periodically, and though the infestation affected the size of the tubers, the effect on their growth rate was not measured. The cages did not affect yield, and caged and uncaged plants not infested yielded at a rate equivalent to 16 tons/acre, presumably because the larger haulms of caged plants compensated for the less light they received. In addition to measuring the direct effects of aphid feeding, this experiment will be used to test a widely held idea that attacks by aphid and blight interact. (Bardner)

The effects of tipulid larvae (leatherjackets) on barley. This experiment well illustrated the difficulties in assessing damage, but also the need of such work.

An experiment in 1963 using known tipulid populations in Proctor barley largely failed because it was sown late and because aphids infested it. Nevertheless, it showed that plants attacked by tipulid larvae had fewer stems able to bear ears than the unattacked plants, because in the short growing season plants had not enough time to recover from attack. In 1964 the experiment was repeated with a mildew-resistant variety, Maris Badger, and insects were put into the plots and pots before sowing. Birds took much of the grain from the plots although it was protected. Leatherjackets attacked the seedlings from the time they emerged until the plants grew too large to be examined in detail without damaging them.

Shoot-numbers between infested and uninfested plots differed most in

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late May, when unattacked plots had an average of 4·30 shoots per plant and the most heavily attacked plots 3·11 shoots. The ripening grain was netted against birds, and yields measured were related to differences in the initial plant stand, and so depended on damage done by birds and leatherjackets before the seedlings emerged; it is hoped that these two factors can be separated. Gaps in the crop caused by local destruction of several plants were important in determining effects of leatherjackets on yield.

Experiments were also made in pots sown with Maris Badger; aphids were excluded with terylene netting and individual plants were measured frequently and the grain from individual ears was weighed. The large tipulid populations had little effect on yield; at the equivalent of 10^6 insects/acre, 10 of 60 seedlings were killed or failed to emerge, and 18 plants were damaged by the leatherjackets during growth: in uninfested pots 2 out of 60 seeds sown failed to emerge. Despite the difference in numbers of plants, the infested pots (though not the individual attacked and unattacked plants) produced nearly as many ears (78) as the uninfested ones (89) because damaged plants and pots with fewer plants compensated by producing extra tillers. Damage that was not lethal or was limited to scattered plants had only transient effects and was not reflected in the final yield.

Damage by wheat-bulb fly, *Leptohylemyia coarctata* (Fall.). Larvae of the wheat-bulb fly periodically cause winter wheat to fail in early spring. Attempts to forecast effects on yield from the number of larvae in the soil or the number of shoots or plants attacked in spring have largely failed, except when the early attack is obviously devastating. Methods of measuring damage and larvae were therefore developed to study the effect of infestation on plant growth up to harvesting (*Rothamsted Report* for 1960, p. 164). Analysis of experiments on the Alternate Wheat and Fallow showed that infestation by larvae first checks plant growth then stimulates tiller production. At harvest 225 undamaged plants had a mean of 1·6 shoots/plant and 49% had one shoot, whereas 194 damaged plants had a mean of 2·7 shoots/plant and 39% had three shoots. The mean number of shoots, in early May, on plants infested before 1 April was 2·8 and 2·6 on plants attacked later.

With no competition between plants the effect of the initial check may persist and the infested plants may produce fewer shoots than the non-infested plants. But with competition the reverse may happen; damaged plants produce more shoots than undamaged ones, and the effect is emphasised as time goes on and the attacked plants, with more shoots, compete with the unattacked plants. At harvest many of these extra shoots on damaged plants were blind and shorter than 15 cm; whereas only 2% of undamaged plants died and 91% bore ears, 15% of damaged ones died and only 65% bore ears. This represents a grain loss of 40% by weight. Comparing the results from different years on the same site shows the importance of weather and time of sowing on the extent to which infestation affects plant growth, and that effects are least in a mild winter and spring. (D. B. Long with M. Morris, Statistics Department)

This work is being continued and extended to another site where there are many wheat-bulb fly eggs (up to 3 millions/acre) but where oviposition

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was prevented on some areas by covering with black polythene between July and October. The growth and yields of infested and uninfested crops, sown at different dates, will be compared and the reactions of plants attacked at different stages of growth will be observed. (Bardner)

Soil fertility and wheat-bulb fly attack. It is too often assumed that the all-important factor in differential crop damage is the general size of pest population, but this is not always justified. Other factors can be critical, such as the way a pest is distributed in a field (discussed above) and the ability of the plants to recover from insect attack, as is shown by wheat-bulb fly on Broadbalk, where some of the plots in their first year after fallow are usually much more damaged than others.

In 1963, when after the very severe winter plants were still in the single-shoot stage in late April, 60–70% of plants on plots 10, 11, 12 and 14 were infested (these plots were ploughed in later), whereas less than 40% were infested on plots 2, 3, 5, 6, 13 and 15. In 1964 infestation generally was greater than in 1963, and at the end of March 69–75% of plants on plots 10, 11 and 12 were infested and from 49–64% on plots 2, 3, 5, 7, 13 and 14. However, the damage was less than in 1963 because the plants were tillering and shoots per plant ranged from 2 on plots 3, 10 and 11 to 2·8 on plot 2. Consequently, although the yields of some plots were well below their long-term average, damage was less severe than in 1963. To test whether the differences in infestation between the plots were because more eggs had been laid in some plots than in others, plots 2, 3, 5, 7, 10, 11, 12, 13 and 14 were intensively sampled for eggs at the beginning of February. Some differences were found, but they did not correspond to, and could not account for, the differences in plant damage found in March. It seems that on infertile plots tillering was delayed and plants were thinned at the single-shoot stage by larvae and were less able to withstand attack than plants with more shoots on more fertile plots where tillering began earlier. Although the infertile plots 10 and 11 had the greatest percentage of infested plants and shoots at the end of March, there were fewer larvae there than on some other more fertile plots, such as plots 2, 3, 5 and 7, that carried more plants and shoots, and so enabled more larvae to survive, but to do less damage.

Present methods of controlling wheat-bulb fly with insecticides are somewhat unsatisfactory, and alternative methods are desirable. One possibility is to develop resistant varieties of wheat. To test for resistance, short rows of 10 wheat species, 10 rye varieties and 15 varieties of bred wheats, provided by F. G. H. Lupton of the Plant Breeding Institute, Cambridge, were sown in Stackyard field. Laboratory tests are also being done. (Raw and Lofty)

Frit fly and its predators. In the autumn and winter frit-fly larvae burrow in shoots and tillers of grasses, pupate and in the spring give adults that lay eggs in shoots and tillers of oats. Larvae from these eggs destroy the oat stems, and pupate to give adults that lay eggs in the ripening oat panicles to produce the larvae that destroy the grain. As little is known about predators of frit fly, an experiment was made to assess their effects

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on the generation that attacks oat tillers. Some plots were left untreated for frit fly and predators to invade unhindered; others were surrounded by straw barriers dipped in DDT, to exclude predators entering over the ground and give the frit flies time to multiply unhindered. Others were not only protected with a similar barrier but also sprayed twice when in the 3–4-leaf stage with parathion emulsion (0·5% a.i.) to kill the frit fly. Frit-fly eggs, larvae and adults were estimated in all plots and then parasites and predators were recorded.

The first observed effect was that fewer eggs were laid on the untreated plots (18/100 plants) than on the plots with a DDT barrier (34/100 plants), and most were on the plots with barrier and Parathion (45/100 plants). However, most plants were attacked on the DDT plots because there were fewer predators than on the untreated plots and on the DDT/parathion plots the larvae were killed by parathion spray. Effects of the differences in attack were very evident; for example, the mean lengths of shoots were 15·5, 18·5 and 33 in. on DDT, untreated and DDT/Parathion plots respectively, and the yellow, attacked stems averaged 32, 27 and 0·4/100 plants. Crops on the plots with parathion flowered and grain ripened soonest; they also produced 10% more panicles, 24% more grains and 31% more weight of grain than the other plots. Adult frit fly emerged in greatest numbers from the DDT plots; fewest emerged from the parathion plots.

Thus, although predators had a small effect compared with parathion spray on the growth of oats, they cannot be neglected as factors influencing yield. The predators seemed to be mainly spiders and empids, especially *Tachydromia*, attacking adult frit fly, and carabid and staphylinid beetles; they are being further studied not only in relation to frit fly but also to total diptera, for many are general predators. (M. Jones)

Wheat-bulb fly predators. An attempt is also being made to assess how predators and parasites of the wheat-bulb fly affect it at stages of its life history. Only a small proportion of eggs laid become adult; for example, on the Kitchen Garden plot, where the initial population per acre was $2{,}558 \times 10^3$ eggs, there were $1{,}486 \times 10^3$ established larvae, of which 390×10^3 became pupae and 285×10^3 emerged as adults. Thus only about one-tenth of the eggs matured, and many deaths occurred between the egg laying and the first-stage larva entering in wheat stems. The most critical period is probably when larvae, especially first instars, are in the soil seeking shoots, but the extent to which eggs are destroyed was not studied (elsewhere 80% of eggs were destroyed, probably by mites, see p. 192). There are many possible predators, notably carabid and staphylinid beetles, and preliminary serological tests of the gut contents of ground beetles show that some species feed on *Leptohylemyia*. (Ryan)

The effects of shelter on insect density and crop infestation. The work on aerial dispersal at Rothamsted over the last 15 years has shown the part played by wind in dispersing flying insects and how wind affects the site of initial infection, explaining such features as "edge effect" in aphid-infested crops (*Rothamsted Report* for 1951, p. 102).

The subject of wind-flow round crops, hitherto approached empirically,

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is now being studied systematically and experimentally, to evaluate the mechanisms of wind and shelter and the behaviour of flying insects in relation to the infestation of crops. Shelter was provided by a wooden lath fence with 45% open area, 3 ft high and 90 ft long and of known aerodynamic properties, on a plot of lettuces 43 × 30 yd. The density of insects in the air to windward and leeward of the fence was measured with suction traps and the crop sampled to find how insects were distributed in it. The shelter produced by the fence extended to 12 times its height to leeward and to its height to windward.

In the air 14½ in. above the ground the density of most species increased to leeward of the fence when winds impinged on it at angles more than 45°. The extent of the increase extended between two and six times the height of the fence, depending on the species and the time of day when the insects flew; the effect was less with night-flying than with day-flying species. The screen had no effect on insect density in the air farther than the height of the fence to windward. The maximum increase recorded (with Syrphidae) was 27 times the density behind the fence as elsewhere.

The distribution of *Pemphigus bursarius* on the lettuce was correlated with the degree of shelter produced by the fence, and with the wind direction while the winged migrants were flying from poplar, where they overwinter. The root aphis eventually killed nearly all the lettuce plants in rows nearer the fence than six times its height, but not in rows farther away. (Lewis)

Soil Fauna

Wireworms. An experiment was started in New Zealand field to study the immediate and residual effects of several organophosphorus compounds being tested as alternatives to chlorinated hydrocarbons for controlling wireworms in wheat. The treatments were *Sprays*: Bayer 38156, Bayer 37289, thionazin (= zinophos) and sumithion, all with 1·5 lb a.i./acre, and aldrin, as a standard, at 6 pints of Aldrex 30/acre. *Seed dressings:* Bayer 38156, Bayer 37289 and BHC (as a standard) at 2½ oz/bushel of a 20% dressing and dieldrin (to compare with the aldrin spray) at 12 oz a.i./bushel; these seed dressings contained fungicide, and the seed drilled on the other plots was dressed with fungicide alone.

Four weeks after the sprays were applied, soil samples were taken from the plots treated with Bayer 38156, thionazin, sumithion, aldrin and dieldrin, and from the control plots. Only the samples from the plots sprayed with aldrin or drilled with the dieldrin-dressed seed contained significantly fewer wireworms than samples from the control plots. The other arthropods collected from the samples were chiefly millipedes, centipedes, thrips, carabid and staphylinid larvae and adults and, most abundantly, fly larvae (chiefly *Mycetophilidae*). None of the treatments seemed to have significantly affected the abundance of these arthropods. (Raw and Lofty, with Griffiths, Insecticides Department)

Pitfall traps were also used to collect the fauna active on the soil surface, which included carabid and staphylinid larvae and adults, some phytophagous beetles and larvae, spiders, millipedes and leatherjackets (*Tipula*

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paludosa). Five collections at 2-day intervals were made at the beginning of May. The catches varied greatly, and no significant effects were detected, except that only one-fifth as many leatherjackets were trapped on plots treated with Bayer 38156, aldrin and the dieldrin seed dressing as on the control plots. (Raw and Lofty)

The food of wireworm larvae in the ground will change from year to year if different crops are grown; the adults fly soon after they emerge, so have the opportunity to seek a particular crop. Whether the diet of larvae or adults affects their development, behaviour or fecundity is unknown. Larvae reared in soil at different temperatures grew faster when feeding on wheat or carrot than when feeding on lucerne or potato; they grew slowest on field beans. Newly emerged adults (*Agriotes obscurus* and *A. sputator*) laid more eggs when fed on grass, wheat or carrot than when fed on lucerne, potato or field beans. Both species laid significantly fewer eggs when feeding on potato than on any other plant food. Egg-laying increased to a peak and then decreased on some diets, but continued at a constant rate on others. (Sriharan)

Effects of insecticides in the soil. The experiment on Highfield for studying 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 continued; the plots kept fallow had fewer of some animals, particularly dipterous larvae and oribatid mites, so that differences between the treated and untreated plots were becoming obscured. An odd feature is that prostigmatid mite populations were increasing in the fallow land. Now, after three years, nearly all the aldrin originally applied has been converted to dieldrin, and the insecticide remaining n the aldrin-treated plots is about 45% of the original dose. DDT-treated plots continued to lose insecticide more slowly than those treated with aldrin. (Edwards with Jeffs, Insecticides Department)

The residues from 6 lb of DDT and 4 lb of aldrin have now, after 3 years, become too small to affect symphylids or thrips, and the increase in numbers of both onychiurid and isotomid Collembola in DDT-treated plots, a consequence of their mite predators being killed, was much less than in the two previous years.

The experiment at Levington Research Station (by courtesy of Messrs. Fisons Fertilizers Ltd.) continued, and after 4 years cumulative effects of repeated small doses of aldrin are showing. Numbers of mites have gradually increased in the soil, so they now resemble those in the untreated plots, and Collembola, dipterous and coleopterous larvae have much decreased; the last group has been almost eradicated. (Edwards and Arnold)

Our measurements on the disappearance of chlorinated hydrocarbons from soil were combined with those from other sources, and regressions were calculated for each insecticide. On average after one year 80% of the amount of DDT originally applied remains, 75% of dieldrin, 55% of lindane, 50% of chlordane, 45% of heptachlor and 25% of aldrin. After 3 years the proportion remaining is about 50% of DDT, 40% of dieldrin, 23% of lindane, 12% of chlordane, 6% of heptachlor and 5% of aldrin. (Edwards)

The side-effects of organophosphorus insecticides were studied. In an

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experiment on New Zealand field Bayer 38156, Bayer 37289, zinophos and sumithion affected soil animals much less than did chlorinated hydrocarbons. Zinophos significantly decreased numbers of isotomid Collembola and sumithion significantly affected the isotomid Collembola, but increased numbers of oribatid and other mites. (Edwards and Raw, with Griffiths of Insecticides Department)

The effects of diazinon (4 lb a.i./acre), parathion (4 lb a.i./acre), disulfoton (2 lb a.i./acre) and the two Bayer chemicals were further studied in Highfield. Disulfoton significantly decreased numbers of mites, isotomid Collembola, millipedes, dipterous larvae and thrips. Parathion affected mites, isotomid Collembola and pauropods only, and diazinon affected isotomid Collembola, millipedes, centipedes and dipterous larvae. Parathion and diazinon had similar effects in other types of soil at Woodbridge, Suffolk, and Ampthill, Beds., sampled by courtesy of the Shell Chemical Co. (Edwards and Arnold)

The effects of herbicides in lessening the numbers of most groups of soil animals (*Rothamsted Report* for 1963, p. 148) lasted for only 4–5 months, after which time, treated and untreated plots had similar populations. Two new field experiments with simazine again showed effects on soil animals, but much smaller than in the first experiment, except with dipterous larvae, whose populations were lessened in the second experiments. (Edwards and Arnold with Dr. J. D. Fryer, Weed Research Organisation)

Soil fauna survey of different habitats. To see how the cropping history and soil type affect the composition of the soil fauna, four common habitats (an oak woodland, conifer woodland, arable field and pasture or ley) were sampled each on five different soils. The animals were extracted from the soil samples and are being identified. (Edwards, Heath and Arnold)

The recolonisation of sterilised soil by arthropods. Nematicides and insecticides in the soil kill many, often all, arthropods there, and little is known about how quickly and by what route treated soil becomes recolonised. Soil was therefore treated in the field with D-D mixture, methyl bromide or metham-sodium, or by heat indoors and then replaced in the field in September. Some plots were surrounded by buried polythene barriers, so allowing them to be invaded only from the air; and those without the barriers could be invaded from the surrounding soil also.

Some species of Collembola rapidly invaded the plots, so that numbers exceeded the populations in unsterilised plots; but their numbers decreased during the winter. In the spring the populations in the sterilised plots did not regain the sizes before treatment nor reached those in unsterilised plots, probably because of changes in the treated soil. However, *Folsomia quadrioculata* and *Isotoma notabilis*, which were slow to return, after 15 months achieved populations of the same order as before the soil was treated. The Collembola that invaded the soil quickly and soon reached large numbers, and achieved lasting large populations, were *Isotoma viridis*, *I. olivaceae*, *Entomobrya multifasciata*, *Sminthurus viridis*, *S. pumilis*, *Bourletiella repanda* and *B. bilineata*. Some Acarina, *Alliphis*

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halleri, *Pergamasus* spp. and *Gaeolaelaps aculeifer* behaved similarly. Polythene barriers buried in the soil to a depth of 12 in. round the sterilised soil delayed the return, even for 15 months, of some Collembola and mites that live deep down. Invasion by the others, therefore, seemed to be through the air, and observations were made to test this.

Water traps, sticky traps and suction traps were set up at different heights up to 4 ft above the experimental plots. The surface-dwelling Collembola especially (and these have well-developed springing organs) were commonly caught by the traps and showed a diurnal periodicity in the air, with a peak of aerial population at about 10.00–11.00 hours GMT. More were caught over grass than over fallow land. During the year the aerial numbers paralleled the terrestrial populations, with two peaks of abundance, one in spring, one in autumn. The species most commonly caught were those that most rapidly recolonised the sterilised plots.

Folsomia quadrioculata, a subterranean species, spread into loose, sterilised soil by moving through soil crevices, and it multiplied in fallow land, whereas the other species did not. Soil sterilised by chemicals was recolonised by all arthropods more slowly than soil sterilised by heat. (Buahin)

The breakdown of litter by soil animals. Breakdown of litter has so far been studied intensely only in restricted localities at Rothamsted; if the process is to be linked with changes in soil fertility it needs extending to other soil types and places. Therefore, four kinds of woodland were chosen at Alice Holt Forestry Research Station in which to study the rates at which leaf material is destroyed and the kinds of arthropods responsible. The woodlands range from oak-dominated forest on a light, acid soil, through young oak on a heavier, more basic soil, to Corsican pine woodlands on both soil types. On the light, acid soil the oak litter accumulates to make a thick, partially decomposed layer, in which earthworms are few. On the heavier soil organic matter does not accumulate and earthworms are more numerous. The coniferous woods show typical lack of diversity and poorness of undergrowth. The disappearance of oak-leaf discs and pine needles from different-meshed nylon bags (*Rothamsted Report* for 1962, p. 154) was assessed, by photometry and weighing. Excluding earthworms from oak discs by nylon bags on the heavier soil under oak showed that the discs then disappeared at a third the usual rate. There was no such effect under oak on the light sandy soil; under conifers in both soils oak discs disappeared about as fast as under oak on the heavier soil when worms were excluded. On all four sites, whether worms were excluded or not, Corsican pine needles lost about 15% of their dry weight in the first 8 months.

Soil and litter samples are being taken every 3 months to measure changes in the fauna and to see whether these are related to litter-breakdown. (Heath and Arnold)

Changes in soil fauna with sod-seeding. An experiment with Paraquat on Pastures field to see how sod-seeding affects soil fauna succeeded only partially, and another was started on New Zealand field. Not only will

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effects on soil fauna of sod-seeding after killing the turf with Paraquat be compared with effects of conventional cultivation, but the lethal effects of the herbicide Ioxinyl on slugs will also be studied. (Heath and Newell)

Biology of Slugs

Damage to potatoes. The extent to which slugs are a primary cause of damage to potato tubers is unknown; indeed, it seems possible that they may rarely, if ever, eat into them unless another pest or mechanical damage has opened a way. As different varieties of potato differ greatly in their susceptibility to damage by slugs, it is important to know whether these differences reflect intrinsic susceptibility to slugs or proneness to other kinds of damage.

Mature, unblemished potato tubers were therefore carefully reared in sieved peat; in pairs, one tuber intact and another with a scratched surface, they were presented to slugs in glass dishes. Each comparison, with a damaged and undamaged tuber, was repeated three times with five varieties of potato and two subterranean species of slug that commonly attack tubers, namely, *Milax budapestensis* and *Arion hortensis*, making a total of 30 tests.

The tests were made (with slugs previously starved for 2–3 days), out of doors, between 2° and 10° C and in the dark. In none of the tests was an undamaged tuber attacked, whereas 21 of the 30 scratched tubers were eaten—Table 3 shows that the times taken for different varieties to be attacked differs.

TABLE 3

Minimum time elapsing before artificially damaged tubers were attacked by two species of slugs during a 12-day trial

	No. of days before slugs attacked damaged tubers	
Variety	*Arion hortensis*	*Milax budapestensis*
King Edward	5 (slight damage)	4
Up to Date	7 (slight damage)	7
Majestic	10 (slight damage)	4
Ulster Chieftain	No damage after 12 days	No damage after 12 days
Viking	No damage after 12 days	No damage after 12 days

How slugs find tubers is unknown, but tests in an olfactometer showed that, in 9 out of 10 trials, *Agriolimax reticulatus* chose crushed King Edward tubers instead of distilled water. Responses of *M. budapestensis* and *A. hortensis* are difficult to interpret because these slugs react to air-movement in the olfactometer. (Stephenson)

These are preliminary experiments; unblemished tubers are difficult to obtain in quantity, and the behaviour experiments require much replication, but the results indicate that the problems warrant fuller investigation.

Irrigation and slug attack. The incidence of slug damage to tubers of the varieties Redskin and Majestic was examined in crops grown with four water régimes and planted at two dates, 30 April and 1 June. A total of 10,784 tubers were examined, and angular transformations of the percentage of tubers damaged by slugs showed that damage was significantly

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greater with complete irrigation or irrigation during the latter half of the growing season than with irrigation during the first half of the growing season or no irrigation at all. In all treatments Redskin was more severely damaged than Majestic ($P = 0{\cdot}01$). Date of planting did not affect the amount of damage to either variety. (Stephenson, with Lapwood, Plant Pathology Department)

Slug parasites and predators. A survey of Rothamsted Farm showed the slug-killing fly *Tetanocera elata* is confined to the uncultivated areas in the southern half of the farm and is particularly common near woods or tall hedges. A sample of *A. reticulatus* collected on an abandoned allotment had 14% infested with 1st or 2nd instar larvae. Adult *T. elata* did not fly after mid-September; soil samples taken to assess the over-wintering pupal stage have yet to be examined

Eggs of *A. reticulatus* parasitised by phorid larvae were collected in Denmark by Dr. L. V. Knutson. The larvae were reared through to pupae, but adults have not yet emerged, so the parasite has yet to be identified. Adults of *Euthycera chaerophylli* collected by Dr. L. V. Knutson in Denmark were maintained in culture and larvae carried through to the 2nd instar in living *A. reticulatus*. In contrast to *T. elata*, these larvae penetrate into the body cavity of the slug, where they move around freely.

Seven species of carabid beetle (*Pheronia nigra*; *Abex parallelopipedus*; *Pheronia vulgaris; Pheronia madida; Harpallus rufipes; Nebria brevicollis* and *Carabus violaceus*) were compared in laboratory tests for their ability to prey on *A. reticulatus* when individual beetles were offered live slugs. *C. violaceus*, the most voracious, ate 5 in 4 days, *P. vulgaris* 5 in 14 days and *A. parallelopipedus* 4 in 10 days. *P. nigra* and *P. madida*, although offered no other food, each ate only 1 slug during 15 days. *H. rufipes* and *N. brevicollis* did not attack the slugs. When 6 starved *P. madida* and 3 *P. vulgaris* were confined with 20 adult *A. reticulatus* in a soil-filled 3ft.-square arena, containing clumps of grass as cover and sliced carrot as food for the slugs, all the slugs were eaten in 24 days. Solitary starved *P. madida* and *H. rufipes* did not eat *A. reticulatus* eggs in 9 days. These results confirm earlier reports that some carabids feed on slugs, but how much they affect field populations is not known. (Stephenson)

Assessing slug populations. Accurate field work with slugs is hampered by the difficulty of measuring the population in a given area. The methods that have been used either attempt to extract all the slugs from soil samples (usually by flotation) or to measure the amount of food eaten from standard-sized leaf discs or numbers of wheat grains. The second method estimates combined activity and numbers in the population. Attempts were made therefore to develop a method that could estimate population and distinguish between changes in numbers and activity.

A. reticulatus were marked by feeding them with Phosphorus-32, when they were released among natural populations, which were sampled periodically and the total population estimated from the proportion of recaptured slugs in the samples. The first experiment, which showed that marked slugs could be detected 1 month after marking, estimated a popula-

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tion of 72,000 per acre $\pm$ 32% with approximately 95% fiducial limits; however, estimates were acceptable only within the first week because too few marked slugs were caught thereafter. In a similar experiment two 8 $\times$ 8yd plots were sampled daily to increase both the numbers of slugs and the numbers of estimates. Results of both experiments are now being analysed.

Time-lapse photography of *A. reticulatus* on the soil surface showed that slugs usually begin to be active after sunset and stop just after sunrise. The periods spent crawling, resting, feeding and mating are being measured to get a full record of behaviour and to study the evidence that some slugs return after being active above ground to the same holes from which they emerged. (Newell)

Slug populations and their control with ioxinyl. Sod-seeding has been reported to increase damage by slugs, so in the experiment on New Zealand field, containing some sod-seeded plots (p. 186), slug populations were assessed by the release–recapture method before plots were treated with herbicide and will be measured periodically afterwards. Some of the plots were given loxinyl, a herbicide that killed slugs in laboratory tests and promises to control slugs in field crops. (Newell, with Henderson, Insecticides Department)

Insect Migration and Dispersal

An experimental approach to migration. Pests are among the most mobile of insects. Nearly all are migrants that characteristically breed in temporary habitats such as crops, and are adapted to migrate to and from them regularly. An understanding of the mechanism of migration is therefore fundamental for understanding pest behaviour. But the subject has been controversial and the causes of migration obscure, partly because many entomologists thought that insects were migrating adaptively only when making mass flights while keeping a linear course, seeming to control the direction of their displacement for long distances. By contrast, dispersal was seen quite differently, as accidental and passive, with insects scattered mainly by wind. However, the two processes merge into each other, and much flight regarded as passive is active and adaptive, and many classical migrants depend on the wind for their direction of travel. It is the prolonged and undistracted flight, rather than the linear course, that makes a migrant.

Important, too, are the causes for mass flights, for these give clues to the causes of migration. Mass flights were hitherto thought of as an assembly of variously aged adults; they are now known to follow mass emergences, and all the migrants start as young insects, the females usually undeveloped sexually. Migration usually ceases when ovaries are ripe. Migration, once largely unpredictable, is now less so; it can be studied experimentally, and physiological and ecological explanations of migration can be sought. To this end, the flight ability of insects is being studied in relation to their age, sexual condition and the factors that affect the maturation of ovaries. (Johnson)

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The flight of frit fly. *Oscinella frit* females were flown, in tethered flight at 25°–28° C, in a headwind of about 5 mph. Flies flew longest when they were 4 days old; thereafter the ability to make long flights diminished, though flies could fly for considerable periods until about 3 weeks old. On average, flies of the panicle generation from the field flew for 42 minutes when about 6 hours old, for 140 minutes when 4 days old and they flew for 44 minutes when 28 days old. Flies about to copulate or oviposit did not fly. Individuals often made several long flights during the first 3 weeks of their lives, and lived another week or two after they became reluctant to fly.

Tethered flight shortened the period before eggs were laid, especially with insects flown on the day they emerged; additional flights every second day did not further shorten this period. The number of eggs laid and the longevity of the flies were not affected by a single flight in early adult life, but insects that flew every second day laid fewer eggs and died sooner than the others. (Rygg)

The diamond-back moth. The peak of flight activity, as indicated by the number of flights/unit time, occurred about 3 days after the moth emerged, usually before they laid eggs, and declined thereafter. Flight hastened egg laying. Ovary development was not influenced by crowding and starving the larvae, nor by breeding them at different temperatures; no association was detected between flight ability and the release of neurosecretory material. (Cockbain and Johnson)

Thysanoptera. Most migrating female thrips caught in traps are sexually immature. Mass flights of thrips occur when migrants have accumulated on plants and the weather is suitable. The most common species caught in S.E. England are grass and cereal thrips, especially *Limothrips* spp. The aerial density of thrips at a source may be very great, up to 60,000/10^6 cu ft of air (enough to irritate the skin and eyes); away from the source, near the ground, densities may be 150–12,000/10^6 cu ft. In these flights immature females predominate, and a larger percentage of immature *L. cerealium* females was caught at a distance from a source (wheat) than immediately above it, suggesting that the immature disperse farther than the mature females, and that the two kinds fly differently. (Lewis)

Long-distance migration of Lepidoptera and synoptic meteorology. In addition to species already studied (*Rothamsted Report* for 1963, p. 158), the arrival of *Nomophila noctuella* Schiff. and the Silver-striped Hawk Moth *Hippotion celerio* L. in Britain in February 1961 and October 1963 respectively was also shown to be related to the wind system operating over the East Atlantic at those times. The arrival-times of all immigrant species for one year, 1963, are now being related to wind to see how general this system of movement is. In 1964 the moth *Eurois acculta* L., which was reported in many parts of England well away from its normal breeding areas in Scotland, may also prove to have been transported from another part of Europe. (French)

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Hitherto, many amateur entomologists have contributed to the recording of immigrant Lepidoptera. Some records have been visual observations, some of light-trap catches, and there is a need to standardise and make more regular observations to supplement the existing system, and to increase the area of recording. A system of light traps will therefore be used for this purpose, and this is being arranged. In addition to Lepidoptera, the traps will catch many other night-flying insects and will supplement the continuous suction-trap pest-census mentioned below. So far nine traps operate constantly throughout the year in five counties, and there will be more by the end of 1965. We have had active co-operation from Field Study Centres, and some schools will take part. The work is voluntary and done by amateur entomologists, many of whom identify the catch; the fear of some naturalists that the traps will deplete the local insect population is unwarranted. (French and Taylor)

Many migrant Lepidoptera, especially the butterflies, were abundant in 1964 after a series of years when there were few. This suggests that once these migrant insects have arrived here, weather, especially during July and August, mainly determines their abundance. *Vanessa cardui* L. (Painted Lady), *V. atalanta* L. (Red Admiral) and *Colias croceus* Fourc. (Clouded Yellow) were all more abundant than during any of the previous 10 years. The regular migrant moths, except *Macroglossa stellatarum* L. (Humming-bird Hawk Moth), were not particularly numerous. *Plusia gamma* L. (Silver Y Moth) and *Nomophila noctuella* Schiff. (Rush Veneer) were probably less numerous than usual. *Leucania unipuncta* Haw. (White-speck Wainscot) was most plentiful since 1928, and *Heliothis peltigera* Schiff. (Bordered Straw) was unusually abundant as a result of an immigration in May, and possibly another in June. The most interesting feature of the year was the unusually large number of *Eurois acculta* L. (Great Brocade) which arrived in the British Isles on 12 August, probably together with *Enargia palaecea* Esp. (Angle-striped Sallow). The possible association between the movement of these last two species and the synoptic meteorology is being studied. (French)

A Continuous Insect Pest Census for Forecasting Insect Attack

C. B. Williams developed empirical methods for forecasting insect abundance (and therefore the likelihood of pest attack) from light-trap catches and the weather. Suction traps developed at Rothamsted enabled this work to be extended to day-flying insects which include many pests. A new type of suction trap has been developed, with its opening at 40 ft, and operated for more than a year. The height is a compromise to obtain an adequate sample of the general aerial population without an excess of the fauna from the adjacent vegetation. A second trap is now operating at Rothamsted, and two more are ready to be installed at Broom's Barn and Dundee. Others will be placed elsewhere, to form the basis of a wide system which, integrated with the light traps for studying long-distance insect migration, are planned to explore over several years, the needs and techniques for forecasting. (French and Taylor)

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Wheat-bulb fly populations are also being studied over some years with the same aim, but in addition to suction-trap sampling a census is made also at each stage in the life history on permanent reference plots on Great Harpenden I and on a wheat plot in part of Stackyard field that was fallowed in 1963. Soil samples taken from the fallow sections of these plots in mid-October showed that there were about 1½ million eggs per acre in the reference plots and about 2 millions per acre in Stackyard field. However, whereas 80% of the eggs from Stackyard contained live larvae, about 80% of those from the reference plots were empty and seemed to have been attacked by predators, possibly mites. There was no evidence of such a loss in 1963, and possible causes are being investigated.

On the reference plots an 18-in. suction trap and cylindrical sticky traps were used for an exploratory study of the composition and movements of the adult population in relation to the weather and to the alternate strips of wheat and fallow. The suction trap was set at crop height in the middle of the centre strip of wheat. Four sets of six sticky traps were spaced regularly over the area. Each set of six consisted of two in the crop (at crop level and 3 ft above the crop) and four on the adjacent fallow (at ground level, 2 ft, 3 ft and 6 ft above the ground). The trap catches were collected daily from late June till early September. The suction trap caught equal numbers of males and females, which agrees with the sex ratio of flies reared from pupae. The numbers caught, particularly of males, diminished towards the end of July. The sticky traps caught four times as many males as females. Forty-six per cent of the flies were caught at crop height in the crop, 20% were caught 2 ft above the fallow and 20% at ground level on the fallow. Only 5% were caught 3 ft above the crop, and only 0·7% were caught 6 ft above the fallow. This does not necessarily mean that more insects occur below crop height than above it, for the volume of air above the crop is far greater than below it, and though insect densities above it are small, insects may be more numerous. The relation between the trap catches and the weather is being analysed. (Raw and Lofty)

Aphid Studies

The multiplication of aphids on virus-infected plants. Several reports suggest that phytophagous sucking insects, such as aphids and leafhoppers, accept virus-infected plants more readily and develop faster and reproduce more on them than on uninfected plants. Preliminary tests were, therefore, made for such possible effects with *Aphis fabae* and *Acyrthosiphon pisum* on broad beans and field beans infected with pea mosaic virus (PMV), pea enation mosaic virus (PEMV) or pea leaf-roll virus (PLRV).

Natural infestations were observed on randomly arranged, replicated plots of virus-infected and virus-free field beans (var. Herz Freya), sown on 17 April and infected with PMV on 23 May, or with PEMV or PLRV on 8 and 12 June respectively. The primary migration of *A. fabae* was small, and by the second week in July only 26% of the infected and 28% of the uninfected plants were infested. For *A. pisum* comparable figures were 59% and 58%. Thus there was no evidence that more aphids alighted on infected than uninfected plants; but on average more *A. fabae* were produced

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on infected plants, especially those with PEMV, than on uninfected plants. By contrast, colonies persisted longer on uninfected plants. *A. pisum* colonies rarely exceeded 20 individuals on either infected or uninfected plants.

The growth of aphid colonies on infected and uninfected broad beans (var. Sutton Dwarf) were also compared in the glasshouse. Eighteen days after the plants were uniformly infested with 1st instar nymphs, plants infected with any one of the viruses carried between 1·1 and 1·5 times as many *A. fabae* as uninfested plants, but the differences were not statistically significant.

The problem of assessing the effects suggested by these preliminary experiments are great: many more points along the population curve need to be measured; the effects of predators, the large variation in growth rates between individual colonies on apparently similar plants, errors in estimating aphid numbers and variation in the amount of initial infestation will all need to be very carefully assessed, but there seems to be an effect worth investigating. (Cockbain, with Gibbs, Plant Pathology Department)

***Myzus persicae* as a vector of sugar beet yellowing viruses.** Tests with winged *Myzus persicae* raised on virus-infected beet suggests at least a partial explanation for the fact that mild yellows virus (BMYV) is now usually more prevalent than yellows virus (BYV) and spreads faster in field crops. Whereas fewer than a third of such aphids raised on plants infected with BYV were infective, more than three-quarters were infective when raised on plants with BMYV. Also, whereas most of the aphids carrying BYV lost their ability to transit during the 3–4 days when they could fly, the ability of those carrying BMYV was unimpaired. (Cockbain, with Heathcote, Broom's Barn Experimental Station)

Aphid feeding. *Aphis fabae* was more fecund on one variety of tic bean (*Vicia faba*) than on another, though equal amounts of sap were ingested during the lifetime of the aphid from both varieties. This suggested that fecundity depended on the quantity and quality of nutrients in the sap rather than on the quantity ingested, so further measurements were made to estimate the total nutrients ingested and assimilated from the two bean varieties by aphids at all stages of their lives. Results are in the abstract of publications of paper 10.22. (Banks and Macaulay)

Hibernation of Coccinellidae

Many Coccinellidae (ladybirds) that prey on aphids hibernate; how many survive and are able to fly to aphid colonies in the spring will be affected by how they accumulate food and use it during hibernation. Changes in food reserves are being studied with *Coccinella 7-punctata*, *Adalia bipunctata* and *Propelaea 14-punctata*. Water, fat and glycogen in the body increase rapidly during the last (4th) larval instar, and about 85% of the glycogen and 70% of the fat so accumulated was used during the pupal stage; less of the water was used, so the adult emerged with relatively more water than the early pupa. The diet of aphids affected the accumulation of reserves and water. Newly emerged *Coccinella 7-punctata* and *Adalia bipunctata* were heavier from larvae reared on *Acyrthosiphon pisum* than on

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Aphis fabae, and had more water, fat and glycogen; also *A. bipunctata* from pupae collected in the field from stinging nettles infested with *Microlophium evansi* were heavier and had more reserves than those collected from broad beans infested with *Aphis fabae*.

Some adults accumulate food, and their content of fat and glycogen is greatest just before they hibernate; these insects are the ones most likely to survive until spring. Those that contain more water and little dry matter die during hibernation. Adults that emerge from pupae late in the season have little chance to accumulate reserves, so the proportion of adults that survive hibernation depends on when the population is greatest during summer.

Adults that survive during hibernation begin the winter containing about 40% of fat and 1% of glycogen and 50–55% of water. The food reserves are consumed fastest early, during September to October; by late April and early May, before they feed in the spring, *A. bipunctata* had used about 80–90% of the glycogen and 70–85% of the fat, and their water content had increased to about 65%. The other two species used rather less fat, but otherwise behaved similarly.

All three species hibernated with inactive gonads, with the ovaries undeveloped, but with mature testes. Oogenesis in *A. bipunctata* began in late April, before feeding, and ovaries became mature after feeding began; ovaries of the other two species began to mature after feeding started. Mating occurred after feeding, on warm, sunny days.

In the laboratory *A. bipunctata* laid more eggs when fed on *A. pisum* than when fed on *A. fabae*. The amount of food adults contained when they emerged from pupae did not affect the number of eggs they laid. (El Hariri)

Aggregation in the Heteroptera

Many Heteroptera aggregate at some stage during life and disperse at others. When they aggregate they can often be damaging to crops locally. The mechanism of this alternate clustering and dispersing is a feature to be studied, for it might be able to be used against pests. We are studying it with *Dysdercus intermedius*, which is a convenient insect and also resembles cocoa capsids (serious pests in West Africa) in its aggregation behaviour. It is also a serious pest of cotton.

The responses of the insect to various factors suspected to be associated with aggregation are being studied. Soon after hatching, the young larvae and also later instars form dense clusters that break up periodically and reform. These opposing responses are determined to some extent by the roughness of the surface and by the atmospheric humidity. Thus, when 3rd, 4th and 5th instar nymphs were put in a gradient of different-sized sand particles (0·5–5·0 mm), or were offered a choice of coarse and fine particles in a "choice-chamber", they settled always among the coarsest particles, and without these settled against each other. They collected at the driest end of a humidity gradient. When offered dry and wet surfaces they always collected on the dry surface, though they often drank from free water. When the substrate became damp, clusters of insects broke up. Whether clustering affects feeding, development, maturation of gonads (and hence flight), fecundity and mortality is being studied. (Youdeowei)

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