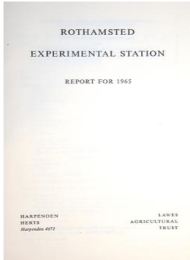
Rothamsted Experimental Station Report for 1965



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Entomology

C. G. Johnson

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ENTOMOLOGY DEPARTMENT

C. G. JOHNSON

L. R. Taylor returned after twelve months as visiting professor at Kansas University, G. W. Heath left to join the Headquarters Staff of the National Environmental Research Council and Mrs. Marjory Morris and K. E. Fletcher joined the department, Fletcher with a Royal Society Grant in connection with the International Biological Programme. Visiting workers included Mr. C. L. Costa of the Agronomic Institute of Campinas, Brazil, Mr. W. E. Taylor of Njala University College, Sierra Leone, Mr. M. J. P. Shaw of Kutsaga Research Station, Rhodesia, Mr. A. R. Thompson of "Shell" Research Ltd., Woodstock, and Mr. D. G. Gibbs and Mr. D. Leston of the Confectionary Alliance Cocoa Capsid Research Unit.

C. J. Banks attended a symposium on the Ecology of Aphidophagous Insects, in Prague. R. Bardner was awarded a W. G. Kellogg Foundation Agricultural Scholarship and spent four months in the U.S.A.

Mr. G. K. A. Buahin, Mr. G. El Hariri and Mr. P. F. Newell were awarded the Ph.D. degree of London University.

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

Aphid damage to potatoes. Experiments described in last year's Report (p. 179) were repeated. *Aphis rhamni* Koch was introduced at different times in the season into cages covering Majestic potato plants in the field; aphids introduced on 25 May lessened the final yield by 34%, but aphids introduced on 2 June or later had little effect on yield, probably because the weather did not favour aphid reproduction.

As in 1964, severe aphid damage made tubers smaller but not fewer. Loss of yield may have been caused partly by aphids prematurely killing the haulm; but interim sampling on 22 June and 29 July showed that the plants infested with aphids since 25 May then had less than half the tuber weight of uninfested plants, although the maximum aphid population was in late July. Thus, aphids affected the rate at which tubers bulked. As in 1964, yield at harvest was inversely proportional to the product of the intensity and duration of aphid attack.

A defect of this type of experiment is the atypical growth of plants in cages. A larger field experiment without cages, planned for next season, will use the experience gained in handling aphids and in estimating their effects on the crop. The relationship between the development of aphid colonies, the growth of the haulm and the bulking of the tubers will then be studied more closely.

Work on the possible relationship between aphid attack and blight infection was continued in collaboration with J. M. Hirst (Plant Pathology Department), but natural aphid populations were again small, and the

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slight increase in yield after insecticide spraying was not statistically significant.

Winter wheat and wheat-bulb fly. Wheat-bulb fly (*Leptohylemyia coarctata* Fall.) is the most serious insect pest of winter wheat in Britain. Strickland recently estimated the average potential loss of the wheat crop in England and Wales at £1·39 million annually. Even after using insecticides, the average annual loss is still £0·44 million, and losses may be double this in some years. The seriousness of the attack can sometimes be forecast by estimating the number of eggs in the autumn, but damage also depends on the stage of growth the crop has reached when eggs hatch in the late winter, and on the amount of compensatory growth during and after the attack.

An experiment was started to study the effect of wheat-bulb fly attack on the crop as a whole, rather than on individual plants. The site chosen had 1 million eggs/acre in the autumn, and serious crop losses were likely. Egg-laying had been almost prevented on half the plots by covering them with plastic sheets in the late summer. Cappelle wheat was sown at 3 bu/acre in late October, late November and late December. Eggs hatched between mid-February and mid-March. The plots sown in late October had a plant population of about $1\frac{3}{4}$ million/acre and a maximum larval population of 570,000. Those sown in late December had a plant population of only 800,000/acre in March and fewer than half the larvae than on plots sown in late October, for the survival of larvae was related to plant and shoot density. The late October-sown plants had tillered before the attack started (so halving the risk of a shoot being attacked); plants with two or more shoots survived the loss of one shoot, and wheat-bulb fly had little effect. Plants from the late sowings had not tillered when the attack began, attacked plants died and the plant population was halved; wheat-bulb fly larvae move from shoot to shoot, and by mid-April all surviving plants of all sowings possessed more than one shoot and only a few of the surviving plants were killed.

As with most pests, attacked plants were not distributed evenly throughout the crop, but were in patches, so that their deaths caused gaps in the rows and bare patches in the crop. The extent of the gaps was measured after harvest by examining the rows of stubble. Gaps of 2–6 in. long occupied from 22 to 32% of row length in all plots. On plots protected from wheat-bulb fly gaps over 6 in. occupied 6–7% of row length, whereas on unprotected plots those sown in late October had 10%, those sown in late November 29% and those in late December 31%.

All plants surviving at the end of the period of attack except on plots sown in late December had more shoots than produced ear-bearing shoots at harvest. In May the crop on the late-sown unprotected plots seemed a complete failure, but it partially compensated for the damage by producing more ears per plant and more grain per ear than in other plots. Unprotected plots yielded less than protected ones, but unexpectedly from the earlier appearance of the plots, the differences were not statistically significant. There were large differences between similarly treated plots, probably caused partly by different wheat-bulb fly populations in the plots. This

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awaits further analysis. However, the crop lodged, and harvesting conditions were bad so that much grain was shed.

Probably losses from wheat-bulb fly are caused mainly by complete destruction of patches of plants, rather than by lessening the yield of attacked plants that survive. Further experiments will be needed to clarify this, but they demonstrate the increasing need to study the factors that cause insect pests to aggregate. (Bardner)

Effects of leaf-feeding insects. It is difficult to estimate the damage done by insects in terms of plant growth. Perhaps the simplest type of damage is caused by leaf-feeding insects whose primary effect is to damage or destroy some photosynthetic tissue. The area affected can be measured by simple, though tedious, methods, and the replacement of damaged tissue and the partitioning of dry matter produced by photosynthesis between various organs of the plant can be studied. Such damage can also be partially simulated by artificial defoliation. Over the past three seasons such experiments have been done with radishes (*Rhaphanus sativa*) attacked by flea-beetles (*Phyllotreta* spp.). Radishes are good subjects for this purpose because they have a large storage organ and mature quickly. Wild populations of flea-beetles vary from year to year, and have been scarce for the last two years. Repeatable defoliation experiments have proved difficult in the glasshouse, but are being continued in controlled-environment growth-chambers. (Bardner)

Other work on leaf-feeding insects deals with the relation between the responses of plants to injury and the amount of food consumed. Two insects easy to rear and handle are being used, namely the Diamond Back Moth (*Plutella maculipennis* Curtis) and the Mustard Beetle (*Phaedon cochleariae* F.); the hosts are radish (French Breakfast) and turnips. The light and temperature most suitable for growing the plants indoors and plant-growth patterns are being studied. Food requirements of larvae, the effects of diet on fecundity, host preferences of the insects and the relation of all these to the growth of plants in controlled environments will then be analysed. (W. E. Taylor)

The interaction of wireworms and *Cephalosporium* on the growth and yield of wheat is reported by D. B. Slope (Plant Pathology Department) (p. 126).

Effect of bean leaf-roll virus on yield of lucerne. Because of the apparently great incidence of bean leaf-roll virus in some lucerne crops, glasshouse experiments were done to assess the effects of infection on yield of four varieties. Plants were infected by feeding infective aphids on them. Subsequent tests showed that though more than 80% of the plants were infected, less than 2% developed the vein-yellowing symptoms regarded as typical of infection with BLRV (see p. 191).

Infected plants yielded less than uninfected plants. The differences in yield (1st cut) of du Puits, Provence, Chartainvilliers and Rhizoma lucerne were 17, 22,* 5 and 38%* (dry weight) respectively (* $P<0{\cdot}02$); corresponding differences for the 2nd cut were 16, 24,* 20 and 12%. (Cockbain, with Gibbs, Plant Pathology Department)

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Effects of aphid infestation and virus infection on yields of field beans var. Herz Freya. Beans were sown out of doors on 17 April 1964, and all plants on replicated plots were artificially infected with pea mosaic virus (PMV) on 23 May, with pea enation mosaic virus (PEMV) on 8 June or with bean leaf-roll virus (BLRV) on 12 June. The main purpose of the experiment was to study effects of virus infection on the growth of aphid colonies (see p. 190 and *Rothamsted Report* for 1964, p. 192), but it also gave information on loss of yield. The plants that became naturally infested with *A. fabae* yielded less than naturally uninfested plants, and virus-infected plants yielded less than uninfected plants (Table 1). The primary migration of *A. fabae* was small, and most plants had finished flowering before they became infested. Those plants (4%) infested before or during flowering yielded 95% less weight of beans than uninfested plants, and many of the infested plants died without producing pods.

TABLE 1

Yield (g) of beans per plant

(Values in brackets are numbers of plants sampled)

	Uninfected plants	Plants infected with PMV	PEMV	BLRV	Mean
Uninfested plants	24·1	13·9	13·3	14·6	16·5 (207)
A. fabae-infested plants	17·2	11·8	6·7	11·9	11·9 (242)
Mean	20·2 (120)	13·1 (121)	9·4 (110)	13·3 (98)	

The experiment was repeated in 1965, and yields were taken of infected and uninfected plants (all plots were equally infested with *A. fabae*). PMV-infected plants yielded 55% less weight of beans than uninfected plants, PEMV-infected plants 70% less and BLRV-infected plants 93% less. The yield of uninfected plants was 74% less than last year, when only 56% of plants (same variety) became infested with *A. fabae*, and most of these only after flowering and seed-set. Unlike 1964, the effect of viruses alone or of *A. fabae* alone could not be measured, for all plants were aphid-infested. (Cockbain, with Gibbs, Plant Pathology Department)

Comparison of methods to assess loss of yield of oats by frit fly. Frit fly on oats are being used to study methods of assessing the effects of attack by cereal stem-borers. Of the methods tested in 1964, namely, plants in pots, caged plants in the crop and comparing yields from naturally attacked and unattacked plants in a crop, the last was the most promising, and was further tested on two plots of about $\frac{1}{11}$ acre each to assess the effects of attack on tiller and main shoot. The effects of the panicle generation of flies attacking the grain was assessed with groups of plants in the crop artificially infested under cages. The percentage germination of the grain was measured by the official seed-testing station for England and Wales, Cambridge, and Messrs. Heygate & Sons, Ltd., Bugbrooke, Northampton, assessed the commercial value of the grain.

Yields of sets of plants with uninjured shoots were compared with those of plants attacked in tillers only, and with others attacked in tillers and main shoots. Plants were labelled when very young by encircling them with

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plastic-covered and galvanised wire rings of three different thicknesses to indicate the three categories. Labelled plants were selected in two ways: (*a*) after the first sign of shoot attack on the crop; (*b*) 1,000 plants in the two-leaf stage were ringed with green rings and later with the other rings to show whether attacked in main stems and tillers or in tillers only. The second method is probably the better, and results given are those obtained with it. How much the surviving plants compensated for gaps caused by these killed has yet to be properly assessed.

Of all the plants 48% were attacked in tillers only and yielded 13% less weight/1,000 grains than those not attacked; the 35% with both main stem and tiller attacked yielded 19% less weight/1,000 grains. The commercial value of the grain as livestock food was unaffected by the frit fly, but not even the grain from plants unattacked in the shoot was of value as seed or for milling.

Shoot attack and the germination of seed were not correlated. As in 1964, plants with uninjured shoots were more attacked in the grain by panicle generation flies than plants with injured shoots. This is an important factor when assessing the effects of panicle attack. The yield losses given above include those from panicle attack, but its extent is not yet assessed.

A separate experiment on the effects of panicle attack only, done with artificially infested groups of plants caged in the crop, showed that, even with 65% of grains injured, loss of weight of 1,000 grains was only 9%, and its value as livestock food was unaffected; germination, however, was only 60% of unattacked grain. (Judenko)

The Aggregation of Pests

Pests that congregate and attack patches of plants often cause much more loss than the same infestation spread more evenly through the crop, because damage to individual plants can often be compensated for by extra growth of the surviving plants. The factors that cause insects to accumulate in some places rather than in others are still little understood, but an important one is the effect of shelter in depositing insects in dense clusters; another is the behaviour of insects themselves.

The effect of shelter on insect density. Wooden-lath fences with 45% open space used in 1964 had shelter-effects extending to one fence-height to windward and 12 to leeward. Insect population in the air to leeward was greatest between 2 and 6 times fence-height, depending on the kind of insect, and day-flying species are concentrated more than night-flying ones (*Rothamsted Report* for 1964, p. 183). The profiles of aerial density of insects normal to the fence closely resembled those of inert particles.

In 1965 fences with 0%, 25% and 70% open area were compared, and preliminary analysis of the results suggests that near the fences the aerial density of many insect taxa, including aphids and many families of Diptera and Hymenoptera, is influenced by the permeability of the fences; the more open the fence, the farther to leeward are insects most dense in the air above the ground.

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The fences also affected the distribution of insects on crops and of plants infected with aphid-borne viruses. Turnip mild yellows virus was more prevalent in turnips between 2 and 6 H (i.e. 2–6 times the height of the fence) to leeward of a 45% fence than elsewhere, and more lettuce plants became infected with lettuce mosaic virus to leeward of both a 45% open space and a solid fence than elsewhere, but especially to leeward of the solid fence. (Lewis and Stephenson)

Aggregation by the Heteroptera. The behavioural mechanisms that cause some Heteroptera to form dense clusters on plants or on soil were studied in the laboratory with the Cotton Stainer *Dysdercus intermedius* Dist. (Heteroptera : Pyrrhocoridae), that aggregates while feeding and resting; groups of insects of all stages struggle to feed on the same seed when offered many seeds. In aggregation, dorsal, ventral or lateral physical contact is always maintained between the individual insects. All stages aggregate, but especially larvae 1 or 2 days before moulting. Adults cluster most when they are 1 day old and much less on the 2nd and 3rd days, but tend to cluster again on the 4th day when mating begins.

The factors that cause insects to aggregate while feeding and resting are being studied separately. At least two responses cause aggregation during feeding; insects find cotton seeds, on which they feed, by smell, and the olfactory receptors are borne on the terminal segments of the antennae and not on the tarsi; but they aggregate on one or a few seeds mainly because they see each other. *Dysdercus intermedius* reacts, by tarsal contact, to free water in the substrate and to atmospheric humidity when the substrate is dry. Thus, in a gradient of atmospheric humidity of 10–95% over a dry substrate, 1st and 2nd instar larvae aggregated at the moist end, but later instars and adults aggregated at the dry end. There seems to be a transitional stage in the 2nd instar larvae, which go to both ends. When free water rises through a substrate (such as sand) aggregations begin to break up when the water-level is 5–10 mm below sand-surface, and contact between the insects is lost when the surface of the sand becomes wet. Given a choice of coarse or fine sand particles, the coarse particles are chosen when dry but avoided when wet. The insects aggregate closely in cold and begin to scatter when the temperature rises above 30° C.

Starving, blinding, blocking or removing the olfactory receptors significantly lessens the degree to which 3rd, 4th and 5th instars aggregate while resting, and olfactometer experiments suggest that the larvae are attracted to each other by scent; the role of the substance produced by the dorsal abdominal scent glands is being studied. (Youdeowei)

Insect Migration and Dispersal

Long-distance aphid migration. All problems of insect migration involve two elements, the flight behaviour of the insect and the weather. Current ideas about aphid migration generally have been largely formed from the behaviour of aphids and especially *Aphis fabae*, in the British Maritime climate, where we think of daily movements of up to about 100 miles, by flights lasting up to about 4 hours. Reported long-distance migrations

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of aphids in the Central States of the U.S.A. for distances of 800–1,000 miles require a quite different association between behaviour and weather; the aphids must fly for a far longer time, and the pattern of wind movement must be much more consistent over a greater area than in Britain.

An opportunity was taken to study continental migration of aphids by work on flight behaviour in the laboratory and with field experiments in the U.S.A. Aphids migrating at high altitudes were also sampled by aeroplane traps during both day and night. Measurements of aerial density at low altitudes were obtained with suction and other traps sited from Winnipeg in Canada through the States of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Texas and into Mexico; that is, in a line over a distance of 2,000 miles. This study was initiated during the tenure of a National Science Foundation Fellowship at Kansas State University, Manhattan, and will continue for some years in conjunction with similar work in Britain. (L. R. Taylor)

Light-trap survey for immigrant insects. Over the last thirty years many amateur entomologists have regularly recorded immigrant Lepidoptera, but their records have tended to be opportunistic and not standardised. Since the appearance of immigrants was associated with the synoptic weather systems over the Atlantic, Baltic and North Sea (*Rothamsted Report* for 1964, p. 190–1), it has become desirable to supplement these records with quantitative sampling, so a system of standard Rothamsted-pattern light traps is being organised to operate continuously.

Long-distance migration of Lepidoptera and synoptic meteorology. In the British Isles the moth *Eurois occulta* L. (The Great Brocade) breeds only in Scotland, but it is occasionally recorded in other parts, where it seems to be an immigrant. Records from England from 1955 to 1964 were studied in relation to the synoptic weather at the time the moths appeared; and a back-track of the wind on each occasion led to Scandinavia. Very probably some of the moths caught in Scotland also come from Scandinavia.

Other species were treated similarly; for example, *Plusia acuta* Walker, a rare moth in Great Britain, with a North African distribution, was successfully back-tracked to North Africa by analysis of the wind charts. *Phytometra biloba* Stephens, a North American moth, was shown to be wind-assisted in its journey across the Atlantic on the two occasions, in 1954 and 1958, when it was caught in the British Isles.

All records for migrants in 1963 were examined in relation to the current meteorological situations and, though there were few immigrants, their arrival was correlated with the wind direction on several occasions. In 1963, when conditions rarely favoured wind-assisted flights from North Africa (the principal source of some migrants), immigrants were also few.

Some of the recent past records of *Hippotion celerio* L. (Silver-striped Hawk Moth), *Daphnis nerii* L. (Oleander Hawk Moth) and *Celerio galii* Rott. (Bedstraw Hawk Moth) were examined and, although on most occasions wind tracks can be produced leading back to known possible sources in Europe or North Africa, on one occasion, June 1961, meteoro-

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logical evidence suggested that many *C. galii* had crossed the North Atlantic. (French)

Suction Trap Survey for Predicting Pest Outbreaks

We now have six suction traps sampling air from 40 ft above the ground, situated as follows: 2 at Rothamsted, 1 at Broom's Barn Experimental Station, Bury St. Edmunds, Suffolk, 1 at National Agricultural Advisory Service Experimental Husbandry Farm, High Mowthorpe, Malton, Yorks., 1 at Cockle Park Experimental Station, Morpeth, Northumberland, and 1 at Scottish Horticultural Research Institute, Dundee, Angus. It is hoped to establish another trap in south-west England in 1966.

All these traps are operated by the staff of the station where they are located, and daily catches are sent to Rothamsted for analysis. The sorting and counting of the insects caught, particularly from June to September, is arduous, and A. J. Arnold (Insecticides Department) is attempting to make an instrument to do it automatically. The trapping system is practical, for a trap has now run continuously at Rothamsted for 2½ years with little maintenance, and the successful running of the traps at the other localities has also been demonstrated. It is hoped in 1966 to send a monthly summary of catches of particular interest to the trap operators and other interested persons. (French)

Insect diversity and pest status. Studies, with light and suction traps, of the abundance and movement of insects in relation to synoptic meteorology links with another study, namely the changes in diversity of insect populations in different places at different times.

Only very few of the enormous numbers of insect species become pests. There are many reasons for this; some pests reflect such agricultural practices as monoculture and the use of pesticides, which tend to eliminate many species and so diminish diversity, but may encourage the multiplication of a few species.

The diversity of mixed populations—the numbers of species relative to numbers of individuals—can be measured by an index devised at Rothamsted by R. A. Fisher and C. B. Williams, but this was never used systematically to relate pest incidence to agricultural practice or to land-use generally, partly because of the difficulty in sampling diverse situations and identifying large numbers of insects. The difficulty has now been overcome, and with the help of amateur entomologists, schools and other research organisations, we are studying the changing diversity of insect populations in different places with different kinds of land-use all over the British Isles. To begin with, night-flying moths are the experimental group, partly because some are pests, partly because they are easily sampled and identified by amateurs, partly because their diversity is easily measured. (L. R. Taylor)

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Soil Fauna

Effects of insecticides on soil fauna. The experiment on Highfield to study 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 continued. After three years' continuous fallow numbers of dipterous and coleopterous larvae, oribatid mites and some Collembola had diminished greatly, so the plots were resown with grass, to encourage the return of these animals; the insecticides continued to kill the same groups of animals as when first applied.

In previous years numbers of Collembola increased greatly in DDT-treated plots, probably because parasitic mites that attack them are killed by DDT. The species of Collembola from the experiment have now been identified. Twenty-three species were found in the untreated plots, where *Tullbergia krausbaueri* and *Lepidocyrtus cyaneus* were most common. The aldrin-treated plots contained only 14 species, all fewer than in the untreated plots. There were 27 species in the DDT-treated plots, and *Onychiurus edinensis*, *Tullbergia denisi*, *Tullbergia krausbaueri*, *Isotoma notabilis*, *Isotoma viridis*, *Isotomodes productus*, *Lepidocyrtus cyaneus*, *Pseudosinella alba*, *Hypogastrura denticulata* and *Isotemiella minor* were all much more numerous than any species in the untreated plots. *Heteromorus nitidus*, not found in all untreated plots, was quite numerous in the DDT-treated soil. How this species and others undetected in the untreated soil reached the DDT-treated plots is unknown.

Parasitic mites in the DDT-treated plots have gradually become fewer in successive years, in spite of regular seasonal increases and decreases, and in the summer of 1965 none was found. Collembola in the DDT-treated plots were then four or five times as abundant as in previous seasons. Parasitic mites also became fewer in the untreated plots, presumably because of the continued fallow, where numbers of Collembola also increased.

Studies with heptachlor confirmed that it killed not only earthworms but also enchytraeid worms. Doses of 4 and 8 lb a.i./acre halved the numbers of trombidiform, parasitic and oribatid mites after one year. Isotomid Collembola were particularly susceptible, and plots treated with 8 lb a.i./acre contained only 6% as many as in untreated plots. (Edwards and Arnold)

Organophosphorus insecticides are now being widely tested as alternatives to the chlorinated hydrocarbons, and their effects on soil animals were further studied. Bayer 38156, Bayer 37289, "Zinophos" and "Sumithion" all at 1·5 lb a.i./acre were applied on New Zealand field in 1964, but none had any effect lasting into the second year after application, when numbers of animals in treated and untreated plots did not differ significantly. Some of the plots not treated in 1964 were subdivided and treated with "Sumithion" and "Zinophos", again at 1·5 lb a.i./acre and with Stauffer N 2790. "Sumithion" and "Zinophos" affected coleopterous and dipterous larvae more than in 1964, but Collembola less. The only animals affected by Stauffer N 2790 were parasitic mites. (Edwards and Raw with Griffiths, Insecticides Department)

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The soil fauna in 1965 was also unaffected on other plots treated in 1964 with diazinon (4 lb a.i./acre), parathion (4 lb a.i./acre), disulfoton (2 lb a.i./acre), Bayer 38156 and Bayer 37289.

A further six experiments with organophosphorus insecticides chlorfenvinphos (Shell 7859, "Birlane"), thionazin ("Nemafos", "Zinophos"), carbaryl ("Sevin"), trichlorphon ("Dipterex"), phorate ("Thimet"), parathion and diazinon were regularly sampled in 1965. The results with thionazin, carbaryl, trichlorphon and phorate are not yet complete; parathion and diazinon behaved as in 1964, but parathion at 4 lb a.i. of emulsifiable concentrate per acre halved the numbers of earthworms.

Chlorfenvinphos ("Birlane") seems to be a promising substitute for the chlorinated hydrocarbons in controlling soil-borne pests, so its effects on soil animals were studied in some detail. It does not persist long in soil, but preliminary results suggest that it is particularly toxic to dipterous larvae in soil, less so to coleopterous larvae. It also lessens numbers of Collembola and parasitic mites, but oribatid mites are much less affected. The effects occurred equally where the insecticide was applied as granules or an emulsifiable concentrate, but the granules persisted longer. (Edwards, Arnold and Thompson)

The possibility that chlorinated hydrocarbon insecticides are leached from agricultural land into nearby water is being studied, by applying large amounts of dieldrin to land close to suitable ponds. Soil samples are taken along transects across the land and into the floor of the ponds, and the fauna and chemical residues are being assessed. (Edwards and Thompson)

The animals in different types of soil. Little is known of the number of species or populations of soil animals in various types of agricultural land and woodlands on different soil types, so a survey is being made. Four common habitats (oak woodland, conifer woodland, arable field and pasture,) each on five different soil types, were sampled with 2 in. × 6 in. cores in autumn 1964 and spring 1965; earthworms were sampled by the formalin method. To date, only the Collembola have been identified and, in all the sites together, 53 species were found of which only 30 species were numerous and 15 species very common. Numbers of species and numbers of individuals differ with both soil type and surface vegetation, and the greatest differences are probably between woodland and arable sites. Neither very peaty nor very sandy soils had large populations of Collembola. (Edwards, Heath and Arnold)

Extraction methods for soil animals. There are several methods of extracting animals from soil that differ in type and efficiency, so results of different workers, especially about animals from different soil types, are often not comparable. A start was made to standardise methods of extraction for the International Biological Programme. The patterns of emergence of arthropods from Tullgren funnels under different régimes of temperature and humidity show that, with a gradient of about 10° C through the soil sample, extraction is fastest in 30–36 hours and ceases after about 3 days. Collembola and soft-bodied animals such as Symphyla, Pauropoda and

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dipterous larvae tend to emerge before those with more sclerotised exoskeletons. Other extraction methods will be compared and, it is hoped, standardised. (Edwards and Fletcher)

Wireworms. An experiment on New Zealand field was started in spring 1964 to test the efficiency of various insecticides against wireworms (*Rothamsted Report* for 1964, p. 183). The residual effects of the insecticides then applied have now been studied. Some of the previously untreated plots were also used for a supplementary experiment to test the effectiveness of thionazin (="Zinophos") and fenitrithion (="Sumithion"), applied to the seedbed as sprays, and N 2790 (*O*-ethyl *S*-phenylethyl phosphonodithoate), applied to the seedbed as granules at 1·5 lb a.i/acre. In 1965 all plots in the main and supplementary experiment were drilled with spring wheat dressed with a fungicide only. Yields on treated and untreated plots did not differ significantly, and the experiment was ended because the wireworm population of the untreated plots was too small for further tests.

Soil samples taken in May 1965 confirmed that the plots sprayed with aldrin or drilled with dieldrin-dressed seed in 1964 had significantly fewer wireworms than the control plots. None of the treatments in the supplementary experiment significantly affected the wireworm population, but N 2790 seemed to kill some predaceous mites and N 2790 and thionazin isotomid Collembola. Fauna active on the soil surface of the plots in the main experiment were sampled with pitfall traps; the only effect attributable to the chemical treatments was that fewer insects, except Carabidae, were trapped on plots treated with aldrin. However, the trap catches in 1965 differed greatly from those in 1964; whereas in 1964 phytophagous insects predominated, in 1965 carnivorous insects predominated and tipulid larvae, which were particularly abundant in 1964, were not trapped in 1965. These changes doubtless reflect the change from grass to arable cropping after New Zealand field was ploughed in autumn 1963. (Raw and Lofty, with Griffiths, Insecticides Department)

Slugs. The feeding behaviour of *Agriolimax reticulatus* was studied using time-lapse ciné filming, which showed that the slugs usually feed on several occasions each night while above ground and often on different foods. Thus, methods that estimate populations by measuring damage may only be measuring numbers of occasions slugs feed; whereas methods using the amount of food removed (as with loss of leaf area) may, when food is scarce, be measuring the appetite of slugs in the population. However, the amount of food eaten seems to be related to the mean night-temperature: the higher the temperature, the more eaten. A field experiment was made on New Zealand field to determine the relationship between the amount of standard foods removed by slugs and the numbers of slugs present as measured by a mark, release and recapture method. This work showed that standard brassica leaf-disks yielded a more reliable index to slug numbers than damage to wheat grains. (Newell)

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Changes in soil fauna with slit-seeding. An experiment was made on New Zealand field, to study how "slit-seeding" of wheat in a pasture sward killed by paraquat affects the soil fauna, as compared with conventional ploughing and drilling. The effects of a diazinon drench applied to control wireworms were also studied (*Rothamsted Report* for 1964, p. 186). Total soil fauna, populations of slugs, wireworms and earthworms were also estimated, together with numbers of plants, damaged tillers and the final yield.

The activity of the soil fauna in breaking down vegetable matter in the soil was estimated by the standard leaf-disk and mesh-bag method. The plots were sampled for earthworms in May with the formalin method. The weight of worms in the slit-seeded plots was three times as much as on the ploughed plots and, by the end of the year, leaf disks in large-mesh bags had disappeared 50% faster in the slit-seeded than in the ploughed plots. By contrast, leaf disks in small-mesh bags disappeared at the same rate on the two plots; thus, though there were differences in soil fauna other than earthworms (for cultivation lessened numbers of all species) there was no difference in the rate of litter breakdown when earthworms were excluded by small-mesh bags. Wireworm populations in May were large in the slit-seeded plots, small in the ploughed plots, and unsprayed slit-seeded plots had more damaged tillers than any of the other plots. But the number of healthy tillers was the same on both slit-seeded and ploughed plots after diazinon treatment. Damage by slugs was negligible.

The wet summer, considerable regrowth of grasses and difficult harvest made analysis of the final yield of little value. The diazinon, slit-seeded plots yielded 1 ton/acre of dry grain and the diazinon-treated ploughed and drilled plots, 27 cwt/acre. (Heath)

Breakdown of litter by soil animals. The experiment at Alice Holt Forest Research Station on litter breakdown on light and heavy soils growing either oak or conifers continued (*Rothamsted Report* for 1964, p. 186). Under oak the heavy soil has a pH of 4·7 and the light soil a pH of 3·8. The heavy soil had 1·8 g/sq ft of earthworms of the species *Lumbricus rubellus*, *Allolobophora chlorotica*, *A. longa* and *Dendodrobena octahedra*. The light soil had only 0·1 g/sq ft, solely of *Bimastus eiseni*. As expected, in the first year leaf disks in large-mesh bags disappeared nearly twice as fast from heavy soil as from light soil, because earthworms entered through the large meshes; in the second year they disappeared only about 15% faster.

With so few worms in the light soil under oak, leaf disks were expected to disappear with equal speed from both large- and small-mesh bags, but they still disappeared faster in the large-mesh bags. This was thought to be caused by the many dipterous larvae in the light soil during mid-summer, which the small mesh excluded as the larvae grew. There are no earthworms under conifers either on light or heavy soil, but dipterous larvae occur in coniferous woodland litter on light soil; also leaf disks disappear in coniferous litter faster on light than on heavy soil (the reverse to deciduous woodlands), presumably because of the dipterous larvae there.

Sampling litter of all the sites for arthropods showed that, in addition to light soil having more dipterous larvae than heavy soil, the heavy soil

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growing oak has fewer Acarina than the soil on the other sites. The litter under conifers on heavy soil is drier than in other sites and usually had more Acarina, with much of the litter consisting of the faecal pellets of mites. However, litter has not accumulated much there, probably because the plantation is relatively young. (Heath)

Wheat-bulb Fly

A census at each stage of the life cycle of the wheat-bulb fly was again made on the permanent reference plots on Great Harpenden I and on a plot in Stackyard field. Cylindrical sticky traps were used to study the composition and movements of the adult population on the alternate strips of wheat and fallow on the reference plots. In the wet, cloudy summer of 1965 adult activity on the plots was more evenly spread over the period July–mid August than in 1964, when it was more concentrated into the first two weeks of July, but otherwise the two seasons' results were similar. However, this is a long-term study, and several seasons' work will be needed before the main factors responsible for fluctuations in wheat-bulb fly populations can be identified. (Raw and Lofty)

Tests for resistant varieties. None of the 10 wheat species, 10 rye varieties and 16 bread-wheat varieties sown in short rows in a field infested by wheat-bulb fly (about 2 million eggs/acre) resisted attack or proved to be unsuitable hosts for wheat-bulb fly. However, some varieties germinated unevenly, and wheat-bulb fly eggs were patchily distributed, so making analysis difficult. Infestation is also affected by the stage of development of the plants when the eggs hatch, which can differ considerably with different varieties and species. Newly hatched wheat-bulb fly larvae are attracted chemically by root exudates from wheat plants and this helps them to find host plants (*Rothamsted Report* for 1964, p. 151). Laboratory experiments to test the attractiveness to newly hatched wheat-bulb fly larvae of cubes of alginate jelly in which a grain of wheat or rye had germinated suggested that the root exudates produced by some wheat and rye varieties, and species were less attractive than others. These laboratory tests continue, and field tests for resistance are being supplemented by tests done in boxes of soil containing known numbers of wheat-bulb fly eggs. (Raw and Lofty)

Aphid Studies

Growth of aphid colonies on virus-infected beans. Natural infestations of aphids were again observed on replicated plots of virus-infected and virus-free field beans (var. Herz Freya). The beans, sown at the beginning of April, were infected with pea mosaic virus (PMV), peaenation mosaic virus (PEMV) or bean leaf-roll virus (BLRV) towards the end of May.

The primary migration of *Aphis fabae* was large, and by mid-June, when most infected plants were showing symptoms, 95% of infected and 91% of uninfected plants had small colonies on the young leaves of the crown. Populations then increased so much that it became difficult to estimate

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numbers of aphids on individual plants, but there was no evidence that *A. fabae* either colonised infected plants more readily than uninfected plants, or populations initially increased faster on infected plants. The largest infestations of *A. fabae* were on uninfected plants when colonies on many infected plants were starting to disperse, probably because the stunted infected plants started to senesce early; thus by the second week in July 10% of uninfected plants, but only 0·6% of infected plants, had estimated populations of more than 10^3 individuals.

There was no indication that other species colonised infected plants more readily than uninfected plants; by mid-June 21% of infected and 16% of uninfected plants had small colonies of *Acyrthosiphon pisum* on the leaves; only few colonies increased to more than 20 individuals (maximum 50) on either infected or uninfected plants. Very small colonies of *Megoura viciae* and *Myzus persicae* occurred on 2% of both infected and uninfected plants. (Cockbain, with Gibbs, Plant Pathology Department)

Overwintering sources of the pea aphid and bean viruses. The pea aphid (*Acyrthosiphon pisum*) is the main vector of bean-leaf roll virus (BLRV) and peaenation mosaic virus (PEMV). Adult aphids, in contrast to nymphs, rarely become infective with either virus even after prolonged feeds on infected plants. Presumably, therefore, these viruses are mainly brought into annual crops by alatae that develop from nymphs on infected plants, and not by those that alight and feed on infected plants during dispersal.

Acyrthosiphon pisum overwinters in the egg stage on different biennial and perennial legumes, and work is being done to find what are the main overwintering hosts of the aphid and of the two viruses. Preliminary results indicate that many more *A. pisum* overwinter on lucerne than on clovers; thus, in spring 20 times as many fundatrices were on lucerne as on an adjacent crop of white clover, and 40 times as many on lucerne as on alsike. To extend the range of host plants surveyed, plots of the common pasture and fodder legumes were sown; oviparous females occurred on all legumes, but most on lucerne; eggs have still to be counted.

Of many perennial legumes, including known winter hosts of *A. pisum*, tested in the glasshouse for susceptibility to PEMV, none become infected. Lucerne is reported to be one of the main overwintering hosts of this virus in parts of the U.S.A., but four of the commonest varieties grown in the United Kingdom (du Puits, Provence, Chartainvilliers and Rhizoma) did not become infected. Also, of over 2,500 aphids collected during the year from lucerne (4 varieties, 1–3-year-old crops, 2 areas) none transmitted PEMV to test-plants. The susceptibility of lucerne to different isolates of PEMV is to be studied. Two annual legumes, suckling clover (*T. dubium*) and hairy tare (*Vicia hirsuta*), not previously recorded as hosts of PEMV, were susceptible.

Only lucerne, of the perennial legumes so far tested, was susceptible to BLRV. Infected plants rarely show distinct symptoms, and many aphids taken from symptomless lucerne in the field proved infective when tested in threes on *Trifolium incarnatum*. Table 2 shows the percentage transmission of BLRV by *A. pisum* taken in July from lucerne in the ley–

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arable experiments at Rothamsted. Only a few plants in the third-year lucerne on Foster's showed the brilliant vein-yellowing symptoms reported by Dutch workers as typical symptoms of BLRV in lucerne, although many others were infected.

TABLE 2

Percentage transmission of bean leaf-roll virus by A. pisum *from lucerne of different ages*

	1st year	2nd year	3rd year
Highfield	10	90	96
Fosters	8	84	96

A few *A. pisum* from white clover in the field were infective with BLRV; although white clover is less important than lucerne as a winter host of the aphid, it is ubiquitous and may be a common source of BLRV in the spring. Aphids taken from alsike and sainfoin were not infective. (Cockbain, with Gibbs, Plant Pathology Department)

Aphid nutrition. The fecundity of the bean aphid (*Aphis fabae*) kept under standardised laboratory conditions is significantly greater when reared on bean plants (our variety B) grown earlier in the glass-house under mercury vapour fluorescent lamps than when reared on plants grown in daylight alone (see *Rothamsted Report* for 1964, p. 307). The aphids apparently received a more nutritious sap from the irradiated plants. The fecundity of the pea aphid, *Acyrthosiphon pisum*, which also readily feeds and reproduces on the same kind of bean plant, was not significantly increased when fed on such illuminated plants, although it was slightly increased and the reproductive life (but not the post-reproductive life) was also somewhat lengthened.

In contrast to *A. fabae*, which feeds on phloem sap, larvae of another phytophagous insect, the moth *Plusia gamma*, eats the whole leaves of bean plants. The moth grew faster and had a shorter pupal life when fed on plants grown in daylight alone than on plants grown under the fluorescent lamps. Thus, although the irradiated plants seem more nutritious for *A. fabae*, they are not for *A. pisum* or *P. gamma*.

The variety of field bean known as Rastatt is well known as "resistant" to *A. fabae*. In our experiments *A. fabae* was much less fecund on Rastatt plants than on B or a field bean called Strube, that is less suitable than variety B for the aphid. In contrast, *A. pisum* was only slightly less fecund on Rastatt than on variety B. Larvae of *P. gamma* developed more slowly on Rastatt than on variety B, although they eventually reached the same average weight. That is, Rastatt retarded the growth of *P. gamma* larvae and the fecundity of *A. fabae*, but had no significant effect on *A. pisum*. (Banks and Macaulay)

Races of *Aphis craccivora* Koch. *Aphis craccivora* from Kenya and from Nigeria differ in their ability to transmit groundnut rosette virus (*Rothamsted Report* for 1964, p. 129). Careful examination revealed no external structural differences between the two kinds, though the average dimensions and proportion of various parts differed significantly. Trials with

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many different host plants showed that soya bean and *Gomphrena* sp. were more readily colonised by the Nigerian than by the Kenyan strain.

Single apterous females of both kinds, kept in individual leaf-cages and fed on groundnut plants, produced about the same number of apterae (Nigerian, 47–230; Kenyan, 46–152). Apterous females that gave birth to more than 100 young were large, with long cornicles and hind tibiae. Single, alate females of both strains produced a maximum of over 70 young on both bean and peanut. Thus the *A. craccivora* from the two countries can be considered as two races, differing in their physiology. (Jones)

Diseases, Parasites and Predators of Insects

Insect pathology. A survey was started of the incidence of diseases in some pest species, to try to assess their effects on field populations. So far work has been mainly on the wheat-bulb fly (*Leptohylemyia coarctata*). Fewer than 4% of its eggs buried in soil in the field or insectary in August, and protected from predators and macro-parasites, were abnormal when examined after 3 months (normal duration of egg stage is 6–7 months) and only 0·8% contained micro-organisms. The commonest micro-organism, in both field and insectary eggs, were ovoid spores resembling those of a fungus; the infected eggs were dead and their contents black. Attempts are being made to culture the organism and to test its ability to infect healthy eggs, but results so far suggest that the egg becomes infected through the adult.

A large percentage of larvae die in the soil, possibly because they fail to find host plants, but some (usually fewer than 4%) die after entering wheat seedlings. No micro-organisms were found in dead larvae dissected from wheat plants during spring, and larvae wetted with extracts of dead larvae remained healthy. Micro-organisms were found in other stages of the wheat-bulb fly, and their ability to infect larvae will be tested.

Several hundred pupae were collected from different sites during May and June; 65% emerged, 7% were parasitised by a staphylinid beetle (*Aleochara* sp.), 1·3% contained small coleopterous larvae (probably scavengers) and 1·1% were infested with nematodes (family Diplogasteridae). Of the remaining pupae 77% that became abnormal or failed to emerge contained bacteria or other micro-organisms, but it was impracticable to test whether any were pathogens.

In collaboration with D. Hooper of the Nematology Department, the nematodes taken from pupae are being cultured on artificial media and tested to see if they are parasites; so far results are inconclusive.

Several hundred adult female wheat-bulb fly were collected during July and August; 2% died of a fungus infection (*Entomophthora* sp., probably *E. muscae*) within 3 days, and a further 2·2% within 15 days; some that died later may have become infected in the laboratory. Of the other females 2·4% died with no external symptoms, but with the abdominal contents destroyed by fungus, and 0·3% died from a fungus causing an abdominal cyst (see *Rothamsted Report* for 1957, p. 159). Of the remaining adults 29% that died within 10 days of being collected contained

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bacteria of different types (mainly rods) in the body fluid outside the gut, but attempts to isolate pathogens by treating apparently healthy adults with extracts from these flies failed.

Leatherjackets and aphids were also tested for pathogens. Populations of leatherjackets in grassland at Rothamsted were sparse, and of the few *Tipula paludosa* larvae collected, 50% died within 6 days. No obvious pathogens were found, and the many deaths may have been caused by the fluid ("St. Ives") used to extract the larvae from soil. No obvious pathogens were found in larvae that became abnormal or died later.

During routine sampling of legume crops for the pea aphid (*Acyrthosiphon pisum*) during spring and summer, never more than 0·5% of aphids had external signs of infection with fungi. The pathogenicity under different conditions of one fungus (*Entomophthora* sp.) from aphids on beans is being studied. Two types of bacteria, isolated from dead *A. pisum* by J. R. Norris of Woodstock Agricultural Research Centre, were tested against aphids in culture. The bacteria were found in inoculated aphids, but caused no obvious pathological effects. (Cockbain, with Bailey, Bee Department)

Predators of wheat-bulb fly. To determine the extent of predation on wheat-bulb fly eggs, 800 eggs in batches of 20 were buried in petri dish lids in Stackyard field, during December 1964 and January 1965. Ninety per cent were recovered, including 2% that showed signs of having been bitten.

Pitfall traps were used to find which predaceous insects were active on the soil surface of Stackyard field during the oviposition period. Carabids formed 98% of the catches, between mid-August and mid-October. Weekly totals showed that they became much less abundant from the end of August; 8 times as many predators were caught in the first week of trapping as in the last. To estimate the predatory capacity of the most abundant carabid species, 5 of each species were confined individually in crystallising dishes lined with filter paper and offered 100 wheat-bulb fly eggs, during five 12-hour periods. Several species, including the most abundant one in the pitfall traps, *Feronia melanaria*, did not eat wheat-bulb fly eggs. Of those that did, *Trechus quadristriatus*, *Clivina fossor* and *Agonum dorsale* made up 20%, 16% and 2% respectively of the pitfall trap catches.

Pupae were exposed in the field in open petri dishes; 15% were eaten and another 4% showed signs of having been chewed. Of pupae collected from Stackyard field and reared individually, 5% were parasitised, all by Hymenoptera, and 25% failed to emerge. By contrast, of pupae collected from a site in the fens, 7% were parasitised, all by Staphylinidae. This indicates that the predators and parasites differ considerably in different parts of the country, and this factor needs more study in relation to areas in which wheat-bulb fly is a serious or known pest. (Ryan)

Frit fly and its predators. In 1964 DDT barriers prevented predators from invading the oat crop, so allowing frit fly to multiply unhindered. Plots also sprayed with parathion had most frit-fly eggs, but, ultimately, the smallest infestation, because the spray killed frit-fly larvae.

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In 1965 larger plots (2 × 2 yd) were used and two extra treatments added, namely: (*a*) the soil of some plots was twice sprayed with 0·5% parathion solution before oats were drilled and once the day after; the plots were also surrounded by a DDT barrier (0·5% DDT solution on hessian); (*b*) plots were surrounded by the DDT barrier 39 days after drillings. Both these treatments aimed to eliminate predators. Although weather was not conducive to egg-laying, larval attack, as measured by the number of yellowed shoots, was greatest on plots protected from predators by an early placed DDT barrier, and least on the sprayed plots. Plants from plots where only the soil was sprayed were only little more attacked than the sprayed plants, and they grew better than those on unsprayed plots. If the parathion on the soil eliminated predators it also protected plants against frit-fly attack, even though the soil was sprayed long before the oats germinated.

Bad weather caused the tall stems on the sprayed plots to lodge, so the panicles were collected and counted in August. Mean numbers of panicles/sq yd from soil-sprayed plots were 359, and from plant-sprayed plots, 388; unsprayed plots had 245, 212 and 210. Mean weights of grain/sq yd were 350 g from sprayed, compared with 234 g, 180 g and 191 g from unsprayed plots.

Cold weather made predators less active in 1964 and pitfall traps caught few, but there were some small carabids and staphylinids, mostly in unprotected plots. Pitfall traps in sprayed plots sheltered many adult frit fly during May and June. (Jones)

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