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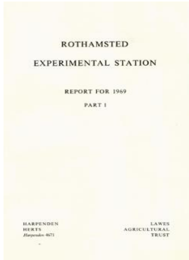
Report for 1969 - Part 1



Entomology Department

C. G. Johnson

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ENTOMOLOGY DEPARTMENT

C. G. JOHNSON

The effect of pests on growth and yield of plants and crops

Invertebrates and pasture productivity. Most old pastures contain a rich and varied population of animals that are potential pests, not only insects of various kinds that feed on the leaves or roots, but molluscs, mites and eelworms. The extent to which these cause damage is unknown, as is the relative importance of different ones. One way of getting evidence is to poison some species but not others and see whether this increases yield. A preliminary experiment suggested that only soil-inhabiting animals affect yield. This was again indicated by the first results of a more detailed experiment, started in June, using larger amounts of pesticides and more treatments, including some directed as specifically as possible against earthworms and nematodes. Yields from the first two cuts of the pasture were unaffected by any treatment, but the yield from the third, taken in September, was significantly increased by these treatments, all of which included aldrin, the chlorinated hydrocarbon insecticide that remains active for long in the soil. Similar treatments were also started on a newly-sown ryegrass ley at Hurley, in collaboration with the Ecology Division of the Grassland Research Institute.

Whether the pesticides used directly affect the growth of grass is being tested in the glasshouse, as is the ability of soil-inhabiting pests to injure grass of different ages. (Henderson)

Losses to field beans

Aphids. Work continued to find the best way of using insecticides to control the bean aphis (*Aphis fabae*) with the least harm to bees, and how aphids affect the growth of the crop and cause loss of yield.

In an experiment done with a crop of Maris Bead sown in March at Rothamsted, treatments and yields were:

(1) Phorate at 1 lb a.i./acre (1·12 kg/ha) applied as granules to foliage on 18 June. Yield—22·0 cwt/acre (2·762 tonnes/ha).

(2) Demeton-S-methyl applied as medium volume spray at 6 fluid oz a.i./acre (421·3 ml/ha) on 19 June. Yield—22·2 cwt/acre (2·792 tonnes/ha).

(3) Demeton-S-methyl spray as above, applied on 14 July at end of flowering. Yield—22·2 cwt/acre (2·791 tonnes/ha).

(4) Demeton-S-methyl spray as above, applied on both 19 June and 14 July. Yield—23·9 cwt/acre (2·998 tonnes/ha).

(5) No insecticide. Yield—20·4 cwt/acre (2·562 tonnes/ha). S.E. of treatment means $\pm$0·61 cwt/acre ($\pm$0·0771 tonnes/ha).

The true yield of the unsprayed plot would probably have been less than shown because the aphid population there was diminished by drift from the spray applied on 14 July. Populations were greatest at the end of July, but exceeded 100 aphids/plant on only about 20% of plants on

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the unsprayed plots. Numbers of aphids/plant, assessed on a logarithmic scale for all the plots, were used for regression analysis. Yield was negatively and linearly related to the product of population size and its duration, as in 1968. However, values for the slope and intercept differed in the two years. These regressions varied too much to be used to estimate losses from measurements of aphid populations.

Several plants in treatments (4) and (5) were marked when they began to flower, and their growth, and the aphid populations on them, were recorded weekly. At harvest the yield of each plant was measured and, although analysis of the results is not yet complete, it seems that aphid attack lessened the number of pods, not the number of nodes bearing flowers. Plants in the sprayed plots were more uniform in growth and yield than plants in the unsprayed plots, which contained both the biggest plants, with the most yield, and the smallest ones. Plants with few or no aphids grew larger than plants with many, and when adjacent, probably compensated for the yield lost by their neighbours.

Bean plants usually produce many flowers that fail to give ripe pods, but little is known about the factors that determine yield. Plants in sprayed plots were therefore mutilated in different ways and their yields compared with those of unmutilated plants. On 24–26 June, just as the first pods were starting to set: (1) heads were removed; (2) leaves were removed from the top half of the plants (except head); (3) leaves were removed from bottom half; (4) leaves were removed from every alternate node; (5) flowers were removed from alternate nodes; (6) half the flowers at each node were removed from the top half of the plant. Yields were significantly smaller from plants without heads (41% of yield from untreated plants), from plants without leaves on the top half of the plant (79·7%), and with leaves removed from every alternate node (74·4%). Yield was significantly increased by removing flowers from alternate nodes (166% of untreated). The mutilated plants were surrounded by undamaged plants, so the direct effects of lessened leaf area cannot be distinguished from indirect effects caused by competition with other plants. (Bardner, Fletcher and Latchford, with J. H. Stevenson, Insecticides Department)

Bean weevil. Most crops of field beans are attacked by *Sitona lineatus* and related species of weevils. Adults eat the leaves and cause a characteristic notching on bean seedlings in the spring; this usually does not affect yield. The larvae also feed on the roots and in the nodules during late spring and early summer, and whether this affects yield is unknown. Some crops at Rothamsted and Saxmundham that grew poorly and had few roots contained many larvae and big populations are also common at Woburn. Therefore an experiment with small plots of beans was made at Woburn to see whether treating the soil with 1 lb dieldrin/acre (1·12 kg/ha) would control *Sitona*. It had some effect but only lessened the numbers of larvae by a third; mean yields which did not significantly differ were: no insecticide, 24·5 cwt/acre (3·070 tonnes/ha); insecticide, 25·7 cwt/acre (3·230 tonnes/ha); S.E. of means $\pm$ 0·61 cwt/acre (0·77 tonnes/ha). In pots, unattacked plants yielded more than plants with larvae, but the differences were not significant. (Fletcher and Bardner)

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Aphids and virus diseases of lucerne. The experiment, started in 1966, to see whether spraying with 'Metasystox', three or four times a year, affected the yield of lucerne in pure stands and with cocksfoot ended. The final spray was applied on 5 November 1968 and all plots, sprayed and unsprayed, were cut on 26 June 1969. At the last cut, the lucerne/cocksfoot plots yielded more than the lucerne plots, but spraying had no significant effect; yields from sprayed and unsprayed lucerne were 3·21 and 2·87 tonnes dry matter/ha respectively and of sprayed and unsprayed lucerne/cocksfoot 4·97 and 4·76 tonnes/ha. Similarly, spraying did not affect the total yields from eight cuts during 3 years; sprayed and unsprayed lucerne yielded 27·36 and 26·54 tonnes/ha and sprayed and unsprayed lucerne/cocksfoot 35·15 and 35·77 tonnes/ha. Although spraying made aphids fewer and checked the spread of viruses on the lucerne (*Rothamsted Report for 1968*, Part 1, 203), it did not increase yields. However, aphids were few and the viruses spread slowly in the unsprayed plots so aphid-infestation and virus-infection had little effect on the yield of lucerne. (Cockbain, with Etheridge, Insecticides Department)

Aphid studies

Aphids and bean leaf roll virus in peas. The susceptibility of a range of pea varieties to infection with two isolates of bean leaf roll virus (BLRV) was tested in the glasshouse, by infesting seedlings with infective *Acyrthosiphon pisum* for 4 days and then spraying them with 'Phosdrin'. Symptoms were recorded after 4–10 weeks. Growth was not affected and symptoms did not develop in plants of Scout, Greengolt and Sharpe's 814; however, virus was recovered from 25% of the inoculated plants of Greengolt and Sharpe's 814, but from none of Scout. Varieties Big Ben, Dark Skin Perfection, Dik Trom, Johnson's Freezer, Maro, Sleaford Sunrise, Sparkle and Vedette were less tolerant of infection; symptoms developed and growth was affected in 5–30%, and virus was recovered from 5–50% of the plants. Varieties Freezer 69, Galaxie and Puget were still more susceptible; symptoms developed and growth and flowering were affected in 60–80% of the plants.

The effects of infecting the varieties Freezer 69 and Jade at different stages of growth were tested in the field. Seed was sown on 10 April and some plants of each variety were infected before flowering (29 May), during flowering (19 June), or when flowering had ended in Freezer 69, and almost in Jade (3 July). Symptoms were recorded at harvest in mid-July. Most plants infected before flowering showed symptoms at harvest, and they yielded only 24% as much as uninfected plants (Table 1). About 15% of plants infected during flowering showed faint chlorotic symptoms in the youngest leaves and shoot tips; whether or not they showed symptoms, they yielded 76% as much as uninfected plants. Plants inoculated after flowering did not develop symptoms and did not yield differently from uninfected plants. Infection affected the yield of the two varieties similarly.

Acyrthosiphon pisum, the main vector of BLRV, usually starts to fly in mid-May, but pea crops are rarely infested until they are in flower, and

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TABLE 1

Effect of time of infection with bean leaf roll virus on yield of peas

		Date of inoculation			
		29 May	19 June	3 July	Uninoculated
Var. Jade	% with symptoms	91	10	0	0
	Mean yield/plant* (g)	4·3	14·4	18·2	19·8
	% decrease	78	27	8	—
Var. F.69	% with symptoms	88	20	0	0
	Mean yield/plant* (g)	4·7	14·2	16·4	18·0
	% decrease	74	21	9	—

* Mean weight of shelled peas per plant, 160 plants per treatment.

infestations are usually small until early July. Infection with BLRV at this time will probably have little or no effect on yield of most early-sown crops, but some crops sown late or near to lucerne are infected before flowering, and in these situations it is advisable to grow varieties resistant or tolerant to BLRV. (Cockbain, with Etheridge, Insecticides Department)

Aphids and other viruses of legumes. A virus, possibly broad bean stain, was common in field beans at Rothamsted, occurring in plants (var. Maris Bead) with leaf symptoms ranging from a light green mottle to a yellow mosaic; the leaves contained many specific particle spheres about 24 mμ in diameter (examined by R. Woods). Plants with symptoms were most abundant near the edge of crops; thus during early July, there were 15% plants infected near the edge but only 5% 10 m within the crop on Little Hoos. Eighty-eight per cent of a sample of such plants tested were infected with a virus resembling broad bean stain and the others with bean yellow mosaic virus.

The virus was transmitted by sap inoculation to broad bean (var. The Sutton), French bean (Prince) and pea (Onward). It was not transmitted by aphids (*Acyrthosiphon pisum* and *Myzus persicae*) fed for 1–2 minutes or 3 days on infected plants, by clover seed weevils (*Apion* spp.) or mustard beetles (*Phaedon cochleariae*) fed for 5 days on infected plants, or by aphids (*A. pisum*), thrips (*Thrips tabaci*) bean weevils (*Sitona* spp.) and clover seed weevils collected from infected plants in the field. However, it was transmitted by 6% of *Sitona* that fed first for 5 days on infected plants and then for 5 days on healthy broad bean seedlings in the glasshouse. Bean weevils were very common in all bean crops examined, but it is not known whether they are the main vector.

Many of the seedlings produced from bean seed shed at harvest on Barnfield and Little Hoos were infected with the virus in October. This was probably not because of seed-transmission, for seed from infected plants produced apparently healthy seedlings when sown in the glasshouse. All infected volunteer seedlings were partly eaten by bean weevils, so the virus may have persisted for several weeks in the vectors living in the soil, or been re-introduced into the field by vectors feeding in the hedgerows.

Further studies of another virus, found in spring migrants of *Acyrthosiphon pisum* during 1968 (*Rothamsted Report for 1968*, Part 1, 202) showed

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that nymphs of *A. pisum* were more efficient vectors than adults; after feeding for one day on infected plants, there is a latent period of at least 3 days before nymphs or adults transmit the virus. The minimum time for transmission by aphids that had fed for several days on infected plants was 24 hours; none transmitted in 4 hours. The virus was not transmitted by *Aphis fabae*, *A. craccivora* or *Myzus persicae*.

Field bean varieties Herz Freya, Maris Bead and Tarvin, and pea varieties Big Ben, Dark Skin Perfection and Kelvedon Wonder, were about equally susceptible to infection when tested in the glasshouse; the broad-bean varieties Claudia Aquadulce, Early Longpod and The Sutton were not susceptible. Infected plants were slightly stunted, with the young leaves curled. Veins on the leaves and stipules were much enlarged, sometimes with enations. Swellings developed around punctures made with fine needles in the stems of infected field beans, but not around wounds in healthy stems. Spring migrants of *A. pisum* caught alive in suction traps during 1969 were not infective with this virus. (Cockbain)

The importance of the leaf-curling plum aphid, *Brachycaudus helichrysi* as a common virus vector. The 40-ft (12·2 m) suction traps operating in different parts of the country show that one of the commonest species of aphids flying during spring and early summer is the leaf-curling plum aphid (*Brachycaudus helichrysi*). It sometimes damages red clover directly, but it is not usually regarded as a pest of other agricultural crops. This species represented 29% of the total catch of aphids at Rothamsted during April, May and June in the 5 years 1965–69, and 12% of the total catch at Broom's Barn; by comparison, *Myzus persicae* represented 0·3 and 0·2% respectively. However, because the winged migrants are so abundant and alight on many different kinds of plants, they could be important in spreading some viruses, so the efficiency of *B. helichrysi* as a vector was studied.

During June alatae of *B. helichrysi* were found at Rothamsted on potatoes, lucerne and sugar beet, but not on peas, field beans or oil-seed rape. Sixty-three per cent of potato plants (var. King Edward) were infested in mid-June, and 27% in late June; as many as seven alatae occurred on some plants. Most were feeding on the inflorescence, and many had started to reproduce; very few were on the leaves. Forty-nine per cent of all alatae found on potatoes were *B. helichrysi*; the other commonest species were *Macrosiphum euphorbiae* (20% of alatae) and *Myzus ascalonicus* (10%). Similarly, *B. helichrysi* represented 40% of all alatae found on lucerne and 3% on beet; the other commonest alatae on these crops were *Cavariella aegopodii* (25%) and *Acyrthosiphon pisum* (9%) on lucerne, and *Aphis fabae* (69%) and *M. euphorbiae* (11%) on beet. The spring migration of *B. helichrysi* was smaller in 1969 than in some recent years, but the results show that the alatae of this species alight, and some settle to feed and reproduce, on crops not regarded as hosts.

The ability of *B. helichrysi* to transmit various stylet-borne viruses was tested in the glasshouse and compared with other species. Cultures were kept on *Chrysanthemum carinatum*. Alatae of *B. helichrysi* transmitted

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bean yellow mosaic, beet mosaic, cabbage black ring spot, cauliflower mosaic, cucumber mosaic and potato Y viruses. In most tests the alatae transmitted about a quarter or a third as often as apterae of *M. persicae*, but they were as efficient as *M. persicae* in transmitting beet mosaic virus to spinach and cabbage black ring spot virus to turnip; also, they were as efficient as *Acyrthosiphon pisum* in transmitting bean yellow mosaic virus to red clover.

Spring migrants of *B. helichrysi* were caught alive in suction traps at Rothamsted during June; 370 were tested for infectivity on various test plants. One of the 127 tested on *Trifolium incarnatum* transmitted bean yellow mosaic virus. Alatae and nymphs collected from lucerne and potatoes were similarly tested, and nymphs from a potato plant with mosaic symptoms (probably tuber infected) transmitted potato virus Y. Hence *B. helichrysi*, an aphid not regarded as agriculturally important may, by its abundance, be a frequent vector of stylet-borne viruses infecting a range of crops. (Cockbain)

Predicting outbreaks of *Aphis fabae*. As part of a national survey, organised by Professor M. J. Way of Imperial College, to obtain information that may help in predicting outbreaks of the black bean aphid, plots of beans were planted at Rothamsted and sampled for aphids throughout the season, and spindle trees in the neighbourhood sampled for eggs, larvae and adults. (Bardner and Fletcher)

Ecology of cereal aphids. Infestations of cereal aphids in fields of spring cereals were studied principally to improve sampling techniques as part of a national survey conducted by the National Agricultural Advisory Service. Transects, perpendicular to field perimeters sheltered by tall hedges or trees, were sampled. Infestations of *Rhopalosiphum padi*, *Sitobion avenae* and *S. fragariae* were largest in the perimeter rows and smaller at greater distances into the field. *Metapolophium dirhodum* occurred most commonly over more exposed places 20–60 yd (18·3–54·9 m) away from sheltered edges. Varying the distances between samples (1 ft (30·5 cm) sections of row) from 2–100 yd (1·83–91·4 m) did not show any appreciable difference in presence or absence of aphids at average aphid densities of about 1/100 tillers; 20 yd (18·3 m) was therefore arbitrarily selected as the standard interval between samples. *R. padi* was first detected along field perimeters during late May and *S. avenae* and *S. fragariae* in mid-June, at densities of about 1/69, 55 and 759 tillers respectively, and within 2–3 weeks after the first alatae were captured in the Rothamsted 40-ft (12·2 m) suction trap. *M. dirhodum* was found more than 20 yd (18·3 m) from the perimeter from mid-June onwards and along sheltered edges only in late June. *Sitobion* and *Metapolophium* were first detected in cereals when less than 8 aphids had been caught in the 40-ft (12·2 m) trap.

R. padi populations remained small throughout the season (maximum 1/46 tillers); *S. avenae*, *S. fragariae* and *M. dirhodum* were most dense during the second half of July, with values of about 1/1, 21 and 9 tillers respectively, but the aphids disappeared by the time cereals ripened before

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harvest (mid-August) and as the proportion of alates increased there was a corresponding increase in numbers trapped.

Staphylinid beetles preyed on *R. padi*, but syrphid and coccinelid larvae were rare until late July and they seemed to cause little loss to aphid populations. A braconid of the *Aphidius matricariae* group was first noticed parasitising cereal aphids during late June and reached a maximum late in July when 40–90% of aphids in the field (depending on species) were parasitised. Preliminary observations indicate that the egg-larval period of *Aphidius* is 7–10 days and the pupal period 4–7 days, the range depending on conditions in the glasshouse. More *M. dirhodum* than either *Sitobion* sp. seemed to be parasitised, and *S. fragariae* more than *S. avenae*. During July, 89% of *S. avenae* and *S. fragariae* were on the ears, while all the *M. dirhodum* were on the upper leaves, and the ratio between *Sitobion* and *Metapolophium* was about 7 : 1. The distribution of 'mummies' between ears and leaves gave a ratio of 1·5 : 1, indicating that *M. dirhodum* was more heavily parasitised than *Sitobion*. (Dean)

The Rothamsted Insect Survey

The Rothamsted Insect Survey aims mainly to predict outbreaks of aphids in different parts of the United Kingdom with widely distributed suction traps and to monitor the abundance of night-flying lepidopterous pests in the light traps. The table of monthly catches of aphids for 1969 and the annual total of moths of economic interest for 1967–68 is in *Rothamsted Report for 1969* (Part 2) and will appear in Part 2 each year in future.

Suction traps. Twelve 40-ft (12·2 m) suction traps are operated in the United Kingdom and Holland. A bulletin giving catches of 34 species, or groups of species, from 11 of the traps (excluding one of the two Rothamsted traps) was circulated to 63 people in the N.A.A.S. and elsewhere each week from May until the end of October. Trapping continued for two extra weeks because of the unusually fine autumn. The bulletin is dispatched from Rothamsted within 5 days of the capture of the last, and hence within 12 days of the first, aphid included in it.

Catches from Aberystwyth and Zeeland were identified by Dr. John A'Brook and Mr. D. Hille Ris Lambers respectively. Catches at Silwood Park and Edinburgh were sorted there and those from Broom's Barn were partly identified by G. D. Heathcote before dispatch to Rothamsted. Catches from six traps were therefore sorted in the department. At the peak period July/August, aphids from nine traps were identified by four of the staff, aided by up to three others doing preliminary sorting. For 2 weeks during July, it was impossible to keep pace with the incoming samples in time to send out the bulletin, and catches from part of the week were set aside for later identification.

Measurement of the airflow through the trap shows that volumetric sample size can be controlled with a suitable diaphragm at the fan intake. An appropriate diaphragm was developed to halve the sample size during the maximum summer migration period during July/August 1970 (weeks 26–31) at Broom's Barn, Rothamsted, Silwood Park and Wye, and in all

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TABLE 2

Cereal Aphids, 1969: dates of first appearance in fields and traps

Aphid species			*R. padi*			*R. maidis*			*M. dirhodum*		
			Date found		Days earlier	Date found		Days earlier	Date found		Days earlier
N.A.A.S. Region	Field No.	Trap site	Field	Trap	in trap	Field	Trap	in trap	Field	Trap	in trap
N. Scotland	i	Dundee	19/6	12/6	+ 7	n.f.	23/6	+	n.f.	25/6	+
N. England	i	Newcastle	n.f.	11/6	+	n.f.	15/7	+	28/7	14/7	+14
N. England	ii	Newcastle	n.f.	11/6	+	n.f.	15/7	+	1/8	14/7	+18
N. England	iii	Newcastle	18/7	11/6	+37	n.f.	15/7	+	18/7	14/7	+ 4
Yorks & Lancs	i	H. Mowthorpe	3/7	11/6	+22	n.f.	14/7	+	17/7	6/7	+11
W. Midlands	i	—	n.f.	n.t.		17/6	n.t.		17/6	n.t.	
W. Midlands	ii	—	17/6	n.t.		17/6	n.t.		24/6	n.t.	
E. England	i	Brooms Barn	n.f.	23/5	+	n.f.	30/6	+	n.f.	20/6	+
E. England	ii	Brooms Barn	n.f.	23/5	+	n.f.	30/6	+	n.f.	20/6	+
E. England	iii	Brooms Barn	n.f.	23/5	+	n.f.	30/6	+	n.f.	20/6	+
S.E. Wye	i	Wye, Kent	n.f.	12/5	+	n.f.	23/6	+	n.f.	13/6	+
S.E. Reading	i	Silwood Park	13/6	20/5	+24	27/6	25/6	+ 2	20/6	22/5	+29
S.E. Reading	ii	Silwood Park	30/5	20/5	+10	30/5	25/6	−25	6/6	22/5	+15
S.E. Reading	iii	Silwood Park	13/6	20/5	+24	30/6	25/6	+ 5	20/6	22/5	+29
S.W. Bristol	i	—	n.f.	n.t.		n.f.	n.t.		n.f.	n.t.	
S.W. Bristol	ii	—	n.f.	n.t.		n.f.	n.t.		n.f.	n.t.	
S.W. Starcross	i	Rosewarne	n.f.	19/5	+	n.f.	15/10	+	n.f.	3/6	+
S.W. Starcross	ii	Rosewarne	3/6	19/5	+15	n.f.	15/10	+	n.f.	3/6	+
S.W. Starcross	iii	Rosewarne	n.f.	19/5	+	n.f.	15/10	+	n.f.	3/6	+
Wales: Aberystwyth	i	Aberystwyth	3/6	9/5	+25	n.f.	14/6	+	n.f.	16/6	+
Wales: Aberystwyth	ii	Aberystwyth	n.f.	9/5	+25	n.f.	14/6	+	n.f.	16/6	+
Wales: Aberystwyth	iii	Aberystwyth	27/6	9/5	+49	n.f.	14/6	+	n.f.	16/6	+
Wales: Bangor	i	—	n.f.	n.t.		n.f.	n.t.		n.f.	n.t.	
Wales: Bangor	ii	—	n.f.	n.t.		n.f	n.t.		n.f.	n.t.	

n.f. = aphids not found. n.t. = no trap in vicinity.
+ means that the trap detected aphids, though field samples had none.

traps during the maximum autumn migration period in October (weeks 40–43). Lessening the amount of identification at these times should enable new traps near Bristol (Long Ashton) and Exmouth (Starcross) to be incorporated without delaying the bulletin.

There were few difficulties in identification this year, except for *Aphis* species. The attempt to separate *A. nasturtii* and the *A. franguli* group was not considered successful and these aphids will be pooled in 1970. The aphid season started late but numbers increased rapidly, especially of the tree aphids, *Drepanosiphum platanoidis*, *Euceraphis punctipennis*, *Elatobium abietinum* and *Myzocallis* spp., followed by the carrot aphid *Cavariella aegopodii*; *Aphis fabae* was more common this year than last. The species composition of the catch seemed to be more diverse this summer than last, when cereal aphids constituted the bulk of samples.

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TABLE 2 (*continued*)

Cereal Aphids, 1969: dates of first appearance in fields and traps

M. festucae			*S. fragariae*			*S. avenae*					
Date found		Days earlier in trap	Date found		Days earlier in trap	Date found		Days earlier in trap	Trap site	Field No.	N.A.A.S. Region
Field	Trap		Field	Trap		Field	Trap				
n.f.	11/8	+	n.f.	9/7	+	25/6	29/7	−34	Dundee	i	N. Scotland
n.f.	23/7	+	n.f.	26/7	+	3/7	20/6	+13	Newcastle	i	N. England
n.f.	23/7	+	n.f.	26/7	+	10/7	20/6	+20	Newcastle	ii	N. England
n.f.	23/7	+	n.f.	26/7	+	10/7	20/6	+20	Newcastle	iii	N. England
10/7	15/7	− 5	n.f.	15/7	+	3/7	14/7	−11	H. Mowthorpe	i	Yorks & Lancs
n.f.	n.t.		24/6	n.t.		24/6	n.t.		—	i	W. Midlands
n.f.	n.t.		24/6	n.t.		24/6	n.t.		—	ii	W. Midlands
n.f.	14/6	+	n.f.	28/5	+	n.f.	12/6	+	Brooms Barn	i	E. England
n.f.	14/6	+	n.f.	28/5	+	n.f.	12/6	+	Brooms Barn	ii	E. England
n.f.	14/6	+	n.f.	28/5	+	n.f.	12/6	+	Brooms Barn	iii	E. England
n.f.	23/5	+	n.f.	24/5	+	n.f.	6/6	+	Wye, Kent	i	S.E. Wye
13/6	13/5	+31	n.f.	15/5	+	20/6	24/5	+27	Silwood Park	i	S.E. Reading
13/6	13/5	+31	20/6	15/5	+36	20/6	24/5	+27	Silwood Park	ii	S.E. Reading
13/6	13/5	+31	20/6	15/5	+36	30/6	24/5	+37	Silwood Park	iii	S.E. Reading
n.f.	n.t.		n.f.	n.t.		14/6	n.t.		—	i	S.W. Bristol
n.f.	n.t.		n.f.	n.t.		n.f.	n.t.		—	ii	S.W. Bristol
n.f.	21/5	+	n.f.	4/6	+	2/6	20/5	+13	Rosewarne	i	S.W. Starcross
n.f.	21/5	+	n.f.	4/6	+	3/6	20/5	+14	Rosewarne	ii	S.W. Starcross
n.f.	21/5	+	n.f.	4/6	+	16/5	20/5	− 4	Rosewarne	iii	S.W. Starcross
27/6	29/5	+29	27/6	7/8	−41	3/7	1/6	+32	Aberystwyth	i	Wales: Aberystwyth
n.f.	29/5	+	n.f.	7/8	+	3/7	1/6	+32	Aberystwyth	ii	Wales: Aberystwyth
3/7	29/5	+35	n.f.	7/8	+	n.f.	1/6	+	Aberystwyth	iii	Wales: Aberystwyth
n.f.	n.t.		19/6	n.t.		26/6	n.t.		—	i	Wales: Bangor
n.f.	n.t.		19/6	n.t.		19/6	n.t.		—	ii	Wales: Bangor

n.f. = aphids not found. n.t. = no trap in vicinity.
\+ means that the trap detected aphids, though field samples had none.

N.A.A.S. field trials. To evaluate the relation between the first observed appearance of aphids in crops and in the Rothamsted suction traps in different parts of the country, N.A.A.S. collaborators offered to take weekly samples, from any spring-sown cereals, preferably wheat. Sheltered fields within a mile of each other or in an area with a history of aphid infestation and if possible within 25 miles of a trap were chosen. It was suggested that from 12 May samples, each of 40 plants, be taken along a traverse of the field on the leeward side of the windward hedge, starting at a distance from the hedge of twice its height and finishing at a distance of seven times its height. Samples from the field were to be bulked and examined in the laboratory. A key was supplied for identifying all cereal aphids. By 4 June G. J. Dean had obtained results (p. 236) that led to amending the scheme so that 20 1-ft lengths of row of cereal plants were

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examined and the transect passed across the field from the windward hedge to a point approximately four times its height from it.

For each species of cereal aphid in each of the fields two dates are given in Table 2; that for the first aphid seen in the field and that for the first aphid in the nearest suction trap. Traps sometimes caught cereal aphids without them being found in local fields but fields never produced the aphids without some being caught in the nearest trap. On 35 occasions the traps caught cereal aphids, on average, 27 days before they were found in the fields. On six occasions cereal aphids were found in fields before being caught in the nearest trap; a local source of aphids may have caused this, but in this first trial there is still some risk of mis-identification.

These preliminary results strongly suggest that suction traps can give adequate forewarning of crop infestation. The relation, if any, between size of catch and accumulation on the crop remains to be found. It is proposed to repeat the comparison in 1970 with the continued cooperation of the N.A.A.S. officers, to whom we are most grateful. (Taylor, French, Cole with Mr. K. George of the Ministry of Agriculture, Fisheries and Food and Mr. R. Gair of the National Agricultural Advisory Service)

Light traps. A hundred light traps were operating by the end of 1969, 26 more than in 1968, and some gaps in the countrywide distribution are now filled, but there are areas, e.g. the Welsh and Scottish borders and in the north of England, where traps are too few. Nevertheless the types of countryside now surveyed cover a wide range of habitats such as urban and rural, coastal and inland, highland and lowland, forest and agricultural land.

The number of individual moths, and of species, caught by the Rothamsted type of light trap is small but this deficiency is, to some extent, overcome by the continuous operation of the traps and their nationwide dispersion. (Taylor and French)

Light trapping in Africa

Analysis of the effect of moonlight on catches of insects in a light trap in the tropics. Light trapping is an important method of sampling insect populations in the tropics and is likely to remain so because maintaining more complex equipment is difficult. Catches during 2 years of continuous trapping at Kumasi, Ghana, and 5 years at Kampala, Uganda, are being analysed.

It has been standard practice to arrange the results as a succession of daily catches beginning either at full moon or at new moon. Both methods were tried with several species and groups of insects and gave different results for the apparent effect of full moon on the catch. This inconsistency led to a study of the ephemera of the moon for the period of trapping (1958–62) for Kampala. As a result a more precise arrangement was devised, based on the phase of the moon, that showed a more consistent effect of moonlight on catch at both full moon and new moon. Also, the derived curves of insects caught in relation to changing moonlight, show large differences between the responses of the insects (between and within

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groups) to intensity and duration of moonlight. There is no doubt that some species become more active as either brightness or duration of moonlight, or both, increases. (Bowden and Morris)

Phenological analysis of African light-trap catches. Comparing the phenologies of many species suggests that regular long-distance movements of insects are associated with dominant meteorological features, such as the Intertropical Front (I.T.F.), and with more transient phenomena such as line squalls, and that such movements are integral features of the insects' ecology.

In addition to the catches over long periods at Kumasi and Kampala, there are also catches for two periods, totalling about 18 months, at Ibadan, Western Nigeria. In Ghana the movement of large numbers of several species seems to be associated with the movement of weather zones related to the I.T.F., whose southerly drift, during the second half of the year especially, brings the second rains to central and southern areas of Ghana. Populations of adults of the Hawk moth *Herse convolvuli*, the cotton stainer *Dysdercus superstitiosus* and the green bug *Nezara viridula* change, simultaneously and rapidly, from none to great abundance during October and within a week or two of the arrival of the rains. The forest species, *Dysdercus melanoderes*, has a different phenology, and change of numbers is not associated with the arrival of rainy seasons. A close connection between *H. convolvuli* and the passage of the I.T.F. was shown at Ibadan, when on three occasions during January 1967 (the middle of the dry season) oscillations in its position brought the I.T.F. over Ibadan; each time *H. convolvuli* was also caught in the light trap, although more were caught when the I.T.F. moved away to the north or south.

Of several periods of unusual abundance at Kampala, two were examined in relation to synoptic weather charts compiled by the Anti-locust Research Centre. These charts are incomplete and a more extensive analysis will require additional meteorological information; nevertheless the analysis strongly indicates that large populations of many species move in association with different wind systems. In the first week of January 1962 there was an unusual easterly incursion of a mass of Congo air, extending eventually as far as Western Kenya. This incursion was associated with very large catches of dozens of species of insects, the most remarkable being on 5 and 6 January; 183 and 265 *H. convolvuli*, more than 90% of which were gravid females, were caught and there were also unusually large catches of the cotton bollworms, *Earias biplaga* and *Heliothis armigera*, the army worm *Spodoptera exempta*, three other species of *Spodoptera*, four of *Plusia*, and other, diverse, insects such as the mole cricket *Gryllotalpa africana*. Tettigoniidae and Odonata were also caught on the same nights. On the second occasion, 14 April 1962, the synoptic charts show a strong south-easterly wind across Lake Victoria; catches were again large, for example 50 *H. convolvuli*, compared with 1 on 13 April and 3 on 15 April, and 170 Tettigoniidae, compared with 6 on 13 April and 7 on 15 April. At the same time, considerable numbers were caught of *Dysdercus* including *D. superstitiosus*, previously rare in the Kampala trap; between 13 and 16 April, 68 of a month's total of 148 were taken. (Bowden)

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Sexual maturity of adult female insects caught in light traps. All female Sphingidae caught at Ibadan between March and June 1968 were dissected and classified for their amount of fat body, maturity of ovaries and whether fertilised or not. A maturity index was devised. Of species such as *Deilephila nerii* (the most abundant sphingid at Ibadan) of which very many were caught during short periods (suggesting migration), most of the females from large catches were sexually immature, which supports the idea that migratory individuals are generally those with most reproductive potential; in smaller catches, taken between periods of abundance, a much larger proportion of females are mature, even almost spent. Of the species whose phenology does not suggest migration, the females caught in light traps have a larger proportion of mature individuals. (Bowden)

Biology of Lepidoptera

Food use by *Plusia gamma*. Small qualitative differences in a food plant can affect its use by caterpillars. The extent and nature of responses by larvae of *Plusia gamma* to such differences are being studied by measuring or estimating increase in bodyweight, weight of faeces produced, and weight of food consumed during each instar of single larvae feeding on young and old turnip leaves. The estimation of food consumed presents the great difficulty of correcting for growth of leaves during larval feeding.

Behaviour of larvae of *Plutella xylostella*. *Plutella* adults, caged on a turnip or radish plant, lay most eggs on mature or ageing leaves; after hatching, most of the larvae move to young leaves. Usually 70% or more of larvae survive, but when individual leaves are grease-banded so that larvae cannot migrate, only about 10–20% survive their first 24 hours and those that die are not killed by the grease. Forty to fifty per cent survive when larvae walk down the leaf but have no other leaf to feed on and 60–70% survive when they can feed on a younger leaf. There seems to be much individual variation in this early behaviour; some larvae migrate before they start to feed, some feed for a time and then either die or migrate either by walking or by lowering themselves on silk threads; others feed and develop without migrating. Hatchlings bred from the adults of larvae that survived confinement by grease-bands had the same survival rate as the parent generation. Fewer survive in cold or on unsuitable food plants, but the proportions of hatchlings with different kinds of behaviour seem not to be altered. Responses to different larval densities were not studied specifically, but behaviour seemed similar over a tenfold range of initial egg density. (Gibbs)

Migration records. The records of immigrant Leipidoptera have not yet been examined in detail and much information has still to be received. However, several regular migrants, especially *Vanessa cardui*, *V. atalanta* and *Plusia gamma*, seemed particularly common in 1969, and reached as far north as the Orkneys and Shetlands. *Colias crocea* and *Macroglossa stellatarum*, which tend to be confined to the southern counties, were also abundant there. This abundance in 1969 was probably caused by the unusually clement weather, which extended into the autumn, and there is

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good evidence that *P. gamma*, at least, was reinforced by large immigrations as late as September and, possibly, October.

Several species of the rarer immigrants were recorded in October, coinciding with *P. gamma*, and may thus have come on suitable winds from source areas to the south. The complete records will be examined in relation to the synoptic weather charts at the time the insects arrived. (French)

Flight of *Plusia gamma*. The flight of *P. gamma* has been studied previously with tethered insects, but the method has many disadvantages. These arise mainly from handling the moths, so a new system was developed by which the flight activity of ten individuals can be monitored separately, continuously and simultaneously, from the time they emerge until they die, without touching the insects. A preliminary experiment during October, in natural light at about 20°C, showed that during the first five days after they emerged the moths flew both during the day and night, as they often do during migration; thereafter flight was restricted to the night-time. (Macaulay)

Aggregation

There are several different methods for sampling the Black Bean aphid (*Aphis fabae*) on beans in the field. Some use the bean stem as a sample unit, usually with some kind of sub-sampling. Three different sets of samples, obtained by different workers using different sampling methods, show that the variation (s^2) and the mean (m) values of a sample are related according to the equation $s^2 = am^b$, and that b remains almost constant though a varies widely. This in itself is useful in deciding which transformation is most appropriate for the data; the transformation also remains constant for samples with few zero counts (*10·37* on p. 413).

However, it has been suggested that the spatial disposition of many insects, as well as those of other organisms, could alternatively be described by $s^2 = (a + 1)m + (b - 1)m^2$, which a preliminary demonstration shows is less satisfactory for wireworms (*10·10* on p. 406).

More than 100 sets of results of field samples of all kinds of organisms are now being analysed, to further test these alternative formulae, for two reasons. Firstly, the transformation of counts is facilitated if the first hypothesis is verified, as for *A. fabae* above. Secondly, the spatial disposition may be characteristic of a species, and a general law relating such dispositions in different species would be useful in theory and practice. For example, if the spatial disposition of a particular pest in a crop can be anticipated, sampling and possibly control, would be facilitated. If populations of other organisms, including human populations, are shown to adopt specific dispositions, some new understanding of regional migrations (even new town developments) may result. (Taylor and Woiwod)

Shelter effects and patterns of distribution of insects

Size of infestations near hedges and tree-belts. Small flying insects accumulate in the sheltered zone near to artificial windbreaks, especially to leeward.

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The height and permeability of the windbreaks and the angle and speed of incident wind largely determine their distribution patterns in the air, which are reflected in populations on the vegetation beneath (*Rothamsted Report for 1964*, 182 and *for 1967*, 193). However, in many agricultural districts, living hedges, or belts of trees, rather than artificial windbreaks provide most shelter. A living barrier is both a windbreak and a habitat, so patterns of insect distribution caused by the 'windbreak' effects are complicated by the addition of insects that spread from breeding and feeding sites in the hedge itself.

Patterns of insect distribution were therefore measured during two seasons near a hawthorn hedge 2 m tall, between Little Knott Paddock and Little Knott, and to leeward of the pine and hawthorn windbreak 20 m tall in Delharding. Aerial populations were sampled with suction traps, and insects in the hedge and trees, and in neighbouring crops, were sampled with a vacuum sampler, to distinguish between insects breeding on the vegetation and those that had been blown there.

For flying insects, the pattern of distribution to leeward of the hedges or trees depended on their origin. For example, the pattern of wind-borne migrants, blown in from elsewhere, such as aphids, thrips, mymarids, mycetophilids and ptiliids, closely resembled the pattern of shelter near artificial barriers (*Rothamsted Report for 1965*, 182). But the pattern made by insects originating in the windbreaks was different. These insects were most abundant immediately to leeward of the hedge or trees, and did not accumulate beyond about 2H to leeward; many families of small flies, jassids and Micro-lepidoptera showed this pattern. Insects that originated a short distance to windward of the barrier, such as dung-feeding flies (Sphaeroceridae) and beetles (Staphylinidae) that flew from sheep dung in New Zealand field to windward of the tall trees, showed a pattern intermediate between the two extremes.

That the aerial patterns were reflected in the populations on the crops beneath was demonstrated during the migration of cereal thrips in spring 1969, when winds blew across the tall belt of trees. The migrants were few, but 6 weeks later, when the young of the new generation had developed in the cereals, their distribution resembled the pattern of shelter that had predominated when the few parent females arrived.

The size of populations that accumulated in the air depended on the speed of wind, and was much greater in strong (3–13 km/h) than in weak winds ($<$ 2·5 km/h). Stated simply, few insects accumulated behind the hedge unless the wind blew them there. The increases in abundance during windy weather ranged from 10- to 550-fold for individual taxa blown from the hedge or from windward of it. No doubt local populations, especially of species that hibernated in the windbreak, contributed to the increases but the direct effect of the hedge on the flow of air caused many more insects, which mostly originated from elsewhere, to accumulate near the living windbreak.

The diversity of the insect fauna in a hedgerow and neighbouring fields was also compared to show how much a hedgerow enriches the fauna of neighbouring crops, and the extent of its local effect. This analysis was done using Williams' index of diversity; this index has so far been

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applied only to groups of closely related species but was used here for insect communities whose members represent many distantly related and diverse lower taxa, collected by suction traps and vacuum sampler. The broad structure of communities was thus compared without detailed identification to genera or species. The analysis showed that the hedgerow community was more diverse than communities in neighbouring fields of field beans and pasture, but this greater diversity did not extend far into the fields. For airborne populations flying to leeward of the hedge, the pattern of diversity reflected the pattern of shelter, and the hedgerow enriched the airborne fauna within distances of three to ten times the height of the hedge to leeward.

The hedges and tree-belts used in these experiments ranged from 2 to 20 m tall. The height of most hedgerows and windbreaks of trees around fields in Great Britain is, perhaps, less than this and the distribution of airborne insects over and within many fields will conform to the principles described. The sheltered zone near tall hedges and trees, with the associated effects on insects, may extend up to 100–150 m into a field.

Practical importance of windbreaks. Knowledge of the way windbreaks affect the distribution of airborne insects might be used with benefit by advisers and farmers to detect invasions at an early date, to predict the site and extent of many infestations of pests and infections by insect-borne viruses, and thereby to restrict the limits of insecticidal treatments. It might also be used to appreciate where most beneficial pollinating insects, parasites and predators may occur. The information so far obtained is too little to decide whether the effect of hedgerows on crop infestation by insects is predominantly harmful or useful. During spring, before the sheltering vegetation and undergrowth is dense, the presence of hedges might increase infestation by pests that are only few but may nevertheless cause loss of crops, such as virus-transmitting aphids or pests attacking small seedlings. Pests arriving in a field later in the season when the hedgerow is dense, and when it has a more diverse flora and fauna, are more likely to be killed by natural enemies near the hedge than away from it; as this local benefit does not extend far into a crop, an appreciable check of this kind on pest populations is most probable in small fields. By contrast, artificial shelter encourages pests to accumulate without the compensatory accumulation of natural enemies. Thus, there are distinct entomological advantages and disadvantages in hedgerows, and it is difficult to say where the balance lies. (Lewis)

The mechanism of accumulation of insects in shelter. The components of wind that might cause insects to accumulate behind windbreaks were measured with cup anemometers and specially-constructed, sensitive, vane anemometers and direction indicators. Horizontal, upward and downward currents behind lath, coir and plastic mesh windbreaks of different textures were measured, and compared with patterns of density of airborne insects. The results are still being analysed, but the most important component seems to be horizontal wind speed. This suggests

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that insects accumulate behind barriers because wind loses its power to carry insects, when it slows down in the sheltered zone, rather than that they are blown downwards in eddies behind barriers. (Lewis and Dibley)

Orchard faunas. A survey of the insect fauna in six commercial apple orchards of Cox's Orange Pippin was made with suction traps while the trees were flowering. Orchards were chosen in the east (Essex), Midlands (Worcs), south (Hants) and west (Somerset), to see whether the different insecticidal treatments over the past 10–20 years might have affected the composition of the faunas, especially numbers of wild pollinators.

Windbreaks were also placed in an orchard of small trees of Cox's during blossoming to see whether the increased density of airborne insects in the shelter (*Rothamsted Report for 1968*, Part 1, 216) increased pollination and yield there. The results are being analysed. (Lewis, with Dr. B. D. Smith of Long Ashton Research Station)

Soil fauna

Effects of pesticides on predatory beetles. Pesticides applied to crops also contaminate the soil and may affect beneficial insects, such as carabid beetles that prey on pests, or arthropods that help in soil formation. Experiments were made with three insecticides, chlorfenvinphos, diazinon and phorate, to test the effect on beetles.

The chlorfenvinphos was sprayed on 9 June 1969 at 8 lb a.i./acre (8·97 kg/ha) on to the soil of plots 12 m^2, planted to wheat and surrounded by polythene barriers standing 18 in. (45·7 cm) above the soil surface and buried 12 in. (30·5 cm) deep in order to prevent entry or exit of any beetles. Pitfall traps in sprayed plots, again as in 1968, caught more staphylinid and carabid beetles throughout the summer than those in unsprayed plots; whether this was because populations increased or whether the beetles were more active is unknown.

Chlorfenvinphos effectively controls Cabbage Root fly and Wheat Bulb fly; perhaps this is, at least partly, because it increases the number or activity of beetles, which are known to prey on their eggs. In 1969, similar plots were treated with phorate granules and others with diazinon emulsifiable concentrate (both at 8·97 kg a.i./ha). They gave very different results from chlorfenvinphos; only about a quarter as many bettles were caught in the diazinon-treated plots as in untreated plots and phorate almost eliminated the beetles.

Insecticides and total soil fauna. Endrin is not usually applied directly to soil but large amounts reach the soil when crops are sprayed, especially to control cotton pests. Endrin is almost as persistent as DDT in soil and some agricultural soils in the United States of America now contain large amounts. To see whether endrin and also some other insecticides, 'Dyfonate' and 'Gardona', accumulate in soil or affect the soil fauna, long-term experiments began in which different amounts were sprayed on soil during the autumn and either left on the surface or cultivated into the soil.

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Molluscicides. 'Frescon', which kills the snails that carry bilharzia, is marketed in the United Kingdom to spray on grass to control *Limnea truncatulata* and hence liver fluke. Two experiments in which it was applied at the recommended amount of 0·45 kg a.i./ha and also at 9·0 kg a.i./ha, showed no effect on the populations of any soil animals from the recommended amount, and of the arthropods only Collembola were greatly lessened by the larger amount.

A surface drench of another molluscicide, methiocarb, at 10 lb of 50% wettable powder/acre (11·2 kg/ha) killed many soil micro-arthropods but not the larger arthropods. A 4% pellet formulation at 10 lb/acre (11·2 kg/ha) had no significant effects on the populations of any soil arthropod. (Edwards, Lofty and Stafford)

Paraquat and slit-seeding. New methods of minimal cultivation could affect both pests and beneficial insects in farmland. Therefore, the soil fauna on wheat crops grown in paraquat-treated, slit-seeded plots and in plots conventionally cultivated were compared for a fourth year. During the first four years one half of each plot was treated with the following insecticides; once with DDT (6 lb a.i./acre; 6·72 kg a.i./ha) and 'Zinophos' (3·4 lb a.i./acre; 3·81 kg a.i./ha) twice with chlordane (8 lb a.i./acre; 8·97 kg a.i./ha) and annually with phorate (10 lb a.i./acre; 11·2 kg a.i./ha), to kill as many of the invertebrate animals in the soil as possible and to compare the yields from these plots with those from untreated plots.

TABLE 3

Yields of wheat in cwt/acre (tonnes/ha) in the slit-seeding experiment

	Paraquat slit-seeded		Ploughed		
Year	Insecticide	No insecticide	Insecticide	No insecticide	S.E.
1966	46·1 (5·79)	44·0 (5·52)	46·8 (5·88)	44·7 (5·61)	0·65 (0·08)
1967	44·8 (5·62)	44·5 (5·59)	58·2 (7·31)	60·3 (7·57)	1·13 (0·14)
1968	32·5 (4·08)	27·1 (3·40)	28·0 (3·51)	28·6 (3·59)	1·74 (0·22)
1969	29·7 (3·73)	24·6 (3·09)	27·1 (3·40)	26·6 (3·34)	1·10 (0·14)

Yields (Table 3) differed greatly between ploughed and slit-seeded plots only in 1967, a year of large yield, when slugs severely damaged the crop in slit-seeded plots. Insecticides had little effect on the yield from ploughed plots but in three of the four years they increased the yield of slit-seeded plots significantly, almost certainly by lessening attack by wireworms which are controlled by repeated cultivation for 4 years in the ploughed plots. There is no evidence that soil invertebrates in the paraquat-treated plots are beneficial in aerating and turning over the soil. Yields were correlated with the incidence of take-all (Prew; Report of Plant Pathology Department) and diminished progressively in both the ploughed and on slit-seeded plots. (Edwards and Lofty)

Effects of cultivation on populations of soil invertebrates. Although soil cultivations are widely thought to help to control soil-inhabiting pests, the idea has rarely been tested. Therefore an experiment was started on Road Piece field on land ploughed from pasture in the spring. Some

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plots were ploughed, rolled, disked five times, harrowed and again rolled (maximal cultivation); others were ploughed, rolled, disked twice and rolled (minimal cultivation); other plots were ploughed in autumn and will be given maximal cultivation in spring. Some plots were left unploughed and under pasture. Before cultivation leatherjackets were 440 000/acre (178 140/ha) and wireworms nearly 1·5 million/acre (607 000/ha).

The populations of all arthropods estimated from six samples taken during the first year, averaged 110·5 million/acre (44·7 million/ha) in the unploughed plots; 91·0 million/acre (36·8 million/ha) in the plots with minimal cultivation, and 58·8 million/acre (23·8 million/ha) from plots with maximal cultivation. The cultivations did not greatly affect the numbers of wireworms after only one year, and only maximal cultivation significantly lessened total numbers of invertebrates. (Edwards and Lofty)

Effects of moisture and temperature on populations of soil invertebrates. As little is known about how weather affects total fauna of the soil, largely because of the difficulties in experimentation, the influence of temperature and moisture was studied out of doors by controlling these factors artificially in small field plots. In the first experiment, from January to September, the soil of one plot was kept about 5°C above the ambient temperature with over-head, infra-red heaters; in another plot, the soil was kept dry with a cover of plastic corrugated sheeting; another plot was flooded for 12 weeks. It is difficult to control temperature and moisture independently for the heated plots became very dry; however, such interactions occur in nature.

Heating had the greatest effect; after 8 months there were six times as many oribatid mites in heated as in unheated soil. Onychiurid Collembola increased briefly after 3 months but finally their numbers were as in unheated soil. Neither gamasid mites nor isotomid Collembola were much affected during the first 5 months, but during the next three they almost completely disappeared from the heated plot, perhaps because the soil dried during the summer. Enchytraeid worms increased in the heated plot during the first 3 months then rapidly became fewer until all had gone after 5 months. There were fewer Diptera and Coleoptera in the heated than in the unheated plot throughout the 8 months of the experiment.

Many groups of invertebrates seemed able to withstand flooding for a month or more but then to suffer. Twelve weeks of flooding had most effect on rhodacarid and gamasid mites, least on podurid and sminthurid Collembola. Enchytraeid worms and onychiurid and isotomid Collembola became fewer whereas oribatid mites were little affected and recovered their initial numbers 5 months after the plot was drained. Dipterous and coleopterous larvae, and adult beetles, were also little affected and were as many as in the unflooded plot at the end of the experiment. However, few other species had then completely recovered from the effects of 3 months of flooding.

Drying the soil from about 20% moisture content in the uncovered plot to about 10% in the covered one had little effect on numbers of soil invertebrates, but increased some mites.

In another experiment, plastic containers filled with soil containing a

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numerous and diverse fauna were kept at 0, 5, 10, 15 or 20°C, and populations assessed at intervals. Numbers fluctuated considerably, but 10°C was the most satisfactory temperature for maintaining, or increasing, populations of invertebrates. At 0 and 20°C populations gradually declined and after 20 weeks were usually smaller than at 5, 10 or 15°C. Nevertheless many animals from most groups survived for long periods at or below freezing point. Exceptionally, sminthurid Collembola increased at about 0°C and with soil often frozen; enchytraeid worms did better at 5°C than at other temperatures. (Edwards, Lofty and Stafford)

Sampling snails. *Limnea truncatulata* is the intermediate host of *Fasciola hepatica*, the liver fluke of sheep and cattle, which kills many animals in the United Kingdom, especially during wet summers. A new approach to controlling liver fluke is to kill the snails in infested pastures with molluscicides. The ecology of the snails is still poorly understood and attempts to assess the effects of treatment have been unsatisfactory because there is no method of assessing snail populations accurately.

Three methods of assessing populations were compared. In one, snails were extracted from soil cores by flotation. Their specific gravity, estimated by floating them in water-glycerol mixtures of different densities, ranged from 1·1 to 1·2. Soil cores 4 in. (10·2 cm) diameter and 2 in. (5·1 cm) deep were taken at random from an infested pasture and washed into Ladell containers under high-pressure jets of water, as in the Salt and Hollick extraction method. Instead of the usual magnesium sulphate solution (S.G. 1·2), zinc sulphate (S.G. 1·34) and calcium chloride (S.G. 1·38) were used to float the snails in the Ladell can, but some failed to float even on these dense solutions. Thirty-three snails were recovered from a total of 30 cores. In the second method, similar cores were also washed under the water jets, but the silt and organic matter were then decanted into a white developing dish, with longitudinal ridges on the bottom, and scanned with a binocular microscope, when the snails were clearly distinguished against the white background. Sixty-three snails were recovered from the 30 cores. About 15 minutes were needed to process a single sample by either method. In a third method, quadrats, 10 in. (25·4 cm) square, were marked out in the fields and snails counted *in situ* on the soil surface after teasing the grass roots apart. Where the washing-scanning method gave population estimates of 34·0 snails/ft^2 the quadrat method gave only 15·1 snails/ft^2 (366 and 162/m^2 respectively). The time taken to process a 10·2 cm diameter core was approximately the same as to scan a 25·4 cm quadrat, but more snails were counted in a given time with the quadrats. Thus, although in a given time the quadrat method discloses more snails many small ones may be overlooked, and the more laborious washing method probably gives more reliable estimates. However, the difficulty remains of telling which snails are alive or dead. (Edwards and Stafford)

Slugs

Susceptibility of different varieties of potato to damage by slugs. Some compounds in extracts of potato tubers, identified by places on chromatograms, stimulate *Arion hortensis* to feed on filter paper (*Rothamsted*

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Report for 1968, Part 1, 271); sucrose and chlorogenic acid at particular concentrations increased feeding but tyrosine did not. Further tests of sucrose, with and without chlorogenic acid, showed that chlorogenic acid greatly stimulated feeding by *A. hortensis*, and slightly by *Milax budapestensis* which also feeds on the potato tubers; but lessened feeding by *Agriolimax reticulatus*, which does not. The mean weights of faecal pellets from ten individuals of each species fed on filter paper soaked in the two solutions were:

	1·0% sucrose	1·0% sucrose + 0·01% chlorogenic acid
A. reticulatus	8·1 mg ± 1·1	3·8 mg ± 0·5
M. budapestensis	9·1 mg ± 1·1	11·9 mg ± 1·9
A. hortensis	1·8 mg ± 0·8	9·0 mg ± 0·9

Extracts of newly-lifted tubers, of the varieties King Edward, Majestic and Pentland Falcon, in two-way chromatograms run in N-butanol-acetic acid–water mixture and in ethanol–ammonia–water, gave the same 14 ninhydrin-sensitive spots, but the concentration of material in the same spots differed. The differences were greatest for chlorogenic acid; King Edward, the most susceptible of the varieties to slugs, contained least and Pentland Falcon, the most resistant of the varieties, contained most. Feeding slugs on filter paper soaked in chlorogenic acid solutions of different concentrations shows that the optimum concentrations for stimulating feeding, in the presence of sucrose, is about 0·005%. Presumably King Edward contains about the optimum amount and Pentland Falcon enough or more to lessen feeding.

Fertilisers and damage to potatoes by slugs. Tubers of King Edward grown with different fertilisers in the Arable Reference plots at Rothamsted and Woburn (F. V. Widdowson, Chemistry Department) were examined for damage by slugs. Tubers from half-plots, given 4·0 cwt/acre (502 kg/ha) $MgSO_4$, cultivated into the top soil at planting, had significantly less damage at Rothamsted but not at Woburn, than those from half-plots without Mg (Table 4).

Additional potassium, seemed to interfere with the beneficial effect of magnesium.

Although the plots were not replicated and their slug populations are unknown, the lessening of the damage by slugs on the clay soil by giving $MgSO_4$ merits further study, and a trial has been planned in co-operation with the Experimental Husbandry Farm, Terrington St. Clement.

Whether magnesium makes tubers less palatable to slugs is being studied. So far, chromatography shows only small differences in the concentrations of ninhydrin-sensitive substances in King Edward tubers grown with and without added magnesium. Preliminary tests in the laboratory do not suggest that $MgSO_4$ added to clay soil in amounts equivalent to 502 kg/ha, has any immediate adverse effects on adult *A. hortensis*. (Stephenson)

Wheat Bulb fly

Movement of newly-hatched larvae. Eggs of Wheat Bulb fly are laid in bare soil and the larvae that hatch crawl through the soil, find wheat

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TABLE 4

Percentage of tubers damaged by slugs

Treatment	Rothamsted No Mg	Rothamsted Plus Mg	Woburn No Mg	Woburn Plus Mg
Basal NPK	14·3	2·8	2·8	0
Basal NPK+N_1	12·5	1·3	1·4	1·4
Basal NPK+P	14·3	7·1	1·4	5·7
Basal NPK+N_1P	5·6	2·8	4·3	2·8
Basal NPK+K	12·3	12·9	6·7	4·9
Basal NPK+P K	8·0	8·2	1·8	5·0
Basal NPK+N_1K	4·6	9·0	2·0	5·4
Basal NPK+N_1PK	10·1	1·2	0	7·5
Basal NPK+N_2PK	6·6	3·6	3·3	4·5
FYM	10·4	10·6	2·3	6·8
FYM+N_1PK	9·0	1·4	5·3	0
FYM+N_2PK	8·1	5·4	5·4	0
Mean	9·6	5·5	3·1	3·7
Difference	4·1 Sig. (P = 0·01)		−0·6 not sig.	

Treatments

Basal NPK 13 : 13 : 20	= 10–12 cwt/acre
FYM	= 20 cwt/acre
N_1	= 0·6 cwt/acre. 'Nitro-Chalk', Rothamsted
	= 0·75 cwt/acre. Ammonium nitrate, Woburn
N_2	= 1·2 cwt/acre. 'Nitro-Chalk', Rothamsted
	= 1·5 cwt/acre. Ammonium nitrate, Woburn
P	= 0·5 cwt/acre. P_2O_5
K	= 2·0 cwt/acre. K_2O
Mg	= 4·0 cwt/acre

seedlings and burrow into them. There is some doubt about how they can travel and how many die before finding a plant. Experiments were therefore done to obtain information on this.

Seed boxes, sown with two rows of Cappelle wheat, 18 cm apart as in the field, and treated with 'Agrosan' were kept in an insectary. Eggs were placed in each box in a row between and at different distances from the two rows of wheat; there were five replicates of each type namely with the eggs, 9 and 9 cm from each row, 6 and 12 cm, 4 and 14 cm, 2 and 16 cm, 0 and 18 cm from the rows. Observation and dissection of the plants during March and April showed that the number of wheat plants penetrated by newly-hatched larvae increased the nearer the eggs were to a row, as follows: 61% (9 and 9 cm), 68% (6 and 12 cm), 73% (4 and 14 cm), 79% (2 and 16 cm), 87% (0 and 18 cm). In a similar set of seed boxes, the plants were left for adults to emerge; 20–33% of the eggs survived to the adult stage, each of which needed 2–3 shoots for their development.

Feeding of Wheat Bulb fly. Both male and female flies feed chiefly on liquids such as dew, nectar and honey dew, and on spores, chiefly of yeast and *Septomyxa affinis*. A further 450 flies from 25 different localities were dissected during July and August 1969. *Septomyxa* spores were found first on 7 July and were in the crops and mid-gut of flies from all except five localities, near Haddenham and Stretham, Cambridge, near Boston and Nocton, Lincolnshire, and near Durham. *Septomyxa* spores occurred in flies from Leadenham, Lincs., and Urpeth, Northumberland, where they

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did not in 1968, when July was wet and cold. Other spores of fungi common in and around wheat fields also occurred and a few pollen grains from Graminae and Compositae.

Development of eggs. Newly emerged male and female flies have similar weights (males 7·6 mg $\pm$ 0·2, females 7·9 mg $\pm$ 0·2); whereas males remain the same weight except for the amount of food they contain, the females become heavier as their ovaries develop and, when the eggs are mature, they are nearly double the initial weight (14·9 mg $\pm$ 0·4). The first eggs were laid on 23 July, but most were laid in August. When all the first batch of eggs have been laid, the second batch ripen in the ovarioles. A small plug in the ovariole, near the base of the second egg, becomes pushed down and is less easy to distinguish as the second batch of eggs enlarges. The presence of the plug indicates that a batch of eggs has been laid. The mean number of eggs ripe at one time is 28·5 $\pm$ 0·43.

Emergence of Wheat Bulb flies in 1969. Usually there is a peak of emergence of adult flies at the end of June or during the first week of July. Exceptionally, there were two peaks of emergence in 1969, one during the first week of July and another, bigger, from 15–23 July. The unusually cold weather of February and March may have slowed the hatch of late-hatching eggs. The mean number of flies to emerge from 1 yd^2 (0·84 m^2) was eight. (Jones)

Spatial distribution of Wheat Bulb fly infestations. The effects of pests on crops depend greatly on how the pests are distributed. If well spaced out they may have relatively little effect. If clumped they may destroy whole areas. It is important to study the distribution of pests in fields. Many fields at Rothamsted, but especially Broadbalk and Great Harpenden, have been sampled during the last 10 years to estimate egg and larval populations of Wheat Bulb fly. Larvae and plants have also been sampled intensively on Stackyard, to study how Wheat Bulb fly affects yield. The results are being used to study the spatial distribution of the pest and the resulting damage to crops.

Most plant and animal populations are distributed so that, in a series of samples, log variance (s^2) is linearly related to the log mean (m); and the slope of the line (b) indicates the degree of aggregation. When the graph goes through the origin, as with most of the Wheat Bulb fly studies, populations are randomly distributed when $b = 1$, and aggregated when $b = > 1$.

For 87 sets of results for eggs, totalling some 1550 individual samples, $b = 1{\cdot}242 \pm 0{\cdot}0515$, indicating that the distribution of the eggs was slightly aggregated. Two series of results exist for larvae; in the first, 68 sets totalling 748 observations from samples taken on different Rothamsted fields during late March and early April, $b = 1{\cdot}203 \pm 0{\cdot}0484$. For the second series, obtained from samples taken at various stages of the attack on infested plots in the Stackyard experiments (84 sets with 1008 observations), $b = 0{\cdot}933 \pm 0{\cdot}0907$, not significantly different from the first set. There are also indications that b for larvae depends on the date of sampling.

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Estimates were made of b for surviving plants in Stackyard in May with 33 sets of results and 396 observations from both attacked and unattacked plots. For attacked plots b was $1{\cdot}056 \pm 0{\cdot}1431$, and for unattacked plots $1{\cdot}056 \pm 0{\cdot}1673$. It is hoped that this information can be used in measuring and predicting yield losses caused by Wheat Bulb fly. (Bardner)

Staff

G. J. Dean was appointed as a supernumerary member of the staff.

C. G. Johnson visited the Cocoa Research Institutes of Ghana and Nigeria and contributed to the 3rd International Cocoa Research Conference at Accra. L. R. Taylor visited the East African Agriculture and Forestry Research Organisation, Muguga, Kenya and contributed to the International Symposium on Statistical Ecology at Yale University. L. R. Taylor and R. A. French visited Mr. Hille Ris Lambers at Bennekom, Holland.

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