SESSION 4

BENEFICIAL ORGANISMS AND PEST MANAGEMENT

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POSTER PAPERS	4A-1 to 4A-23
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MICROENCAPSULATED PHEROMONES IN COTTON PEST MANAGEMENT

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ABSTRACT

Microencapsulated formulations of the pheromone of the pink bollworm Pectinophora gossypiella (Saunders) were successfully used for season long control in Egypt. Additional large scale experiments to integrate using pheromones and conventional insecticides showed that early season applications of pheromones followed by late season application of insecticides was an effective combination. The reverse procedure with pheromone applied towards the end of the season was less effective. The judicial use of pheromones in relation to the preservation of beneficial insects is discussed.

INTRODUCTION

Control of the pink bollworm Pectinophora gossypiella (Saunders) with the sole use of the mating disruption technique was first successfully achieved in Egypt in 1981 by the aerial application of a microencapsulated formulation of the sex pheromone, a 1:1 mixture of (Z,Z) and (Z,E) - 7, 11 - hexadecadienyl acetate (Critchley et al. 1983). Further successful trials were conducted in 1982 not only with the microencapsulated pheromone formulation but also with plastic laminated flake and plastic hollow fibre formulations. (Critchley et al. 1985).

Large scale trials were also undertaken in 1983 with the microencapsulated pheromone for season-long control as well as experiments to examine the feasibility of incorporating pheromones into regimes also using insecticides for the control of other cotton pests.

MATERIALS AND METHODS

Pheromone and insecticide applications

The large scale trial with the microencapsulated pheromone formulation for season long control of Pectinophora covered 250 ha of cotton in the Fayoum Governorate of Egypt. Application was by helicopter using boom and nozzle spray apparatus. A total of five applications of pheromone were made throughout the season using 10g a.i./ha at intervals of two to three weeks, commencing at the beginning of June.

The effectiveness of the treatments was assessed by comparing the

level of Pectinophora infestations in the pheromone treated area with infestations in a 160ha block of cotton situated in the same locality where a conventional regime of insecticides was used. This consisted of successive sprays at the recommended rates of (a) a mixture of chlorpyrifos and diflubenzuron (b) synthetic pyrethroids (c) chlorpyrifos (d) profenofos. The interval between each spray was two weeks with the first application at the beginning of July.

The experimental regimes using combinations of pheromone and insecticidal treatments were applied to five 40ha cotton plots in the Beni Suef Governorate. Pheromone applications from fixed-wing aircraft were used to supplement or replace the four insecticide applications as shown in Table 1.

TABLE 1.

Distribution of successive pheromone and insecticide applications in the experimental sites in Beni Suef, Egypt in 1983.

Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
PHEROMONE 10g a.i./ha	PHEROMONE 7.5g a.i./ha	-		
PHEROMONE 10g a.i./ha	PHEROMONE 7.5g a.i./ha	PHEROMONE 10g a.i./ha	chlorpyrifos & diflubenzuron	chlorpyrifos & diflubenzuron
synthetic pyrethroids	synthetic pyrethroids	synthetic pyrethroids	PHEROMONE 10g a.i./ha	synthetic pyrethroids
triazophos	triazophos	triazophos	triazophos	PHEROMONE 10g a.i./ha
carbaryl	carbaryl	carbaryl	carbaryl	PHEROMONE 10g a.i./ha

An area of 75 ha of cotton treated with the four sprays of insecticide was used as a comparison "control" area in the absence of completely untreated cotton.

Boll sampling

Sampling the developing green bolls during the growing season enabled differences in patterns of Pectinophora infestation to be observed. The procedure was based on methods described by Critchley et al. (1985). Sampling began in July and continued at weekly intervals until late August when harvesting commenced. The 250ha pheromone treated area in Fayoum was divided into three sub-plots and 100 bolls were collected from randomly chosen spots within each plot. Single 100 boll samples were taken from each of the experimental and control plots in Beni Suef.

The collected bolls were examined for the presence of Pectinophora larvae. Counts included bolls from which the larvae had departed but had left characteristic traces.

RESULTS AND DISCUSSION

The season long comparison of Pectinophora boll infestations in the

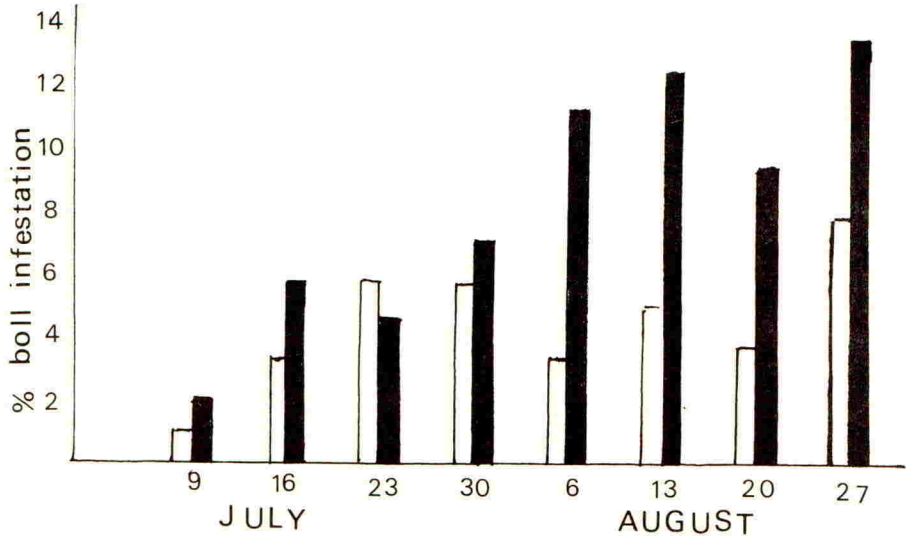

Fig.1. Percentage of Pectinophora larvae in sampled bolls in an area treated season long with microencapsulated pheromone □ compared with ■ cotton treated with conventional insecticides in Fayoum Governorate during 1983.

pheromone and insecticide treated areas located in the Fayoum is shown in Figure 1. In only one week of the eight sampling periods (23 July) did the mean percentage boll infestation in the pheromone treated area exceed that in the insecticide treated area. The level of infestation in the pheromone treated area never exceeded the recommended economic threshold of 10%, although this was exceeded on three sampling occasions where insecticides had been used.

The results from this large scale trial thus confirmed the findings of the previous two years that pheromones appeared as effective if not better than conventional pesticides for the control of Pectinophora.

Little evidence was found for unacceptable increases in the population of other insect pests in the pheromone treated area as was feared might occur in the absence of insecticide treatments. This may be related to the presence of greater numbers of beneficial insects which had been shown to occur in the pheromone treated areas. (McVeigh et al. 1983). Unacceptable increase in other pests can however occur on occasion (Critchley et al, 1985); for this reason the integration of pheromone and insecticide applications was investigated.

It might be expected that pheromone treatments would be most effective when moth populations are low, as occurs early in the season, and least effective towards the end of the season when higher moth populations are found (Campion 1983). The results presented in Fig.2 generally support this view. Two early applications of pheromone applied at the rate of 10g a.i./ha followed by three conventional insecticide applications (Table 1 Fig.2 plot 1) provides effective control, although

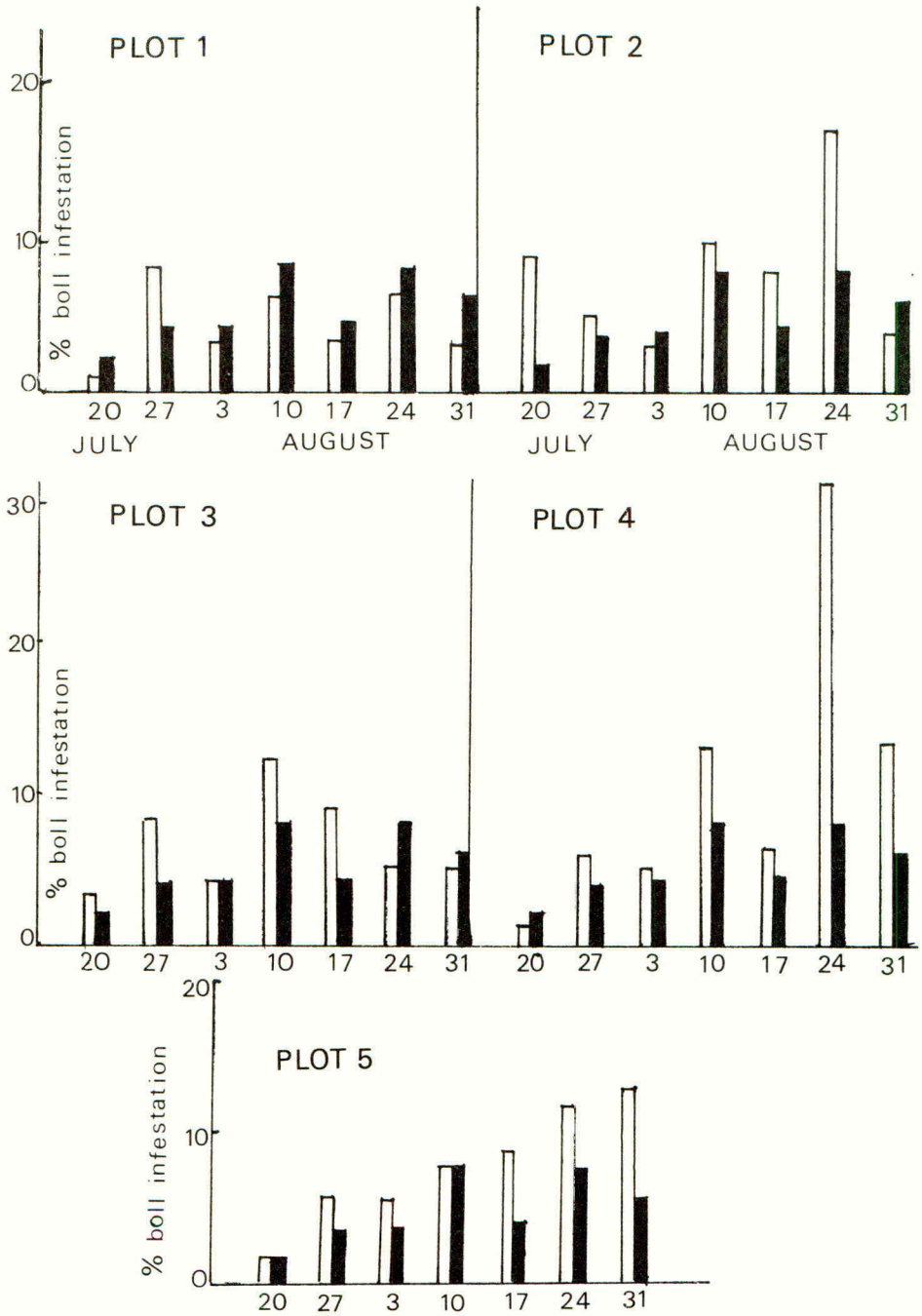

Fig.2. Infestation of Pectinophora larvae in sampled bolls from 40ha plots treated with combinations of microencapsulated pheromone and insecticides as indicated in Table 1 □ compared with conventional insecticide treatment ■ in Beni Suef Governorate during 1983.

a similar regime with a reduced pheromone application rate of 7.5g a.i./ ha was less successful (Table 1, Fig.2 plot 2). The omission of the first recommended pheromone application at the flower bud stage (Table 1, Fig.2 plot 3) resulted in a situation where the levels of infestation exceeded those in the comparison insecticide area in four out of the seven sampling periods. A further delay in applying pheromone by substitution for the second conventional insecticide application (Table 1, Fig.2 plot 4) resulted in high levels of boll infestation with the margin of 10% exceeded in three of the seven sampling occasions, one of which reaching a level of 30%. Substitution of the last two conventional insecticide sprays with pheromone applications was also relatively unsuccessful. In no instance out of the seven sampling occasions was the level of infestation lower in the pheromone treatments compared with the insecticide treatments, while on the last two sampling occasions the 10% level of infestation was exceeded (Table 1, Fig.2 plot 5).

The results suggest that early application of pheromone to protect the flower bud and the early flowering period is necessary to ensure adequate control of Pectinophora, but that later supplementation with conventional insecticides is possible. Such a regime would ensure the maximum utilisation of beneficial insects, since insecticides would only be used towards the end of the season at a time when populations of such beneficial insects would be naturally declining. It remains to be seen whether season long or an integrated approach will be appropriate for Pectinophora in other countries. Further studies are at present in progress in Pakistan and Peru.

ACKNOWLEDGEMENTS

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PHEROMONES IN THE MANAGEMENT OF BENEFICIAL INSECTS

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ABSTRACT

The prospects for using pheromones and other behaviour-controlling chemicals in the management of beneficial insects is discussed in the light of recent discoveries at Rothamsted which illustrate the various possible approaches. Evidence of chemically-mediated attraction of aphid parasitoids (Aphidius spp.) to their hosts and of honey bees as crop pollinators indicates that the effectiveness of beneficial hymenopteran insects might be improved by using behaviour-controlling chemicals. The possibility of keeping beneficial organisms from crops to be treated with pesticide is demonstrated by use of synthetic pheromones to repel honey bees from oil-seed rape. Aphids highly resistant to insecticides show poor response to their alarm pheromone which may improve the effectiveness of predators and parasitoids. The potential for pheromone inhibitors to increase predation is demonstrated by use of (-)-β-caryophyllene, a potent alarm pheromone inhibitor, to reduce dispersal of aphids attacked by a chrysopid predator.

INTRODUCTION

To reduce problems of insecticide resistance and environmental damage, integrated pest management will be adopted more widely. Although insecticides will be employed in most integrated regimes for the foreseeable future, their use can be made much safer and more effective by employing pheromones or other behaviour-controlling chemicals and biological agents (Silverstein, 1981). Behaviour-controlling chemicals can improve effectiveness of insecticides directly by increasing contact between pest and treatment, and indirectly by allowing accurate monitoring of pest populations by means of pheromone attractant traps (Lewis, 1985).

Present studies at Rothamsted investigate the possibility of using pheromones and other behaviour-controlling chemicals to improve management of beneficial insects in agriculture.

MATERIALS AND METHODS

(E)-β-Farnesene was prepared by the method of Dawson et al. (1982) and (-)-β-caryophyllene obtained commercially (puriss, Fluka).

Estimation of (E)-β-farnesene and β-caryophyllene in leaves

Fresh leaves (10g) were extracted with hexane (100 ml) containing tetradecane (100 ng) as internal standard, the extract passed through a column (150 x 10mm) of Florisil in hexane and the eluate concentrated to 4 μl. Portions (0.6 μl) of this solution were analysed by gas chromatography (GC) on an OV 101 Flexsil capillary column (25m x 0.2mm) at 110°C with a flame ionization detector. Identification of peaks from (E)-β-farnesene and β-caryophyllene was confirmed by peak enhancement in GC and by GC linked mass spectrometry under standard conditions (Pickett and Griffiths, 1980). Quantitative estimation was by comparison with chromatograms of standard solutions.

Alarm pheromone against resistant aphids

Colonies of Phorodon humuli were maintained in the laboratory on hops. Susceptible aphids were obtained from Windermere, Cumbria, and resistant aphids from Rosemaunde Experimental Husbandry Farm, Worcester. Leaves bearing aphids were removed and groups of 15-25 adults counted. A droplet of (E)-β-farnesene (60 ng or 6000 ng) in hexane (0.2 μl) from a syringe was placed beside the colony and the number of aphids remaining motionless after 60 seconds was recorded.

Inhibition of aphid dispersal

Colonies of Myzus persicae were obtained by caging 3 apterous adult virginoparae on individual leaves of Chinese cabbage for 3 days. The adults were then removed and the aphids maintained for a further 3 days to develop to the 4th instar, when alarm activity under conditions (i) and (ii) was assessed.

(i) A leaf bearing a colony was inverted and placed in a closed glass vessel. (-)-β-Caryophyllene (250 μl) was applied to a cotton wick inside the vessel. After equilibrium had been achieved, either a droplet of (E)-β-farnesene (60 ng) in hexane (0.2 μl) was placed beside each colony, or a larva of Chrysopa carnea (reared in the laboratory on Drosophila melanogaster and Acyrthosiphon pisum) was placed beside the colony and allowed to attack one individual. The number of aphids remaining motionless after 60 seconds was recorded.

(ii) Plants were placed in a 350 ml glass vessel and, after equilibration, air (20 ml) was removed through a septum into a glass syringe containing (E)-β-farnesene (6 ng). The contents of the syringe were then slowly released (10 secs) over an aphid colony and aphid response was assessed as above.

RESULTS AND DISCUSSION

Pheromones and other behaviour-controlling chemicals could be used to improve the effectiveness of beneficial insects in several ways, for example:-

(i) by attracting them to sites where they are needed;
(ii) by preventing their destruction during insecticide treatment;
(iii) by interfering with the defence mechanisms of insect pests.

(i) Attraction

Many beneficial insects respond to pheromonal and host-derived kairomonal attractants. These could be used to increase the numbers of predators and parasitoids in infestations of pests, and of pollinators on flowering crops, by long range attraction from other sites. It may also be possible to enhance useful behaviour, such as oviposition by parasitoids, within the crop.

Example 1. Parasitic wasps of the genus Aphidius are known to attack various aphid pests of crops. Table 1 shows attraction of two species by volatiles from their host aphids and aphid food plants in a Y-maze olfactometer (Powell and Zhang, 1983). Chemical characterisation of the attractants is in progress, and attempts will be made to use these to improve parasitoid efficiency at low aphid densities and to attract the parasitoids to aphid infestations on cereals sufficiently early to prevent economic damage.

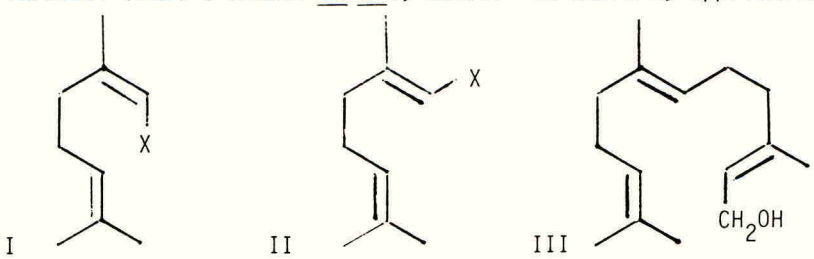
TABLE 1

Attraction of aphid parasitoids by host aphids and their food-plants.

Parasitoid	Aphid or its food-plant	% responding
Aphidius ervi	Acyrthosiphon pisum	62
"	bean leaves	63
"	Metopolophium dirhodum	58
"	wheat leaves	63
A. uzbekistanicus	Sitobion avenae	58
	Metopolophium dirhodum	60
	wheat leaves	68

(P <0.001 for each)

Example 2. Honey bees release Nasonov pheromone from a gland in their abdomen to attract other workers (Free and Williams, 1972). The pheromone comprises seven terpenoids: (Z)-citral (Ia), nerol (Ib), nerolic acid (Ic), (E)-citral (IIa), geraniol (IIb), geranic acid (IIc) and (E,E)-farnesol (III) (Pickett et al., 1980). In Table 2, application of the



I II III

a, X = CHO
b, X = CH_2OH
c, X = CO.OH

seven compounds in their natural proportions, either in polyethylene enclosures or as a spray treatment, increased the number of foraging honey bees on rosebay willow herb (Williams et al., 1981).

TABLE 2

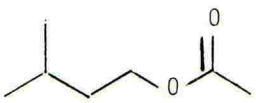
Honey bees foraging on flowers after treatment with compounds Ia-c, IIa-c and III.

No. of honey bees (total 11 experiments) control	treatment	Increase on treated flowers	Significance
1278	2298	79%	P <0.05

Attempts are now being made to devise suitable formulations of the Nasonov pheromone components to improve attraction of honey bees to legume crops for pollination.

(ii) Preventing destruction of beneficial insects

Many pollinators and insect predators are highly mobile. Repellents could be used to keep beneficial insects off crops during insecticide treatment. This would be of particular value for oil-seed rape where insecticides cannot be used at flowering, when insecticides are most effective, because of the danger to foraging honey bees (Stevenson et al., 1978). Honey bees are known to be repelled from food treated with the alarm pheromone components, isopentyl acetate (IV) from the sting gland and 2-heptanone (V) from the mandibular gland (Ferguson and Free, 1979).



IV

V

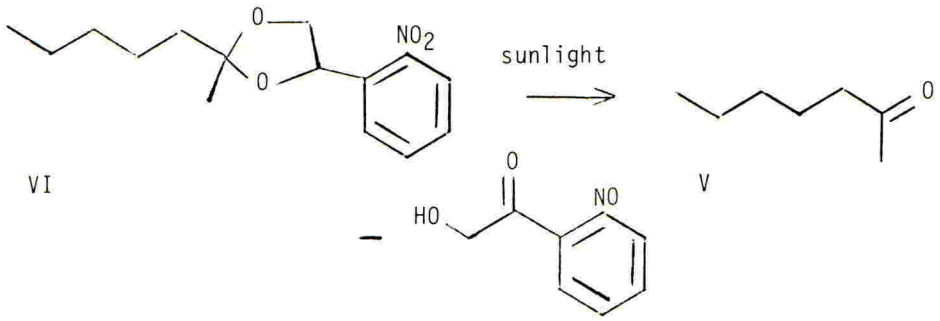
It has now been shown that when applied to oil-seed rape as an aqueous emulsion compounds IV and V substantially reduce the numbers of foraging honey bees (Table 3) (Free et al., 1985).

TABLE 3

Reduction in numbers of honeybees foraging on rape after treatment with compounds IV and V.

Time after treatment min	Reduction in no. of bees relative to control %
0-30	85
30-60	67
60-90	34

Unfortunately, because of the high volatility of these compounds the rates of application are very high (5 kg/ha for best results) and the effect is short-lived. However, more persistent pheromone precursors or propheromones have been prepared which release the active compound under sunlight, such as compound VI (Liu et al., 1984). It is hoped to develop propheromones which could be incorporated into insecticide treatments to allow spraying at the full flower stage in oil-seed rape and to remain active until the hazard to bees has passed (c. 12 hours).



(iii) Interfering with defence mechanisms

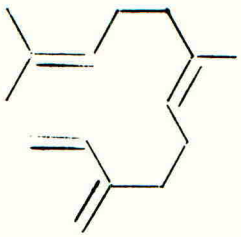
Strains of the aphid Myzus persicae highly resistant to insecticides show ataraxia (indifference) to the alarm pheromone (E)-β-farnesene (VII) which is employed by aphids in predator avoidance (Dawson et al., 1983). Thus, with a strain having a resistance factor of c. 500 to dimethoate, only 30% responded to 60 ng of (E)-β-farnesene whereas with a susceptible strain 99% responded ($P < 0.001$). This surprising phenomenon has now also been demonstrated for the damson hop aphid Phorodon humuli (Table 4). Although increasing the dose gives an improved response, the resistant strain is still less responsive than the susceptible one. Ataraxia shown by insecticide-resistant aphids to the alarm pheromone makes its use against these aphids less promising. If this phenomenon applies generally to insecticide-resistant insects, use of pheromones in crop protection would be severely restricted. However, ataraxia towards pheromones would generally mean relatively lower fitness and in the particular case of the aphids suggests much poorer ability to avoid predators. Thus the effectiveness of aphid predation is likely to be greater with insecticide-resistant aphids.

TABLE 4

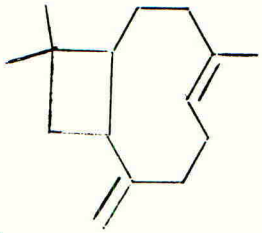
No. of Phorodon humuli moving 60 sec after exposure to (E)-β-farnesene at 60 ng and 6000 ng.

Aphid	No. of aphids moving (%) 60 ng	6000 ng	Significance
susceptible	40 ± 3.21	52 ± 3.96	$P < 0.05$
resistant	15 ± 3.42	36 ± 3.87	$P < 0.01$
Significance	$P < 0.001$	$P < 0.01$	

Recently (-)-β-caryophyllene (VIII), a sesquiterpene hydrocarbon biosynthetically related to VII, was discovered to be a highly potent inhibitor of aphid alarm pheromone activity (Dawson et al., 1984). The effect of the inhibitor VIII on dispersal by aphids attacked by a predator was investigated. The larvae of the lacewing Chrysopa carnea when placed in aphid colonies quickly attacked nearby individuals which responded by producing the cornicle secretion from which the pheromone is released.



VII



VIII

This caused dispersal of the other aphids and the response was similar to that obtained with synthetic pheromone (Table 5).

TABLE 5

Effect of aphid alarm pheromone inhibitor on aphid dispersal.

Dispersal stimulus	No. of aphids moving (%) without inhibitor	with inhibitor	
synthetic pheromone	80	49	P <0.05
predator attack (Chrysopa carnea)	92	58	P <0.01

However, when the air was permeated with the inhibitor VIII the response was significantly lower.

The wild potato, a close relative of the commercial potato, releases (E)-β-farnesene which repels aphids (Gibson and Pickett, 1983). Many other plants produce (E)-β-farnesene but this is generally associated with production of a relatively larger proportion of β-caryophyllene (Table 6).

TABLE 6

Leaf content of (E)-β-farnesene (VII) and β-caryophyllene (VIII).

plant	VII	VIII
	ng/g	
Hop (Humulus lupulus c.v. Wye Target)	15	440
Potato (Solanum tuberosum c.v. Majestic)	140	340
Carrot (Daucus carota c.v. Frubund)	<1	20
Cotton (Gossypium herbaceum c.v. Acala)	<1	20
Chinese cabbage (Brassica pekinensis c.v. Tip Top)	5	8
Sugar beet (Beta vulgaris c.v. Hilleshog monotri)	3	3
Barley (Hordeum distichon c.v. Triumph)	<1	3
Bean (Vicia faba c.v. Sutton)	<1	3

Thus any repellent effect caused by release of aphid alarm pheromone from plants is likely to be inhibited, although of the plants investigated only volatiles from potato, hop and carrot leaves inhibited the effect of exogenously applied (E)-β-farnesene (Table 7).

TABLE 7

Response of Myzus persicae on Chinese cabbage leaves to (E)-β-farnesene (VII) in air taken from above plant leaves.

Plant	No. of aphids moving VII in air	VII in air from above plants %	P
potato	3	88	<0.001
hop	7	87	<0.001
carrot	40	88	<0.001
cotton	66	77	not sig.
barley	89	77	"
Chinese cabbage	90	92	"
sugar beet	93	77	"
bean	95	92	"

(-)-β-Caryophyllene (VIII) applied to crops may improve predation of aphids and its natural production by crop plants could be valuable particularly if enhanced by plant breeding programmes or even, in the long term, by genetic manipulation.

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AGGREGATION PHEROMONES FOR MONITORING THE GREATER GRAIN BORER PROSTEPHANUS TRUNCATUS

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ABSTRACT

The successful development of a pheromone baited trap for the Greater Grain Borer Prostephanus truncatus (Coleoptera: Bostrichidae) is described. Initial tests in farm stores in Tanzania employed components of the aggregation pheromone of Rhyzopertha dominica - "Dominicalures" 1 and 2, and a combination of both. Dominicalure 2 alone was the most effective treatment demonstrating the presence of the beetle about as frequently as thorough visual inspection.

A component of the aggregation pheromone of P.truncatus "Trunc-call" was subsequently identified as 1-methylethyl (E)-2-methyl-2-pentenoate. This compound was twice as effective as Dominicalure 2 when used as a bait in laboratory bioassays or in farm maize stores in Togo. Cardboard traps baited with Trunc-call are now recommended for monitoring P.truncatus.

INTRODUCTION

The Greater Grain Borer, Prostephanus truncatus, is a pest of maize and cassava. It has recently been introduced into East Africa where it may cause weight losses in farm-stored maize up to 35% during 6 months (Hodges et al, 1983a). The beetle now extends over much of Tanzania and into southern Kenya and in January 1984 it was found for the first time in West Africa, in southern Togo.

There is a real need for an effective method for monitoring this pest in order to:

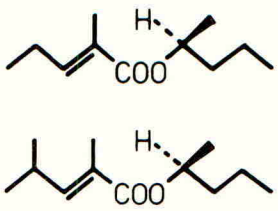
(i) give an early warning of its presence thereby reducing the task of suppression and limiting the use of pesticides;

(ii) undertake surveys of its incidence so that extension worker services and the provision of pesticides may be directed to the areas most in need;

(iii) make an objective assessment of the success or otherwise of control measures.

TRAPPING WITH DOMINICALURES

Initial laboratory tests (Hodges et al, 1983b) showed that P.truncatus is attracted or arrested by "Dominicalures" 1 and 2 (Figure 1), components of the aggregation pheromone produced by the males of the related beetle Rhyzopertha dominica (Williams et al, 1981).



DOMINICALURE 1

DOMINICALURE 2

Fig. 1. Components of the aggregation pheromone produced by male R.dominica. The naturally occurring compounds are the (S)-(+) enantiomers, but racemic materials were used throughout this work.

These components were tested separately and as a 1:2 mixture (cf Williams et al, 1981) during October 1982 in the Tabora region of Tanzania. Traps measuring 9cm square were made of four layers of single layer corrugated cardboard (Burkholder, 1976) sprayed with permethrin (0.1g a.i./m^2). The pheromonal compounds were dispensed from rubber septa impregnated with 5mg of material. Traps were deployed at random in maize stores on 60 farms (15 replicates of each treatment + unbaited traps) for two weeks, and the frequency of detection of P.truncatus by the traps was compared with that by visual inspection of up to 200 cobs taken at random from each store. The results in Figure 2 show that the traps baited with Dominicalure 2 were as effective as thorough visual inspection at detecting P.truncatus. Traps baited with the other two treatments or blank septa were much less effective.

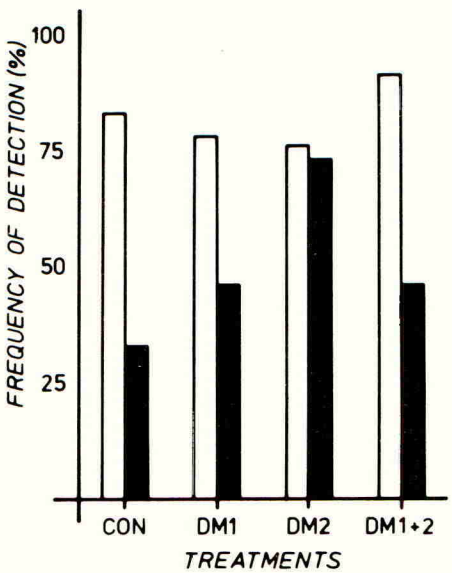
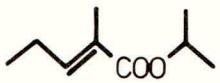


Fig. 2. Frequency of detection of P.truncatus in farm maize stored in Tanzania, October 1982; ☐ visual inspection; ▩ pheromone-traps baited with a blank septum (CON), Dominicalure 1 (DM1), Dominicalure 2 (DM2) or a 1:2 mixture of Dominicalure 1 and 2 (DM1 + 2).

TRAPPING WITH TRUNC-CALL

Examination of the aggregation pheromone of P.truncatus was undertaken in the expectation of obtaining an even more effective bait. Volatiles from male beetles elicited electroantennographic (EAG) responses from beetles of both sex, but volatiles from female beetles were without effect. Beetle volatiles were collected on an adsorbent resin, Porapak Q, and analysed by gas chromatography coupled to EAG. The major EAG-active component was identified as 1-methylethyl (E)-methyl-2-pentenoate (Figure 3), the iso-propyl ester of the acid moiety of Dominicalure 1.



TRUNC-CALL

Fig. 3. Major component of the aggregation pheromone produced by male P.truncatus

This compound is much more active than either of the Dominicalures by EAG and more than twice as active in a laboratory bioassay testing the extent to which beetles are attracted or arrested by the compounds (Figure 4). It is thus assumed to be a component of the male produced aggregation pheromone of P.truncatus and has been given the trivial name of "Trunc-call".

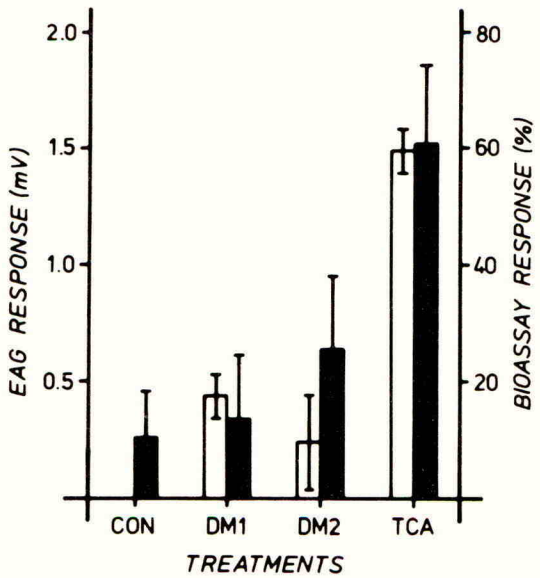


Fig. 4. EAG ☐ and bioassay ▩ responses of P.truncatus to solvent blank (CON), Dominicalure 1 (DM1), Dominicalure 2 (DM2) and Trunc-call (TCA); bars indicate standard deviations.

In January 1984, the effectiveness of traps baited with Trunc-call was compared with traps baited with Dominicalure 2 and unbaited traps, during the first recorded outbreak of P.truncatus in Togo. The traps were as described above, but only 2mg of pheromone per trap was used, dispensed from a polythene vial. These gave a slower and more uniform release of pheromone than the rubber septa (half lives of Dominicalure 2 and Trunc-call were 12 days and 5 days in polythene vials and 1 day and <1 day in rubber septa respectively, at 27°C and 8 km/h windspeed). Traps were placed in 17 farm maize stores for 2 weeks. Those baited with Trunc-call were by far the most effective in terms of the frequency of detection and the numbers of beetles captured (Figure 5).

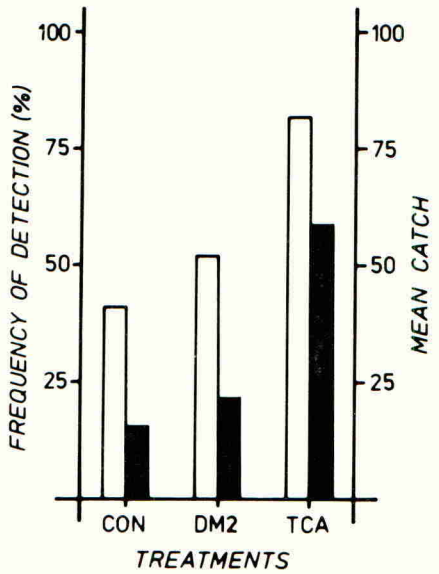


Fig. 5. Frequency of detection ☐ and mean numbers of beetles caught ▩ in maize stores in Togo using traps baited with a blank vial (CON), Dominicalure 2 (DM2) and Trunc-call (TCA).

CONCLUSIONS

Traps baited with Trunc-call are very effective for trapping and monitoring P.truncatus. TDRI is now making these traps available to responsible authorities in areas that are already suffering from, or are at risk from, infestation by P.truncatus.

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A POSSIBLE BIOLOGICAL CONTROL AGENT OF THE GREY FIELD SLUG (DEROCERAS RETICULATUM)

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ABSTRACT

The grey field slug (Deroceras reticulatum) is becoming an ever more troublesome pest throughout Britain, and it is believed that control measures could be improved by the contribution of biological control organisms. A protozoan, a member of the microsporidia has been found to be a common pathogen which attacks the intestine of D. reticulatum. The disease is transmitted by resistant spores passed out in the faeces. Progeny of diseased slugs can be infected by external contamination of the egg. The microsporidian occurs throughout Britain, and has been recorded in the USA. Field studies have shown host density and crop type to be important in disease development and spread. The microsporidian causes a reduction in fecundity, and initial observations suggest effects on slug feeding, growth rates and longevity. Future research, potential uses and problems of the disease as a biological control agent are discussed.

INTRODUCTION

Slugs are serious pests of agricultural crops in Britain. Recent changes in the types of crop grown, and general crop husbandries have resulted in increased slug damage.

Present cultural and chemical methods of control are effective but there is still room for considerable improvement. Thus, as little is known of the contribution of biological organisms in slug control, a study was initiated to find and evaluate possible candidates for microbial control of slugs.

The study concentrated on the most important pest species of slugs, the Grey Field Slug (Deroceras reticulatum). One disease, a protozoan microsporidian, was found to occur particularly commonly. The proven success of the use of microsporidia in insect pest control systems prompted a detailed study of the disease in D. reticulatum.

MATERIALS AND METHODS

Field Sampling

Slugs were obtained by searching under ground cover and by using traps in the form of tiles baited with wheat grains. Best catches were obtained in damp, cool conditions. Slug densities were assessed by soil washing.

Laboratory assessment

The disease manifests itself by the presence of numerous refractile spores, which are conspicuous under phase contrast optics. Fresh smears of tissues were made and examined for the presence of such spores.

Slug culture

Slugs reared from washed eggs were kept in plastic boxes lined with moist tissue paper. The diet consisted of Chinese cabbage, carrot and an artificial diet of 5% Beemax and 3% milk powder combined in an agar gel. Cultures were maintained at 15-20^{o}C, with a 14 hour day.

Microsporidian methods

Infected slugs were dissected and diseased tissue homogenised in distilled water. Spore concentrations were determined with a Haemocytometer, and serial dilutions made to obtain required dosages. Slugs were dosed individually by application of known dosages of spores onto a plug of the artificial diet.

RESULTS

The life cycle of the microsporidian is in Fig. 1.

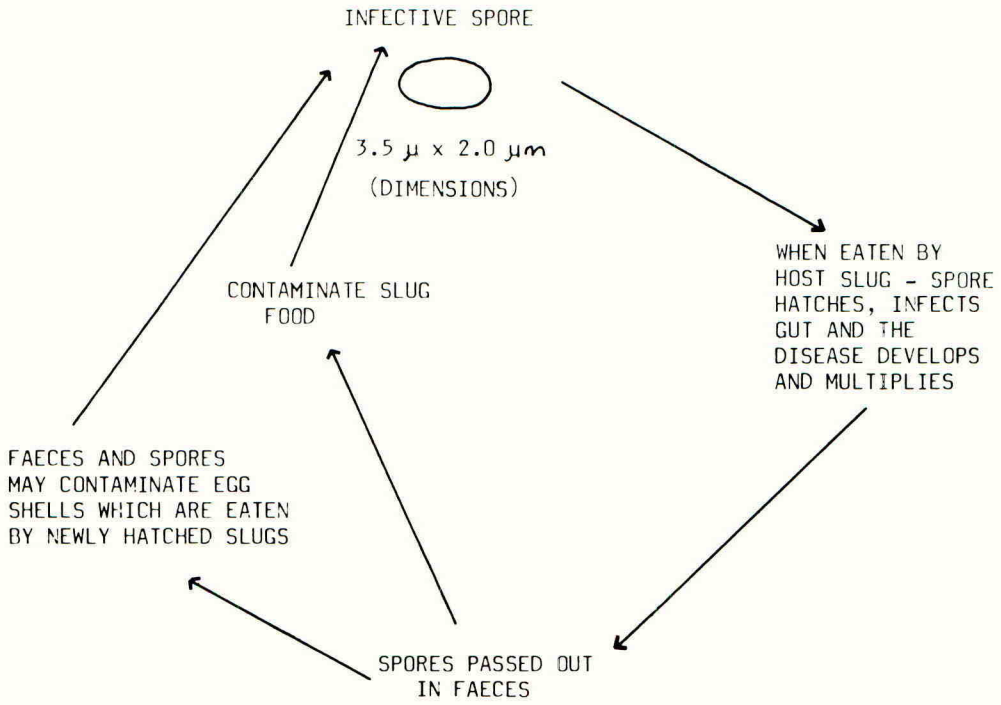

Fig. 1 Life cycle of slug microsporidian

The microsporidian has been identified as a new species and is currently being formally described. The disease only attacks the intestine of the slug. The disease is characterised by the presence of numerous small refractile spores infecting gut cells. The gut may be completely destroyed allowing entry of bacteria and toxins into the haemocoel which subsequently cause death. At 20°C the life cycle can be completed in 12 days. The disease tends to be chronic rather than lethal in character. Sublethal levels of infection decrease nutrient uptake in the intestine and host food reserves normally used for slug activity, growth and reproduction are consumed by the parasite. Spore loads of up to 350,000 spores/mg of slug tissue have been found from field infected slugs. Spores are passed out in the faeces and as infection becomes more severe, increased numbers of spores are disseminated into the environment. Initial observations suggest that only D. reticulatum is attacked although detailed host range studies are under way.

Distribution of the microsporidian disease in Britain

Slugs were sampled from various sites of high slug density where disease is most likely to occur and results show that the disease occurs throughout Britain (Fig. 2). There is also a record of the disease in the U.S.A. (Brooks 1967). Since D. reticulatum occurs throughout the northern hemisphere, the complete range of the disease is not known.

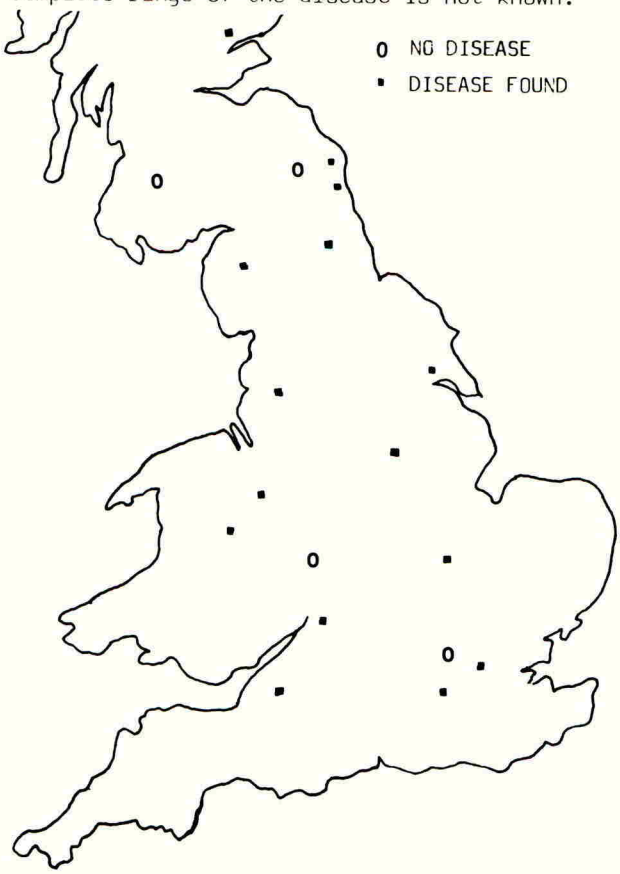

Fig. 2 Distribution of the microsporidian disease of D. reticulatum in Britain

Disease incidence was studied on a more local and detailed scale and was found to be dependent on slug density and crop type. Crops of oilseed rape appeared particularly favourable to disease development and spread.

Disease and slug reproduction

Microsporidia are known to reduce the fecundity of their hosts (Milner 1974; Malone and Wigley 1981). In order to examine fecundity in D. reticulatum, unmated slugs were obtained from the field. Infection with microsporidia was determined by examination and count on faecal spore output. Pairs of heavily infected slugs (50), healthy slugs (40) and healthy and infected slugs (15) were allowed to breed. Egg production of each slug was recorded. At the end of the experiment, slugs were dissected and the spore load calculated.

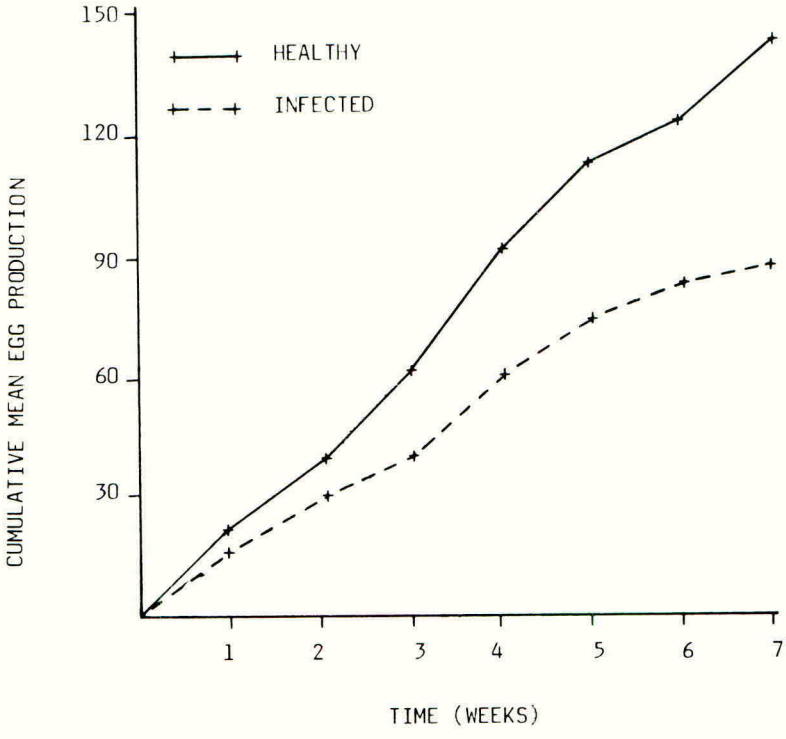

Fig. 3 The effect of disease on egg production in D. reticulatum

The results show that infection (of mean level 261,000 spores/mg of slug tissue) caused a 40% reduction in mean egg production for each slug (Fig. 3). Slugs are hermaphrodite and pairing of healthy and infected slugs showed that infection affected the female organs of reproduction only. Nutrients normally destined for use in host reproduction were depleted and used up by the parasite. There was no effect of the infection on egg viability.

Transovum tranmission

Infection can be transferred from the parent to the progeny via the egg. When eggs are laid, they are sometimes contaminated by faeces and hence spores. On emergence from the egg, young slugs often eat part of the outer eggshell and any contaminating spores on the surface. To assess the efficiency of transovum transmission, eggs from pairs of heavily infected slugs were treated in 3 ways. 30 were carefully washed in a funnel and tube wash, 30 were left as found, and 30 were immersed in a solution of 1.2×10^6 spores/ml. After hatching, slugs were kept in contact with the old eggcases for 7 days. Food was also provided. After 4 weeks, the surviving slugs were dissected and infection assessed (Fig. 4).

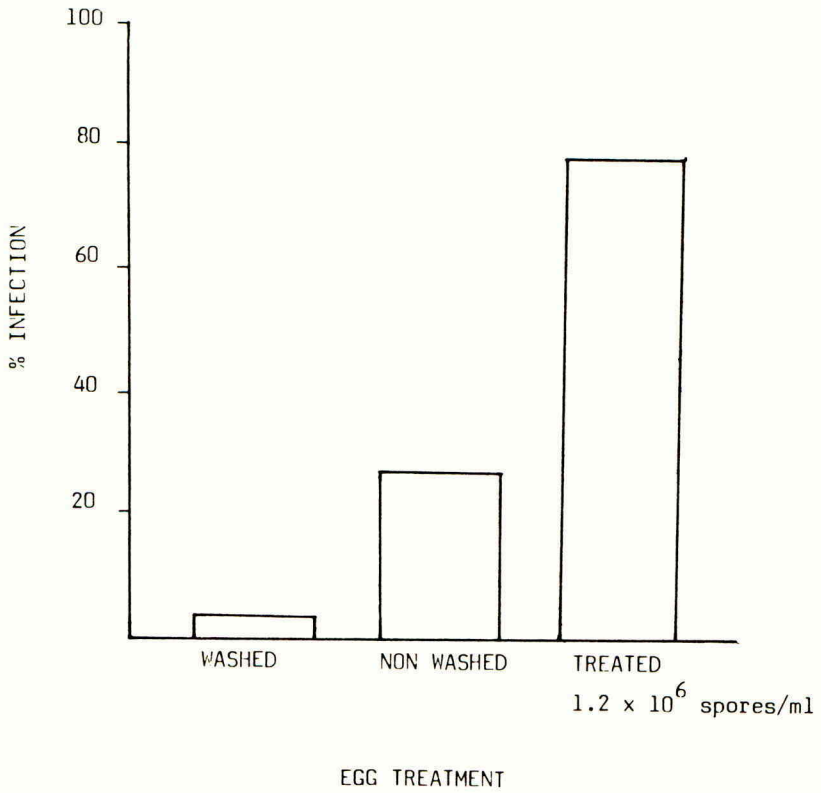

Fig. 4 Transovum transmission of infection in D. reticulatum

The infection of newly hatched slugs is a highly desirable attribute for a control agent, as young slugs are particularly susceptible to mortality from the stresses of weather and food shortage and infection at this age weakens them even more.

DISCUSSION

The microsporidian disease of slugs is a common and widely distributed pathogen. While many of its effects are chronic rather than sublethal, it has many useful attributes. The results described demonstrate that the microsporidian disease reduces slug fecundity by 40% and can be transmitted to the next generation, and our present studies suggest that the feeding rate, growth rate and longevity are also affected. The limited host range suggests that the disease is highly selective, but the problems of efficient and cost effective mass production, formulation and application must be overcome before it can be of use as a biological pesticide. Even then the effects of the disease are slow acting, often neither dramatic nor immediately apparent, and persuading growers that the pathogen does control slugs would be difficult. The microsporidium alone would not provide a sufficient level of slug control, but in combination with molluscides or possibly plant resistance, much improved control would result.

Future research should be aimed at evaluating the microsporidian potential alone, and in mixtures with molluscicides, as a control agent for slugs in field trials.

ACKNOWLEDGEMENTS

The study is financed by the Potato Marketing Board.

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DESCRIPTION AND EFFICIENCY OF A PARASITE BOOSTER TO CONTROL SUGARCANE TOPSHOOT BORER.

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ABSTRACT

Scirpophaga excerptalis Walker, commonly known as the Topborer causes serious damage to sugarcane. As chemical control is inefficient, a technique was devised to conserve and boost up the native egg parasites in the field. Eggmasses (naturally parasitized) were collected and posted through a hole made on an internode of a piece of hollow bamboo (Parasite booster). The periphery of this bamboo hole was smeared with locally prepared adhesive to stop the larvae of the Topborer crawling out for infestation. These boosters were kept in an upright position in the field 6.5m apart and thus allowed the parasites to fly out to parasitize other egg masses of the pest. The technique successfully reduced the pest population and simultaneously enhanced the parasite population in the same field. The treated field had 20% less infestation than the untreated one. The methods of preparing the booster and adhesive are discussed.

The top shoot borer (TSB), Scirpophaga excerptalis Walker (Pyralidae; Lepidoptera) is a serious pest of sugarcane in Bangladesh (Hazarika, 1951; Ahmad, 1962; Kabir and Khan, 1973). This host specific and persistent pest causes damage to the crop throughout the year but is particularly damaging from April to August. Infestation ranges from 5 to 100% and estimated loss varies from 0.8 to 14.0 percent by weight of cane and 1.5 to 29.6 percent by weight of sugar (Miah et al., 1980).

The chemical control of sugarcane borers is not satisfactory despite considerable development in the field of pesticides (Long and Hensley,1972). No chemical pesticide has yet been found suitable to control TSB in Bangladesh (SRI Annual Report, 1973-78, 1979-80; SRTI Annual Report 1981 & 1982) and hence more emphasis has been given to the mechanical, biological and cultural methods of borer control in different countries of the world (Shahjahan, 1979).

There are several natural egg parasites of TSB like Telenomus sp. (4 types), Telenomus dignoides Nixon, Tetrastichus sp., Tetrastichus schoenobii Ferriere, and Trichogramma sp. (SRI Annual Report, 1973-78).

It has been reported that 86.2% egg masses (SRTI Annual Report, 1981) and 62.54% of eggs were found to be naturally parasitized; most of the eggs contained two parasites.

The collection and destruction of the TSB egg masses is the general control measure followed at present by the sugarcane growers and millsfarms every year. However, this practice also leads to the destruction of the natural parasite.

The idea of parasite conservation or boosting up of a population is not new. A technique was suggested earlier called 'a local device to encourage egg parasites of TSB', where two containers of varying sizes, kerosinized water, a covering shed and a stand for hanging the containers were required (Osborn, 1979). This appeared to be complicated and difficult to assemble by the sugarcane growers. Therefore, an attempt was made to devise a technique for boosting up the population of native parasite species and to verify its effectiveness under field conditions.

MATERIALS AND METHODS

The device discussed in this report consists of one internode of hollow bamboo and sticky materials prepared locally. These are described below.

Description of the apparatus

The main device consists of a mature hollow bamboo piece having two or three nodes with a half of one internode on one side (Figure 1).

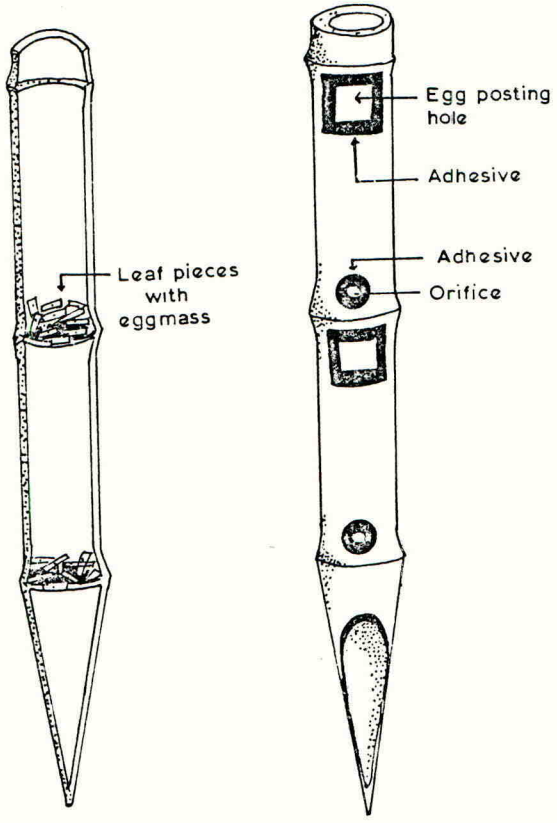

Figure 1. Diagram of the parasite booster : Right - The details of one individual booster. Left - Longitudinal section of the booster showing the eggmass inside.

In each of the internodes, one hole (approx. 3 cm x 3 cm), 4-5 cm below the upper node is cut out (the egg posting hole). On the same side as the egg posting hole, an orifice is made at the lower end of the same internote, but just above the second node (the rain water exit hole). The diameter of this orifice need not be more than 7.0 mm. The half internode portion is tapered and pointed for easy pegging in soil.

Preparation of the sticky material

The device requires a greasy or sticky material for smearing on the periphery of the egg posting hole and the orifice. Therefore, an attempt was made in the laboratory to prepare such a material from resin and castor oil. A measured quantity of castor oil was first heated to boiling point and a measured quantity of resin powder was gradually added. The mixture became thicker on cooling. It was observed that out of several combinations, a mixture of 6 g resin and 5 ml. castor oil gave an adhesive quantity of the desirable consistency.

Use of the device (Parasite Booster)

Egg masses along with a small portion of leaf collected from the field are put into the hollow space of the booster through the upper egg posting hole. The outer surface around the egg posting hole and rain water exit hole are smeared with the locally made adhesive. The bamboo is then put in an upright position, but tilted a little towards the holes/orifice to avoid or drain out rain water, if any, through the orifice. First instar larvae that hatch from the unparasitized eggs try to crawl out and get stuck to the greasy or sticky layer outside and die. Parasite adults emerge from the parasitized eggs, and fly out through the egg posting hole. These parasites disperse in the field and parasitize other egg masses of the top shoot borer.

Assuming that the small parasite can fly only about 6 m from this "parasite booster", 1 ha of land would require 75 such bamboo pieces.

RESULTS AND DISCUSSION

A small trial was set up at the Institute's farm with variety Isd-9/57, (0.14 ha) in August, 1983, comprising (1) booster area(treated) and (2) non-booster area (check). Bamboo boosters were installed in the area, where egg masses were collected daily or at an interval of 5-7 days depending on the availability of the eggs which were kept in the nearby boosters. Adhesive (Resin-Castor Oil) was used for the boosters every fifth day. The efficacy of boosters was studied by comparing the infestation level (Table 1). The variety Isd-9/57 being susceptible to top shoot borer had 27.00% infested plants in August, when the parasite boosters were installed.

Table 1. Efficacy of Top shoot borer egg parasite booster during four months' study (August-December 1983), SRTI.

Variety	Initial infestation (%) August		Final infestation (%) December		Efficiency of booster over check (%)
	Booster	Check	Booster	Check	
Isd-9/57	27.00	28.00	36.00	46.00	21.74

The efficiency of these "parasite boosters" was assessed in December. The area with boosters had 36% infested plants compared to 46% infestation in the area where boosters were not installed (check). Thus, this technique reduced infestation by 21.74%.

The TSB egg parasite booster is a simple device for augmenting the population of natural parasites and trapping TSB larvae. The boosters need to be installed at the very beginning of TSB infestation (Approximately mid-February). Egg mass collection and posting in the boosters should be continued up to June. It is suggested that the continuous adoption of this technique may markedly reduce the TSB population.

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EVALUATION OF POLYPHAGOUS PREDATORS OF APHIDS IN ARABLE CROPS

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ABSTRACT

A range of methods for evaluating the ecological potential of aphid natural enemies in arable crops is given. The aim is to amplify existing rankings of predator species, based on one or two criteria only, so that a battery of evaluation methods can give a more robust ranking. Such rankings are needed to aid interpretation of the selective effects of agrochemicals on 'non-target' species as well as to identify candidate species for use in integrated control programs. Criteria discussed fall into the categories: extent of disruption by agricultural practices; season of activity; field penetration from boundary overwintering sites; responses to prey heterogeneity; and feeding behaviour and consumption rate. Data are presented from some recent studies in which species are compared using some of these criteria; the extent to which earlier published rankings change as a result are discussed.

INTRODUCTION

Arable crops such as winter wheat in the U.K. can harbour hundreds of species of aphid predators and parasitoids. The potential value of the polyphagous groups, in particular members of the Carabidae, Staphylinidae, Araneida and Dermaptera, has been recognized largely in the past decade. Since the early survey-based studies of Potts & Vickerman (1974), which pointed to the general role of such groups in contributing to the suppression of aphid outbreaks, several studies have taken place in which groups of predators have been excluded experimentally from crop areas. An example of one of these is given below. These studies have shown that partial removal of polyphagous predator populations can lead to large increases in aphid numbers. However, such barrier methods are limited in their ability to exclude particular species of predator, being able to influence only major faunal groups, such as soil-surface predators, flying predators and parasitoids etc. There is an urgent applied need to obtain more detailed information on which species have the greatest biocontrol potential. This information is required for the following main reasons:

1) Manipulation of the fauna in integrated control programs. Changes in cereal agronomy (e.g. direct drilling or undersowing) or in field boundary treatments influence different predator species in different ways; the potential ecological benefit of such changes cannot be evaluated without knowledge of individual species' biocontrol potential.

2) Ecological effects of agrochemicals which kill some predator species. If a compound exhibits different toxicities to different predator species, the ecological implications cannot be assessed without a ranking of predators' effectiveness.

An important attempt to rank polyphagous predators in cereals was made by Sunderland & Vickerman (1980). In this work, the density of each species in a group of sixteen polyphagous predators (thirteen carabids, two staphylinids and one dermapteran) was multiplied by the proportion of individuals containing aphid remains following dissection. This gave a

useful 'predation index' which, however, is amenable to improvement through the incorporation of other criteria. Such criteria could include (see Putman & Wratten, 1984):

1) The extent to which the species' populations are disrupted by agronomic practices, such as harvest, ploughing and burning.

2) Season of predatory activity. A high predation rate at or after the aphid population peak is of limited value.

3) Field penetration. Species overwintering in the boundary (the majority; Sotherton 1984) need to disperse effectively and rapidly into the crop.

4) Response to prey spatial heterogeneity. There are theoretical (Hassell 1978) and experimental (Bryan & Wratten 1984) reasons why predators' responses of this type could be useful indices of their biocontrol potential.

5) Feeding behaviour. Some predators obtain aphid prey largely on the soil surface while others are active plant climbers. The role of the former group is not clear as the extent to which they capture living prey is unknown.

6) Assessment of fluid feeders. Spiders, harvestmen (Opiliones) and many staphylinids are fluid feeders and are therefore precluded from being incorporated in rankings of the Sunderland & Vickerman (1980) type.

7) Consumption rate. The ranking referred to above did not quantify the number of aphids in the gut and could be more robust if this were included.

Work at Southampton and elsewhere is concerned with the above additional ways of evaluating predators and this paper contains examples from some of these approaches, emphasising the most recent and novel research areas.

ESTABLISHMENT OF PREDATORS' POTENTIAL - BARRIER WORK

5m x 5m plots of sugar beet were established near Lincoln College, Canterbury, New Zealand, in October 1980; 'ingress-only' and 'egress-only' trenches were used to manipulate soil-surface predator numbers (experimental details in Wratten and Pearson 1982). 'Egress-only' plots received weekly applications of the insecticide carbaryl on the soil surface further to reduce predator numbers. The predator fauna comprised mainly staphylinids, spiders and harvestmen and was reduced by the above methods by 50% compared with the control plots (Fig.1). This limited reduction, however, led to a 40-fold difference in aphid populations (Fig.2). As mentioned earlier, such methods do not identify the predator species which are mainly responsible for the effects on prey populations; other methods are needed to produce these rankings.

FIELD PENETRATION AND DISPERSION OF PREDATORS

In 1983, a 36ha field of winter wheat in the U.K. was sampled every 10-14 days from the end of March to mid August. A vacuum insect net was used in 24 transects across the field, samples being taken at 5, 50 and 100m points along each transect. Each sample consisted of 5, or 10, 0.1m^2 sub-samples taken for 5 seconds. (The larger sample size was used after 13 May when mean densities of most predator species had decreased.) The pattern of dispersion of four polyphagous predators sampled in this way is shown in Fig. 3.

The species shown all overwinter in field boundaries but differ in the extent to which they have achieved a uniform field distribution at the time

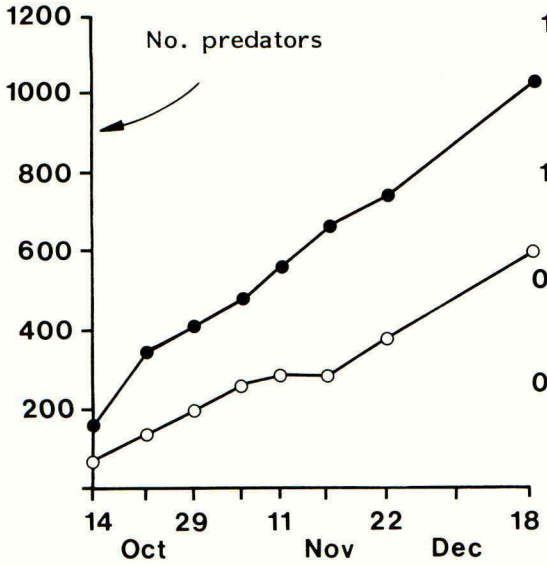

Fig. 1 Cumulative catch of predators in pitfall traps:
●—● control;
○—○ predator reduction.

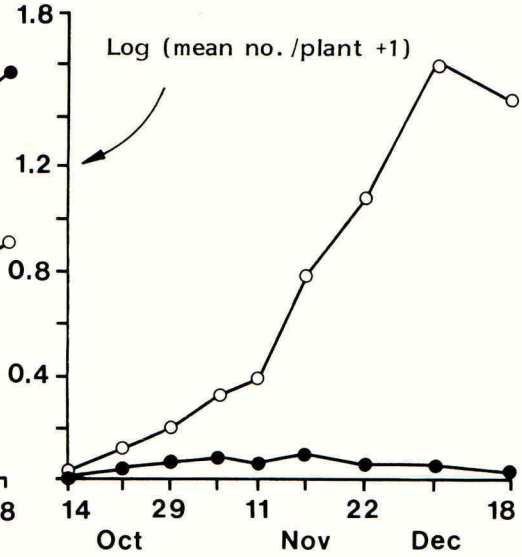

Fig. 2 Aphid numbers/plant:
●—● control;
○—○ predator reduction.

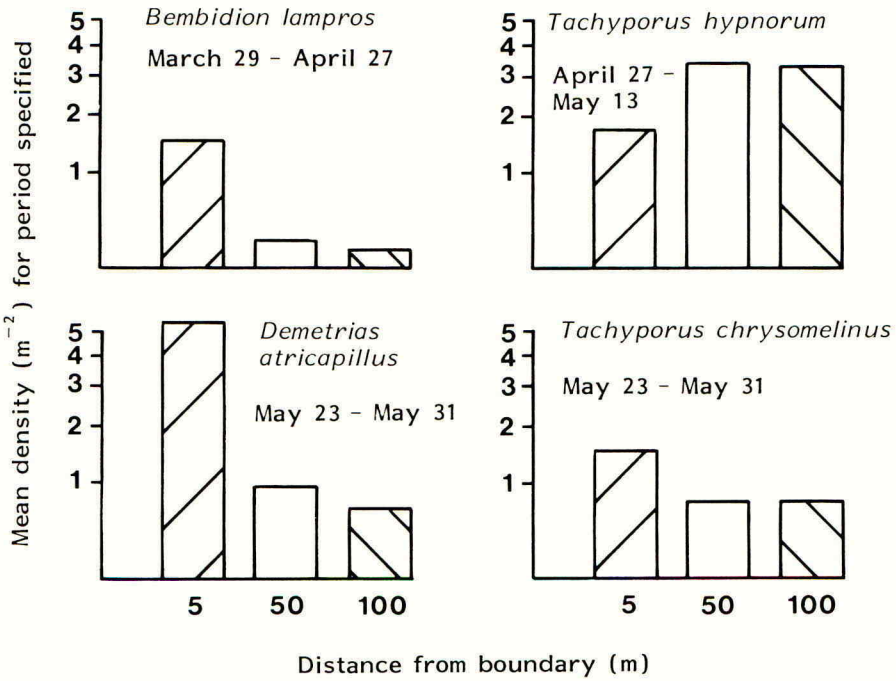

Fig. 3 Distribution within crop and mean density during the period of maximum abundance for each of four predator species.

of their maximum abundance. In Sunderland & Vickerman's (1980) ranking, the carabids *D. atricapillus* and *B. lampros* were placed first and sixth respectively, with the staphylinid *T. hypnorum* being ranked fifth. Fig.3 shows that *D. atricapillus* weakly penetrates the crop, indicating, on this criterion alone, that its potential may be lower than expected.

PREDATOR RESPONSES TO PREY AGGREGATIONS

On 9 May 1983, twenty aggregations of the aphid *Sitobion avenae* were created by infesting winter wheat in field cages measuring 0.88 x 0.88 x 1m. The wheat (cv. Armada) was at the tillering stage. Pitfall trapping began on May 31 in each patch and in each of twenty control (uninfested) areas. Cage covers were removed on that date. Further experimental details are given in Bryan & Wratten (1984).

Carabid and staphylinid species differed markedly in their overall abundance in the traps and in particular in the relative numbers caught in patch and control areas (Fig.4). The trend in Fig.4 shows a very high level of response in a group of staphylinid species, with a carabid of relatively low aphidophagy, defined in terms of patch response, at the other extreme (*Nebria brevicollis*). Similar studies in 1984 have used absolute sampling methods (surface searching) to avoid problems of interpretation of pitfall catches and have given predator rankings similar to those in Fig.4.

T.o., T.c., T.h.: *Tachyporus obtusus, T. chrysomelinus, T. hypnorum;* P.c., *Philonthus cognatus;* A.d., *Agonum dorsale;* B.o., *Bembidion obtusum;* B.l. *Bembidion lampros;* N.b. *Nebria brevicollis.*

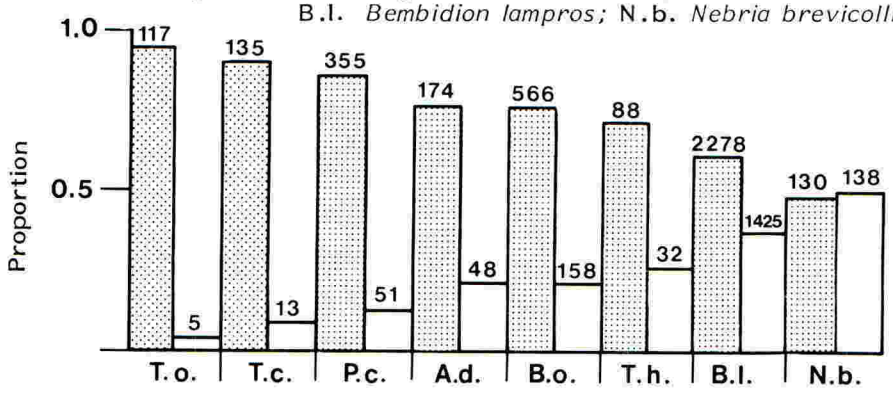

Fig.4 Proportion of predator catch between May 31 and June 6 in patch (shaded) and control (unshaded) areas. Nos. are totals caught.

The behavioural basis of the above responses to prey spatial heterogeneity is not revealed by the above field methods. However, time-lapse video recording and subsequent analysis of predators' responses in a large-scale laboratory arena can give supporting data to that given in Fig.4. A patch of 49 adult *S. avenae* was established in a 49cm² grid in a 10m² experimental arena, comprising wheat seedlings growing in John Innes No.2 compost. The wheat was illuminated with eight 400 watt mercury vapour lamps, a light source which was replaced by that from 16 60 watt red tungsten lamps during the 8h 'dark' period. The room was cooled to 14°C. Sixty adult *Agonum dorsale*, previously starved for 24h, were released into the arena and two video cameras positioned above it, one pointing vertically down onto the prey patch, the other, 2.5m away, onto an aphid-free area.

Cameras were National WV1800B 'Vidicon'; recorders were NEC 9507 U-matic VCRs with time-date generators; lenses were Fujinon CF 125C 12.5mm F1.4 auto iris and monitors were Melford DO1-17 monochrome. The ability of a polyphagous predator to exhibit positive responses to a local abundance of one prey species, indicated by the data in Fig.4, is confirmed in the details of the response, recorded by time-lapse video (Fig.5). *Agonum dorsale* spent longer periods in patch than control areas and rapidly reduced

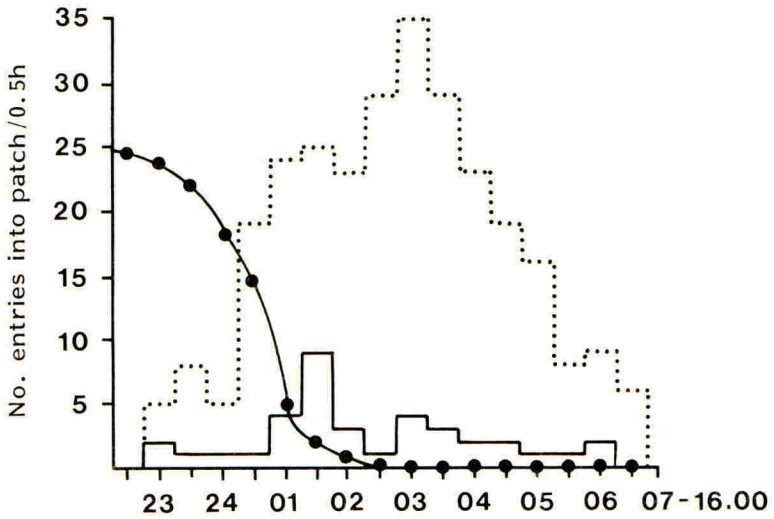

Fig.5 No. entries by *Agonum dorsale* in prey patch (....) and control (-) areas. ●—●: prey no.

the prey 'population' to zero, even though the patch occupied less than 0.05% of the total area. Also, the response to the patch area persisted long after the prey had been removed: the behavioural basis of the latter remains unknown.

CONSUMPTION RATE BY PREDATORS

A small predator may be abundant, respond to prey patches and show good field penetration but exhibit an aphid consumption rate too low to bring about a major effect on the numbers of its prey. A range of polyphagous species were maintained under an 8h dark and 16h light regime with corresponding temperatures of 12°C and 19°C (mean 16.6°C) and offered first-instar *S. avenae* in excess. Although limited, this method does give an indication of maximum potential consumption. There is a 10-fold difference in consumption rate among a range of polyphagous species (Fig.6) which, combined with other predator attributes discussed above, can contribute towards establishing a robust ranking of predators' biocontrol potential.

DISCUSSION

There is an increasing requirement for reliable information on the biocontrol potential of 'non-target' invertebrates in cereals and other arable crops. Agencies such as the International Organisation for Biological Control, and the European Economic Community (through its '6th Amendment' Directive) as well as agrochemical companies all need to make sound ecological decisions on which non-target species should be cultured and used

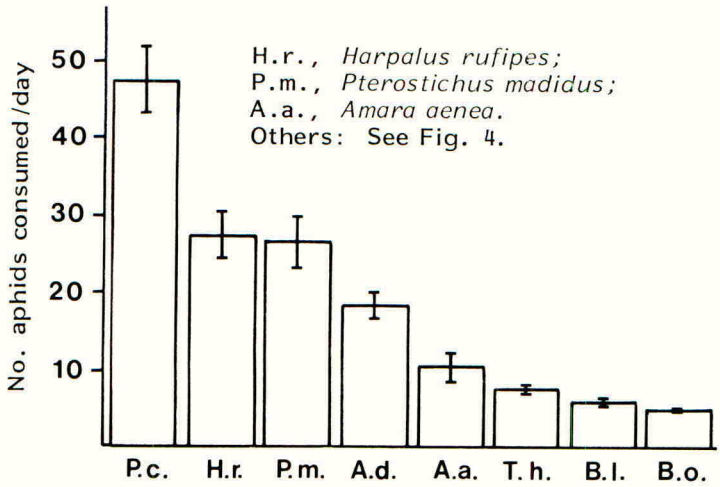

Fig.6 No. first-instar *S. avenae* consumed/day by a range of predators ± 95% C.L.

in bioassays. Only a battery of ecological methods, including some empirical but ecologically sound approaches, can give a robust ranking of natural enemies' potential in arable land.

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PAECILOMYCES FARINOSUS, A POTENTIAL BIOLOGICAL CONTROL AGENT FOR MAJOR PESTS OF AILANTHUS IN KERALA, INDIA

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ABSTRACT

Ailanthus triphysa is a fast growing tree species of considerable economic importance. *Eligma narcissus* (Lepidoptera: Noctuidae) and *Atteva fabriciella* (Lepidoptera: Yponomeutidae) are the two major pests of *Ailanthus* in India. In a natural population, a number of pupae were found parasitised by the fungus, *Paecilomyces farinosus*. Preliminary laboratory studies employing spore suspension of *P. farinosus* sprayed on to the larvae confirmed the effectiveness of the fungus in causing mortality of *E. narcissus*. *A. fabriciella* was also found susceptible to the fungus in similar infection experiments.

INTRODUCTION

Ailanthus triphysa is a fast growing tree species and grown extensively as forest plantations in Kerala. Based on studies conducted in *Ailanthus excelsa*, a species cultivated in dry parts of India, two major pests - *Eligma narcissus* and *Atteva fabriciella* have been reported to cause serious damage to young plants (Chatterjee *et al*., 1969; Mathur *et al*., 1970). The above two pests are also frequently observed in *A. triphysa*. Larvae of *E. narcissus* feed on all the leaves whereas those of *A. fabriciella* web the tender leaves and feed from within. No systematic studies on the control of these pests have been conducted so far.

In recent years, the use of biological control agents such as parasites, bacteria and fungi for controlling insect pests has been advocated to prevent the environmental hazards posed from chemicals. Amongst these three agents, the role of entomogenous fungi as an effective pest suppressive agent has been recognized by various workers (Evans, 1974, 1982; Ferron, 1978; Retnakaran *et al*., 1982; Stairs, 1972).

During the course of studies to record the seasonal occurrence of major pests in *Ailanthus* plantations in Kerala, many dead pupae of *E. narcissus* were found infected with an unidentified fungus. Hence laboratory studies were undertaken to assess the potential of the fungus as a biological control agent against pests of *Ailanthus* and the results are presented in this paper.

KFRI Scientific paper no. 39

MATERIALS AND METHODS

The pupae of E. narcissus infected with the fungus were collected from the field and brought to the laboratory. After removing the silken cocoon, the material was washed in running tap water for 1h and then surface sterilized with 0.01% mercuric chloride for 3 min and subsequently washed in several changes of sterile distilled water. These were then plated on Potato dextro agar (PDA) medium and incubated at 27 ± 2°C. The infected larvae consistently yielded a fungus and this was identified by the Commonwealth Mycological Institute, U. K.

Field collected larvae of E. narcissus and A. fabriciella were employed for the study. Second and fourth instar larvae of E. narcissus and larvae (various instars) of A. fabriciella were used for testing the efficacy of the fungal spore suspension. The spore suspension of the fungus was prepared from a 7-day old culture using sterile water. Two concentrations of the spores were used - 10^4 per ml and 10^5 per ml. The spore concentration was adjusted by using a Neubauerhaemocytometer. In one set of experiments, the larvae were sprayed with the spore suspension using an atomiser. After air drying, the inoculated larvae were carefully transferred into plastic jars (14 cm x 11 cm) containing surface sterilized leaves of Ailanthus. In the second set, three leaves of Ailanthus were sprayed with the spore suspension of the fungus and transferred into plastic jars and the test larvae were introduced into the container. In the case of A. fabriciella only the effect of direct application of spore suspension was evaluated. Fresh leaves were given for feeding, whenever necessary.

In the controls, sterile water was sprayed on the leaves as well as on the larvae. Observations were recorded on mortality, pupation, emergence etc., both in control and treated sets from 24 h onwards, after inoculation. There were three replicates each with 10 larvae for different treatments. Mortality caused by the fungus is expressed as a percentage of the effective number of larvae.

RESULTS

The fungus was identified as Paecilomyces farinosus (IMI.281615).

In treated groups, where the spore suspension was sprayed directly on the larvae of E. narcissus 83-100% mortality was observed within 48 h of incubation (Table I). In the case of second instar larvae, the infection spread rapidly causing death of the larvae within 24 h. Infected insects showed profuse growth of fungal mycelium over the body. Eventhough five inoculated fourth instar larvae pupated, they died in the pupal stage due to fungal infection. In control sets, both second and fourth instar larvae of E. narcissus and those of A. fabriciella, there was no mortality. However, a few larvae of both insects pupated, which later emerged as normal adults.

In the experiments in which larvae were exposed to treated leaves, only 76 - 93% of larvae died due to fungal infection. It took a longer period of 72 h to cause the mortality compared to the first set of experiments. The pupae formed from this group did not emerge as adults and the mycelial growth on the body was also less. In this group, 6-13% of the dead larvae had no external mycelial growth.

TABLE 1

Effect of Paecilomyces farinosus on survival/mortality of larvae of Eligma narcissus and Atteva fabriciella in artificial inoculation trials

Insect/larval stage	Treatment	Percent mortality of larvae at different hours of incubation						Pupated		Live
		Spore Concn. I			Spore Concn. II			Spore Concn. I	Spore Concn. II	
		24 h	48 h	72 h	24 h	48 h	72 h			
E. narcissus										
Second instar	direct spore application	100.0	-	-	100.0	-	-	0	0	0
"	Spore aplied on leaves	26.6	50.0	93.3	40.0	73.3	90.0	0	0	0
Fourth instar	direct spore application	83.3	100.0	-	66.6	83.3	-	0	16.7	0
"	Spore applied on leaves	13.3	80.0	-	36.6	63.3	76.6	20.0	0	0
A. fabriciella										
Various instars	direct spore application	0	0	0	33.3	83.3	100.0	0	0	0
E. narcissus										
Second instar	Control I	0	0	0	0	0	0	0	0	100.0
Fourth instar	Control II	0	0	0	0	0	0	0	14.3	85.7
A. fabriciella										
Various instars	Control III	0	0	0	0	0	0	0	6.7	93.3

Spore Concn I = 10^4 spores per ml. Spore Concn II = 10^5 spores per ml.

100% mortality of larvae was recorded in the case of A. fabriciella after 72 h. However, over 80% of the larvae were found infected within 48 h.

DISCUSSION

The fungus, Paecilomyces occurs on a wide range of substrata all over the world and almost all species are parasitic on insects, sometimes causing epidemics at times of high population build up (Brown and Smith, 1957). Our studies indicate clearly that the fungus P. farinosus is effective in causing mortality of larvae of both the pests, E. narcissus and A. fabriciella.

Although direct application of spore suspension was more effective under laboratory conditions, this may not be practicable in the field situation. The larvae of E. narcissus remain on the under surface of the leaf and those of A. fabriciella web the leaves and feed from within. Here the chance of spores falling on to the larvae is low. The second method i.e. exposing larvae on treated leaves also showed 76-93% mortality. This method of application may be easier, but a large quantity of inoculum will be required. Recently Bajan et al. (1982) have demonstrated the use of P. farinosus as one of the agents in the biological control of Colorado beetle, Leptinostarsa decemlineata.

Our field observations in selected plots during peak incidence (August - December 1983) of E. narcissus showed that over 40% of the pupae collected were infected with the fungus, P. farinosus and nearly 20% parasitised by Dipterans. It is possible that the above factors may be responsible for checking the spread of the pests. Though the fungus, P. farinosus has potential as a biological control agent against Ailanthus pests, its application under field conditions requires further studies.

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BIOTIC POTENTIAL OF METAPHYCUS HELVOLUS

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ABSTRACT

The hemispherical scale, Saissetia coffeae is a pest of tropical crops and ornamentals in heated glasshouses. The scales breed all the year round on coffee and other plants in the Wye College conservatory. The development time in summer took two months, but in autumn the period was doubled. The scales had only 4 to 6 generations per year. The release of 200 female Metaphycus helvolus based on a ratio of scales to parasitoids of 100:1 appeared to be effective against these scale insects. The parasitoids had a shorter life cycle, completing 12-14 generations per year. The parasitoids could breed all year round as indicated by adult emergence from trap plants.

INTRODUCTION

The hemispherical scale, S. coffeae is a pest of tropical crops and ornamentals in heated glasshouses or conservatories. The pest is normally controlled by pesticides but some of these chemicals are phytotoxic to the ornamentals (Brewer & Tippins, 1982). The scale has many natural enemies in the field (Ibrahim, 1983) and one of these, M. helvolus (Hym: Encyrtidae), has been used extensively for the biological control of the black scale, S. oleae (Luck, 1981). The effectiveness of M. helvolus in the field against S. coffeae had been described by Salazar-Torrez (1964). In the glasshouse, Doutt (1952) recorded high parasitization of hemispherical scales. We have investigated the parasitism of S. coffeae by M. helvolus in the Wye College conservatory (30m x 10m).

MATERIALS AND METHODS

The scale population on a coffee plant was monitored from July 1981 to June 1983. During the first year, 20 twig samples, each measuring 200 mm in length and with six leaves, were selected. All stages of scales on the samples except the first instar (crawlers) were recorded; the scale population and number of leaves were assessed at monthly intervals. The second series of observations was made on the same coffee plant after the release of the parasitoids.

The development of the scales on the leaves of sprouting potato tubers was also studied. The sprouts were infested with newly emerged crawlers, within ventilated polystyrene boxes (170 mm x 115 mm x 52 mm), placed in the conservatory and observed from August 1981 to June 1983. When the scales were mature, they were checked daily for the emergence of crawlers. The parasitoid's developmental period was also studied. Second instar scales were exposed to a large number of parasitoids at 26°C for 6 h and then reared within ventilated polystyrene boxes in the conservatory. The boxes were checked daily from February 1982 to April 1983 for the emergence of parasitoids.

On 21st March, 1982, 200 female M. helvolus were released into the conservatory. The ratio of female parasitoid to nymphal scales was 1:100. At regular intervals after the release of the parasitoids, trap plants consisting of green sprouting potato tubers infested with nymphal scales were placed in the conservatory. They were left for one week, after which they were kept at 26°C for recording the emergence of adult parasitoids.

RESULTS

Examination of S. coffeae on the coffee plant in the conservatory showed all stages of the scales to be present. The adult scales measured a mean of 2.8 mm in length and were clustered on young shoots. The nymphal scales produced a high peak in October 1981 (Fig. 1). There was no significant difference in the number of leaves during July 1981 to June 1982 and July 1982 to June 1983. However, there was a low number of scales after the release of the parasitoids.

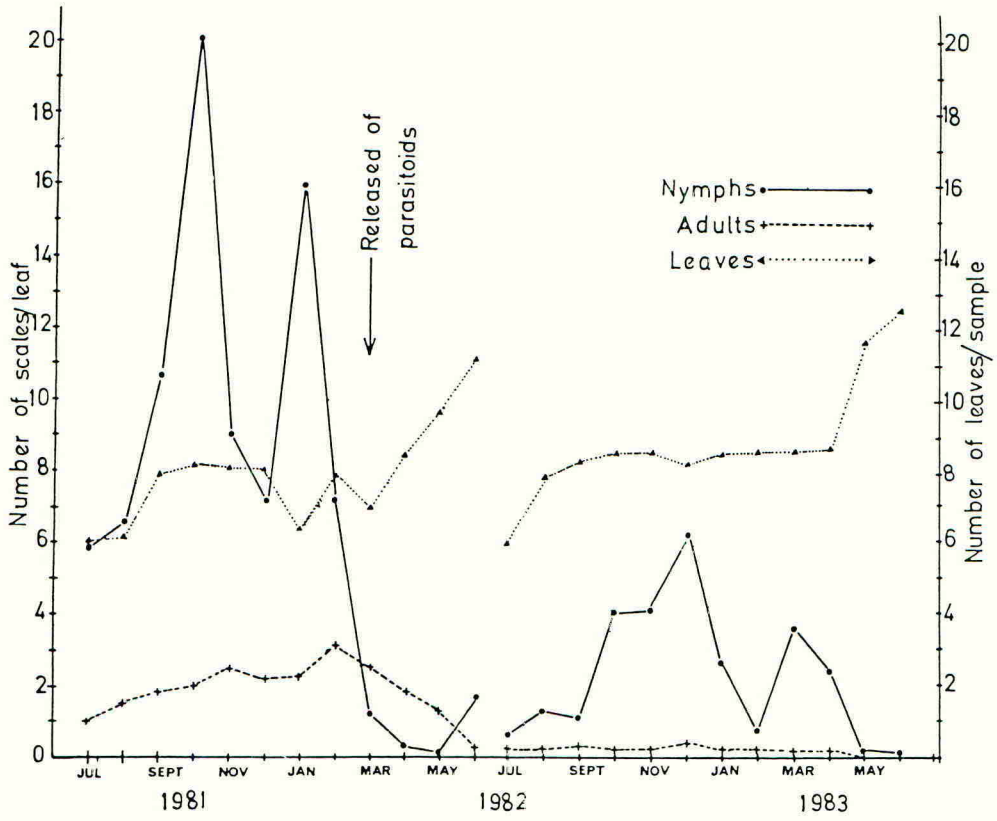

Fig. 1. Seasonal history of S. coffeae on a coffee plant in the Wye College conservatory from July 1981 to June 1983

Table 1 shows the developmental rate of S. coffeae varied on a seasonal basis. The crawler infestation in summer (August 1981) took two months to produce the F_1 generation of crawlers. From the autumn generation (October 1981) F_1 crawlers appeared in the spring of the following year (March 1982), four months later. The development rate of M. helvolus also showed a similar trend to that of the scale. In summer the life cycle took 16.5 days but in winter the average was 26.3 days.

TABLE 1

The life cycle (in days) of S. coffeae and M. helvolus in the Wye College conservatory.

Species	Summer	Autumn	Winter	Spring
S. coffeae	64.5 (62-67)	132 (125-139)	*	75.3 (66-83)
M. helvolus	16.5 (13-20)	26.5 (23-30)	26.3 (24-29)	20.0 (19-21)

* Indicates no emergence. Range in brackets.

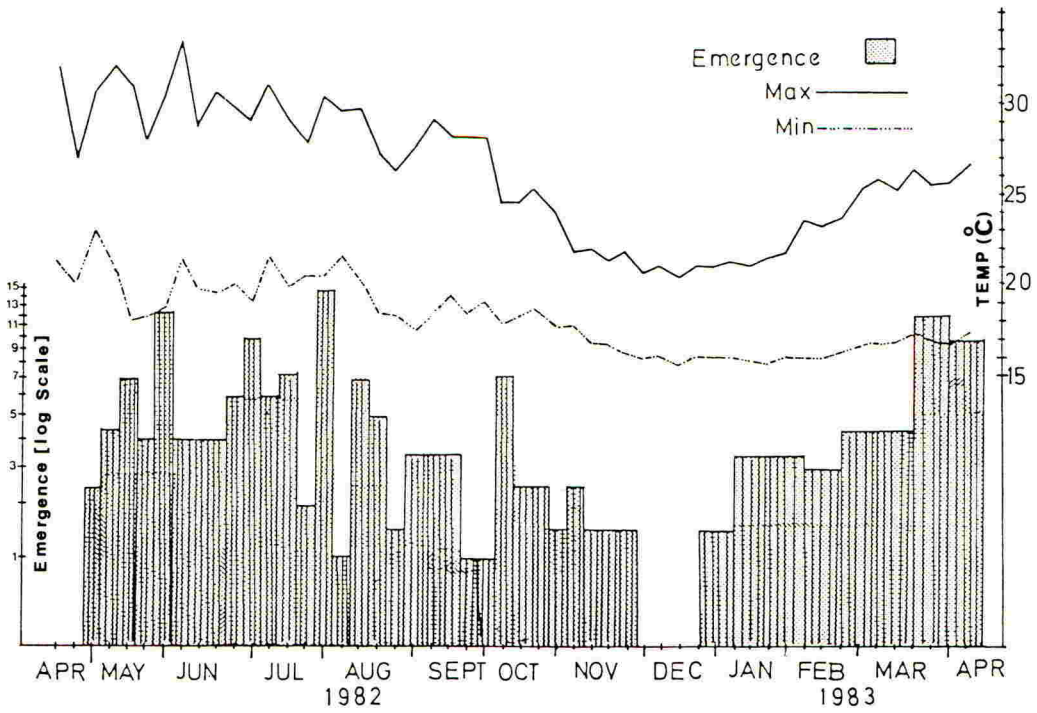

Fig. 2. Emergence of M. helvolus from trap plants in the Wye College conservatory from 20th April 1982 to 5th April 1983.

Metaphycus helvolus responded well to the trap plants and adult parasitoids emerged from the parasitized scales (Fig. 2). However it took five weeks after the initial release of the parasitoids before M. helvolus were obtained from these trap plants.

DISCUSSION

The scale S. coffeae breeds all the year round on coffee plants. The large adult scales also have a high fecundity and there is a good correlation between scale length and egg number (Barber, 1980). The scale infestation was high before the release of M. helvolus despite the presence of Coccophagus lycimnia an indigenous scale parasitoid and the predatory beetle Cryptolaemus montrouzieri. The drastic fall in the number of scales after the release of M. helvolus and the continuous emergence of adult parasitoids from trap plants indicates its biological potential. M. helvolus kills host scales by feeding as well as ovipositing on them (Flanders, 1942).

The glasshouse temperatures influenced the rate of growth of the scales and their parasitoids. The prolonged developmental rate in autumn could be due to many adverse factors such as cold night temperatures (14 °C) and unsuitability of food plants. The scales have 4-5 generations/year but M. helvolus easily attain 12-14 generations/year. This greater turnover of the parasitoids suggests the benefit of utilising M. helvolus where conditions are favourable for biological control. Smith (1946) had similarly confirmed the effectiveness of M. helvolus against the olive scale, S. oleae in California.

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COMBINATION OF *BACILLUS THURINGIENSIS* VAR *ISRAELENSIS* AND A SURFACE ACTIVE MONOLAYER FOR MOSQUITO CONTROL

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ABSTRACT

Laboratory and field work have shown that a mixture of a surface active monolayer (Monoxci) and a stabilized suspension of *Bacillus thuringiensis* var *israelensis* (*B.t.i.*) gave better, more economical control than either agent alone. For *B.t.i.*, the monolayer can be regarded as a formulation agent, itself with complementary insecticidal action. The monolayer killed mainly mature larvae and pupae, and prevented oviposition of some species, while *B.t.i.* killed feeding larval stages. The monolayer spread *B.t.i.* over the water surface and released it slowly. A suitable dosage rate/ha for tropical conditions and polluted water is 1 litre of *B.t.i.* mixed into 50 litres of 15% (v/v) monolayer emulsion in water. The rate should be modified in proportion to the degree of pollution. As little as 5 l/ha of 15% monolayer and 0.1 l/ha *B.t.i.* on clean water may be satisfactory. The application frequency of mixtures is less than that of either agent alone, but variation between pools necessitates monitoring by dipping to determine when re-application becomes necessary. Survival and multiplication of predators delays the need for reapplication. A new monolayer material has been developed, which is applied undiluted to the water surface at only one seventh of the above monolayer rates.

INTRODUCTION

Two new larvicides for use against mosquitoes, a surface active monolayer and *Bacillus thuringiensis* var *israelensis* (*B.t.i.*), each have disadvantages. The aim of this work is to determine whether use of a mixture of the two would reduce or overcome the disadvantages to give a more economic, efficient and long-lasting mosquito control agent.

MODE OF ACTION AND PROBLEMS OF A MONOLAYER

A monolayer is a surface-active material with a high surface pressure that enables it to spread at speed over the water surface, forming a layer only one molecule thick. This is similar to the way oil spreads over water, but faster and invisible. The layer is slowly decomposed by biodegradation. If too much monolayer is applied it will not form multiple layers. Instead, the excess is visible as globular reservoirs on the surface which feed the monolayer as it biodegrades, until the reservoirs are exhausted. The greater the excess, the longer the monolayer lasts. As it is self-spreading there is no need to apply an even spray: a coarse spray, watering can, or even a dropping bottle is adequate. The monolayer sweeps aside surface debris.

When larvae and pupae of mosquitoes and related Nematocera swim to the surface to breathe, their siphons or breathing trumpets are wetted by the

surfactant monolayer, allowing water into their respiratory systems so that they drown. This physical method of control is most effective against late larval stages and pupae. Younger larvae can obtain enough oxygen through the cuticle to survive, but development is retarded. The surfactant also traps adults as they emerge from pupae and adults alighting on the water to lay eggs. Monoxci is harmless to nearly all other forms of aquatic life. In trials, most arthropods dependent on water surface tension escaped from the monolayer except in small, enclosed water masses.

The main problems of a monolayer are biodegradation and poor activity against young larvae.

MODE OF ACTION AND PROBLEMS OF *BACILLUS THURINGIENSIS*

The crystals of proteinaceous toxin of *B.t.i.* act as a specific stomach poison to larvae of mosquitoes and related Nematocera. The toxin has no contact action and takes effect only when eaten by larvae. It must, therefore, be kept suspended in the water where the larvae feed as long as possible, as it has no effect on pupae, adults, eggs or mature larvae that have stopped feeding. Stabilized suspensions of *B.t.i.* sink slowly and dried formulations rapidly. Thus, as it sinks where it lands, *B.t.i.* must be applied evenly over the water surface (Burges, 1982).

The main problems of *B.t.i.* are its specificity to larval feeding stages and its rapid disappearance from larval feeding zones due to sinking into bottom detritus, adsorption onto water plants and removal by filter-feeding fauna. Frequently, field efficacy is limited by these factors to 1-2 days (Burges, 1982).

LABORATORY EXPERIMENTS

Materials and methods

The monolayer used was Monoxci (ethoxylated derivatives of vegetable oils), marketted as a 15% a.i. emulsion in water (C.I. Insect Control Ltd.).

Two stabilised aqueous suspensions of *B.t.i.* were kindly supplied by Tate & Lyle Ltd., Reading, UK and Dunlop Ltd., Birmingham, UK.

Larvae of *Aedes aegypti* and *Anopheles stephensi* were used to check the potency of the *B.t.i.* products. Potencies of *B.t.i.* alone and mixed with the monolayer were measured by bioassays involving 5-7 serial dilutions in distilled or dechlorinated tap water dispensed in 200-ml aliquots in 9.5-cm diameter plastic cups in triplicate, each inoculated with 25 third instar larvae. Deaths were recorded after a 24-h incubation without food at 25°C.

RESULTS

Many experiments, designed in several different ways, showed that *B.t.i.* was held at the water surface by both the globules of excess monolayer (Table 1) and by the monolayer itself (Table 2).

Application of a drop of the mixture at one end of a gutter full of water showed that the monolayer carried *B.t.i.* for at least 2 m as it spread along the water surface (Table 3). Biodegradation of monolayer was simulated in other experiments which showed that the monolayer not only carried *B.t.i.* with it as it moved along the water surface, but also released some *B.t.i.* into the water as it moved (Table 4).

Storage of *B.t.i.* mixed with the monolayer for 5 days caused no loss in activity of *B.t.i.* by monolayer at 25°C (Table 5).

TABLE 1

Retention of *B.t.i.* at the water surface by a monolayer*

Time (h) after application of monolayer	Mortality (%)	
	Without monolayer	With monolayer
2	92	0
3	88	0
18	72	4
20	68	20
22	64	40
24	40	44
Water left after 24 h	60	100

* Each funnel contained 100 ml of water to which 100 µ litres of *B.t.i.* alone, or 100 µ litres *B.t.i.* mixed with monolayer which formed a reservoir, were added at the surface. Samples of 8 ml, drawn from the bottom of the funnel were added to 200 ml volumes of water in bowls, each containing 25 *Ae. aegypti* larvae. Mortality due to *B.t.i.* was scored after 24 h, a period too short for the monolayer to harm the larvae.

TABLE 2

Retention of *B.t.i.* by a monolayer at the water surface*

Treatment	Surface water, % dead in 18 h	Lower water, % dead in 24 h
B.t.i. alone, 0.6 ppm	4	92
50 µl monolayer + 0.4 ppm *B.t.i.*	92	20
75 µl monolayer + 0.6 ppm *B.t.i.*	100	12

* *B.t.i.* alone or mixed with enough monolayer to maintain a reservoir, was added to 3 troughs (24 litres of water; 23 cm deep). After settling for 6 days, 3 litres of water was sucked from the surface of each trough, resulting in a total of six water portions, each of which was inoculated with 50 *Ae. aegypti* larvae.

TABLE 3

Spread of *B.t.i.* by movement of a monolayer containing the bacteria along the water surface*

Section	% dead larvae after 24 h				Comments
	0-0.5 m	0.5-1 m	1-1.5 m	1.5-2 m	
B.t.i. alone	100	0	0	0	*B.t.i.* does not spread
Mixture	100	100	100	90	*B.t.i.* spreads

* A mixture (50 µl) of monolayer and *B.t.i.* was applied to one end of the surface of 3 litres of water in a narrow gutter, 2 m long and only 9.3 cm wide. After 2 min, 3 dividers were placed across the gutter to form 4 sections then each was inoculated with 10 *Ae. aegypti* larvae. Mortality was scored after 24 h, a period in which the monolayer used alone does not kill young larvae.

TABLE 4

Spread of *B.t.i.* by a monolayer which moved from an excess globule at the water surface to replenish surface monolayer removed by simulated biodegradation*

Gutter sections from point of application	No. of larvae	% mortality in 24 h
1	10	100
2	10	90
3	10	100
4	10	100
Overflow	40	95

* In a gutter experiment, set up as described in Table 3, an extra 2 litres of water was slowly dripped into the end opposite the point of application of the *B.t.i.*-monolayer mixture. An overflow aperture at the water surface near the drip allowed surface water to flow out from the gutter into a beaker, carrying the monolayer with it, simulating loss of monolayer by biodegradation.

TABLE 5

Stability of *B.t.i.* during storage mixed with a monolayer*

Treatment	LC_{50} (ppm of *B.t.i.*)	
	Expt. 1	Expt. 2
B.t.i. alone	0.31	0.23
Upper portion of the mixture-treated water	0.19	0.20
Lower portion of the mixture-treated water	0.95	1.00

* One ml of *B.t.i.*, 2 ml of monolayer and 1 ml of distilled water were shaken together and stored at 25°C for 5 days. After dilution with water to 100 ml, standing for 2 h to settle, then removal of the monolayer by sucking off from the surface the upper 30 ml of water, the potency of the upper and remaining lower portion was bioassayed over 1 day (6 serial dilutions between 0.05 and 6.4 ppm *B.t.i.*) with *Ae. aegypti* larvae.

Discussion of laboratory experiments

Bioassays of *B.t.i.* over short periods of 1 to 2 days in the presence of the monolayer often showed higher LC_{50} values than those in the absence of monolayer (Nugud and White, 1982; Chiama Nkasiobi and Amajoh, personal communication). This apparently indicates a reduction of the activity of the *B.t.i.* by the presence of the monolayer. The results of experiments illustrating the power of the monolayer to hold *B.t.i.* at the surface (Tables 1-4) show that the apparent reduction of *B.t.i.* activity is an artefact of the monolayer holding *B.t.i.* at the surface while probably also discouraging surface-feeding species from browsing at the surface.

The experiments showed that the monolayer can carry *B.t.i.* over the surface of water and release it slowly. In the field, the monolayer should spread *B.t.i.*, prevent its rapid loss due to sinking etc., and release it slowly until all the monolayer biodegrades. Thus the effective period of

B.t.i. should be extended to equal the period for which the monolayer was designed to be maintained over the surface by monolayer reservoirs.

Field use of mixtures should reduce the quantity of materials used in three ways. 1. The monolayer can be reduced to last a shorter time because *B.t.i.* would kill young larvae that survive monolayer treatment. 2. Waste of *B.t.i.* due to rapid sinking should be reduced. 3. The interval between treatments should be lengthened. On this basis Fig. 1 illustrates an estimated lengthening from a 9-day period with either material alone to a 15-day period with a mixture, when a reduced amount of the monolayer is applied to last 3 days instead of the normal 7 days (*B.t.i.* alone seldom remains effective for longer than 1-2 days).

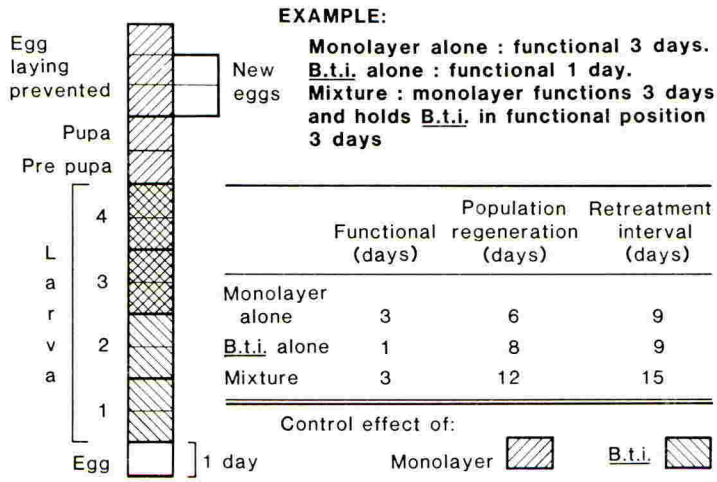

Fig. 1. Example of estimated retreatment intervals using bacteria alone, monolayer alone or a mixture.

FIELD TRIALS

As an example of temperate conditions, trials were conducted in two areas in the UK. In 1983, good control of *Aedes detritus* was obtained by applying the mixture, or either material alone, along different sections of a drainage ditch on Hayling Island. In 1984, with a population containing a high proportion of fourth instar larvae and pupae in many pools on Thorney Island, the mixture gave complete control (only one live larva found, itself moribund 24 h post-treatment; A. Gillespie, Dunlop Ltd., personal communication).

In tropical conditions in Sri Lanka, trials with different proportions of the monolayer and *B.t.i.* were conducted in 85 pools in 1984. The high temperatures (air > 30°C) necessitated higher dosage rates than in temperate climates (against *Anopheles culicifacies* and several culicine species). No clear distinction between different mixtures was demonstrated because of differences between replicate pools and between nearby untreated control pools, degree of pollution, presence of predators, shading and temperature. However, some results indicated that the retreatment interval could be extended in some conditions to 20 days, proportionately longer than that

indicated in the example in Fig. 1.

The laboratory demonstration of the power of the monolayer to carry *B.t.i.* was verified in field conditions in two instances. In one, a large monolayer-*B.t.i.* reservoir sufficient for a pool 15 m long (5.4 m mean width) was placed at one end. This pool was joined by a culvert under a track to another satellite pool containing a teeming Culicine population of all stages. After 48 h, only one larva was found in 30 dips in the satellite pool and none after 4 days. In the other instance, post-treatment rain caused two mixture-treated pools to join with a third untreated control pool. The monolayer must have carried *B.t.i.* to the control pool in which most larvae were killed, whereas the effectiveness of *B.t.i.* alone would have stopped before the rains (control pool: 1.6 to 0.9 larvae/dip in consecutive counts pre-flood and 0.13 to 0 post-flood). The results of this work and of current work will be published in detail later.

CONCLUSIONS

From laboratory and tropical field results, the best estimate of the most economical, successful dosage rate for use in pilot operations is 1 litre of *B.t.i.* in 50 litres of 15% monolayer emulsion/ha polluted water. These materials must be mixed on site: mixing is easy. Additional water *must not* be added because it would destroy the emulsion. For really clear water the dosage could possibly be reduced tenfold.

FUTURE WORK

Mixtures in different proportions are being compared in relatively constant conditions on a large scale in the laboratory. The Sri Lankan trials provided training, which will be used in the second - operational - stage of a self-help programme, eventually involving some 68 villages. A new monolayer material has been developed, which will be applied neat to the water surface at only one seventh of the above rates with the same amount of *B.t.i.* Pools will be monitored by dipping every 4 days. Increasing predator populations unharmed by the monolayer-*B.t.i.* mixture are expected to aid control. Adult abundance, blood counts and malaria incidence will also be monitored. Further trials are being arranged in other countries.

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EARLY SEASON INTEGRATED CONTROL OF WHITEFLY ON TOMATOES USING OXAMYL

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ABSTRACT

The use of systemic chemicals to control the greenhouse whitefly (Trialeurodes vaporariorum) during the winter months in an integrated programme was evaluated. Aldicarb, carbofuran, dimethoate, methomyl and oxamyl were screened for their maximum non-phytotoxic rates and their efficiency at controlling whitefly. Oxamyl (400 mg product per plant) proved to be the best chemical evaluated. This was incorporated into an integrated programme comprising oxamyl treatment during early December to tomatoes sown in mid October followed by Encarsia formosa introductions from the end of February.

INTRODUCTION

The practice of earlier tomato sowing dates combined with lower temperature growing conditions and the use of artificial growing media has seen the development of several new pest and pest control problems, notably whitefly control. When sowing occurs in mid-October, infestation of the seedlings with whitefly (Trialeurodes vaporariorum) during November is commonplace since crops of the previous season are still in place. To take advantage of root restriction and to ensure effective control, young plants should be treated with systemic insecticides while in propagation pots. However, the current manufacturer's recommendation for Vydate is to apply 1 g of product per plant 10-14 days after planting out ensuring that rooting through the pot has occurred. This can lead to unpredictable uptake and, when used on young plants, severe phytotoxic damage can occur (Hussey & Helyer 1981). In addition Vydate has a 2 week harvest interval which prevents its use once cropping has started.

During 1983 35% of growers used biological control methods during the main growing season but such methods are impracticable during winter as low night temperatures prolong the life cycles of both whitefly and parasite causing an imbalance in favour of the whitefly (Hussey, Scopes & Hocart 1981). Therefore, integrated control appears to be the answer to full season whitefly control.

It was against this background that trials to determine suitable insecticides for integrated control on early sown tomatoes were carried out:

a) To establish the maximum non phytotoxic dose of insecticide.
b) To test pesticide efficacy against whitefly under winter conditions.
c) To develop an integrated whitefly control programme.

MATERIALS AND METHODS

To establish the maximum non-phytotoxic rates, tomato plants at the fifth to sixth leaf-stage were treated in the summer with various insecticides. Dimethoate as "Rogor" e.c. and methomyl as "Lannate" w.p. were applied as drenches containing 100, 300 or 500 mg a.i. litre^{-1} using 50 or 100 ml per plant. Aldicarb as "Temik", carbofuran as "Yaltox" and

oxamyl as "Vydate" were applied as granules to the soil surface at 400 and 800 mg a.i. per plant - again with two rates of watering. Fifteen plants were used in each treatment.

For studies on whitefly control 400 tomatoes cv. Dawn were sown on October 16 and maintained at 18°C (day) and 16.5°C (night) from pricking-off until the first flowers became visible. Temperatures were then changed to 20°C day and 12°C night. The plants were treated with systemic insecticides, at rates shown to be non-phytotoxic, on December 8, 27 days after the first whiteflies were introduced, since eggs at 18°C take 33 days to develop into pupae (Lenteren & Hulspas-Jordaan 1983). Twenty-five plants were used to evaluate each insecticide. Aldicarb was tested at the reduced rate of 200 mg/plant.

For the integrated control programme two glasshouse chambers of equal size were used for the trial, one as control, the other for insecticide treatment. Rockwool bags were spaced out in 5 double rows of 6 bags with 3 plants to each bag. The young plants were moved into the glasshouse in mid November and placed in their growing positions on the bags. Both chambers were infested with c. 1 whitefly adult/plant one week before standing out and again one week later. Insecticide (oxamyl) was applied on December 8 at 400 mg product per plant and immediately watered in using drip irrigation.

The first flowers became visible towards the end of December when the temperatures were adjusted by 0.5°C, daily to 20°C day and 12°C night. At these temperatures the development of whitefly from egg to pupae takes approximately 49 days. The low night temperature was chosen for energy conservation and to determine any effects on the parasite. The tomatoes were planted on January 2 (25 days after treatment (DAT)) by cutting a hole in the plastic and placing the propagation pot in contact with the rock-wool.

Black scales of Encarsia formosa were introduced from early March (88 DAT) and began to emerge in mid March (102 DAT). This was later than scheduled in Fig. 1, and the larger number of whitefly adults which emerged (115-130 DAT) required one application of Pestigas BB (bioresmethrin + bioallethrin) to restore the pest/parasite balance.

RESULTS

No phytotoxic damage was observed with dimethoate (100 mg litre^{-1}) or carbofuran (400 mg per plant), while scarcely perceptible marginal scorch was caused by oxamyl (400 mg per plant). However, methomyl and aldicarb caused obvious marginal scorch even at the lowest rates used.

When these insecticides were applied at rates similar to those shown to be non-phytotoxic (carbofuran 400 mg/plant, dimethoate 20 mg/plant, methomyl 10 mg/plant, oxamyl 400 mg/plant, aldicarb 200 mg/plant), examination by destructive sampling of twenty-five plants in each treatment revealed the following proportions of infested plants 4 weeks after treatment:- no insecticide 62%; methomyl 46%; dimethoate 31%; carbofuran 28%; oxamyl 8% and aldicarb 0%.

These results indicated that aldicarb would guarantee whitefly-free plants but current registration bars its use on all but soil-grown tomatoes. In addition, its use is impractical on Guernsey, where whitefly

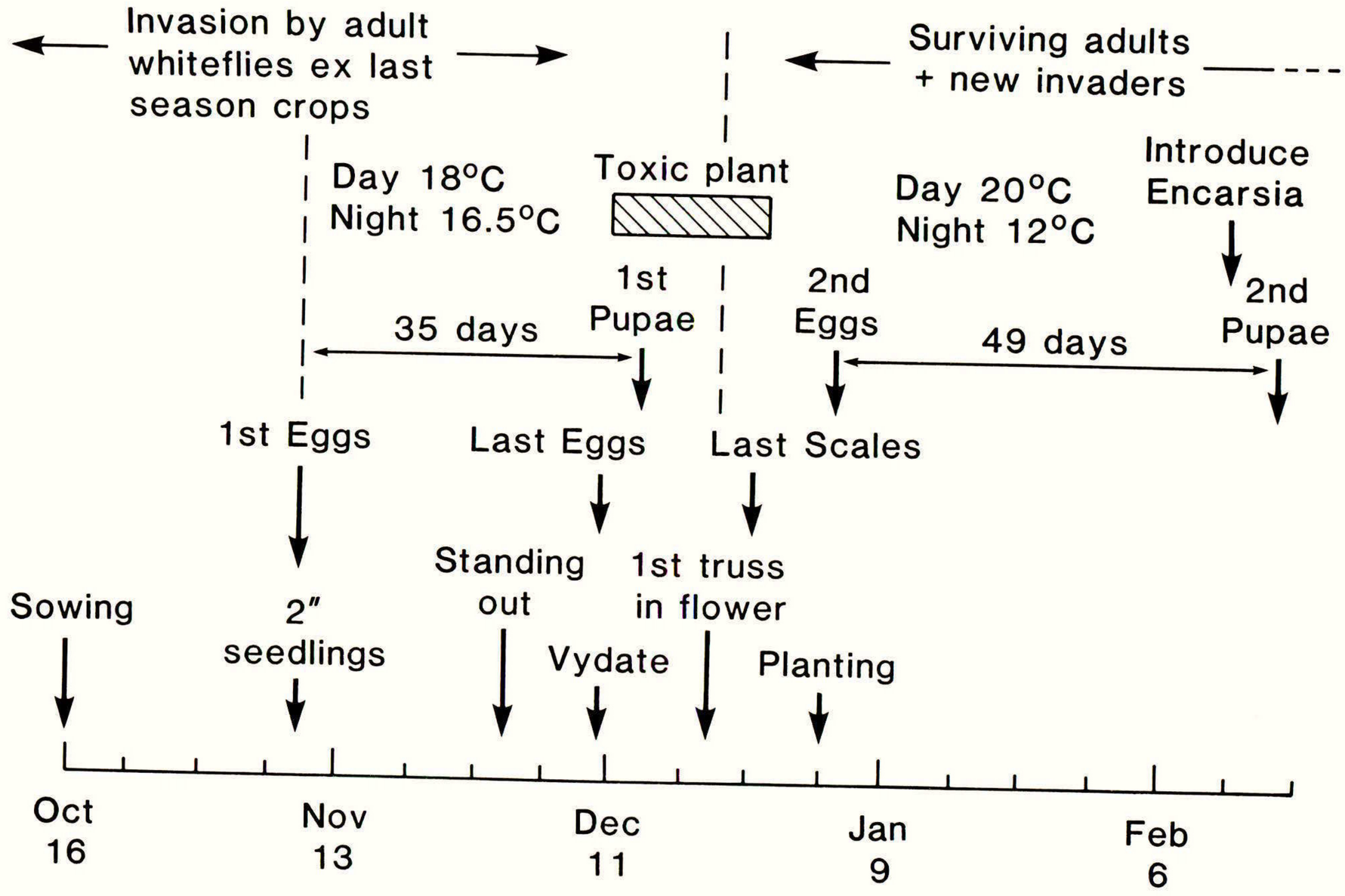

Fig. 1. Schere for integrated control

problems are even more acute, due to possible problems with contamination of soil water. Thus, subsequent work was based on oxamyl using the integrated programme depicted in Fig. 1. In the integrated control trial the untreated control chamber produced a large population of adult whitefly at an early stage (Fig. 2) and the crop was stopped after only 2 months when sooty mould developed. The oxamyl treatment killed all stages of the earlier infestation leaving the plants toxic for about 20 days. At the time of planting (25 DAT) the eggs from surviving adults (second generation) and new invaders were able to develop on the now non-toxic plants (Fig. 1).

The adults then began emerging c. 70 DAT (Fig. 2) to produce a third generation. Parasitism of this third generation should have begun by c. 90 DAT (early March) and would have prevented the rise in adult whitefly numbers evident between 115 and 130 DAT (Fig. 2). The 'Pestigas' spray immediately reduced the adult whitefly population (as well as the adult E. formosa). However, there was no lasting effect on the overall interaction due to the short persistence of the active ingredients, and their lack of effect on the larvae or pupae of whitefly or E. formosa.

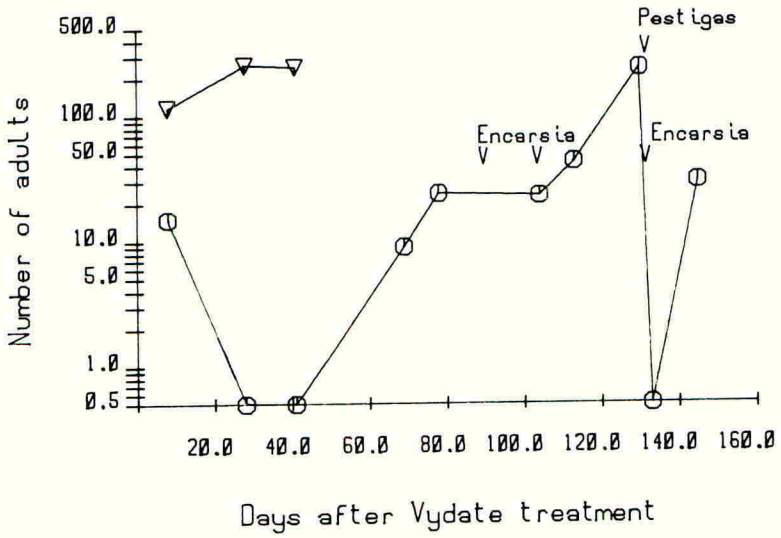

Fig. 2. Comparison of numbers of whitefly adults at the top of Vydate-treated (○) and untreated (▽) plants

The population of black and white scales, (parasitised and unparasitised), is shown in Fig. 3. A count taken on May 1 (145 DAT) revealed 1 adult whitefly per plant top and over 90% parasitism.

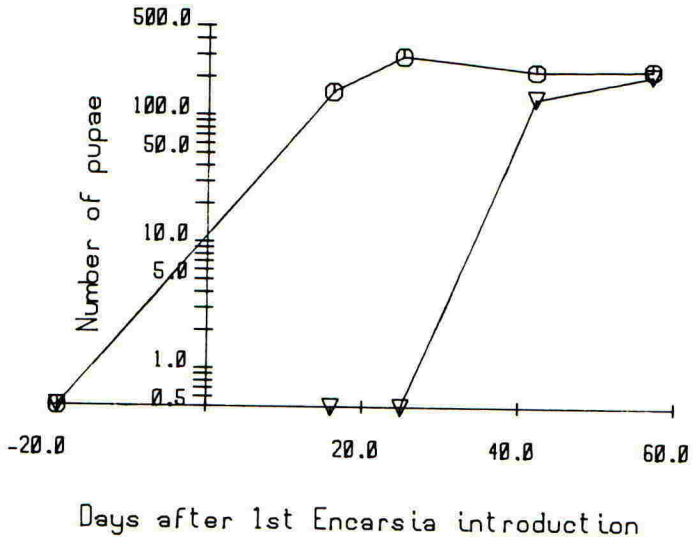

Fig. 3. Parasite establishment - total number of pupae (○) and parasitised pupae (▽) on sixth truss

DISCUSSION

The integrated control programme outlined in Fig. 1 gave good control of whitefly since, by the end of August no further insecticide sprays were needed and parasitism was still over 90%. However, the treatment timing is important. If it had been any later (after planting) the systemic activity would have been unpredictable, leading to poor whitefly control. Foster & Kelly (1978) state (i) that the ceiling for successful introduction of E. formosa is one adult whitefly per 2 plants and (ii) providing the number of adult whitefly does not exceed 1 per plant, no insecticidal sprays should be necessary. If, for some reason the whitefly numbers do exceed those stated above, the use of a short persistence insecticide should restore the balance without affecting the overall interaction.

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INSECTICIDES FOR THE FUTURE: A PACKAGE OF SELECTIVE COMPOUNDS FOR THE CONTROL OF MAJOR CROP PESTS

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ABSTRACT

Despite the constraints which limit Industry's ability to develop selective insecticides for Integrated Pest Management, ICI is working on a package of insecticides in conjunction with Nihon Nohyaku and Ishihara Sangyo Kaisha, comprising chlorfluazuron, buprofezin, PP761 and pirimicarb, which combines efficacy against major pest species with a high degree of safety to non-target organisms. Various projects are described which demonstrate the potential of these compounds as components of IPM programmes; the onus is now on applied entomologists to devise suitable strategies to exploit the tools made available.

INTRODUCTION

Although some broad-spectrum insecticides are relatively selective in practice (e.g. the pyrethroids), it is recognised that intrinsically selective control agents are best suited to meet the needs of Integrated Pest Management (IPM). However, selective insecticides by their very nature are likely to command a small fraction of the total insecticide market. This has, in the main, led Industry to develop (in preference) broad-spectrum insecticides, for sound commercial reasons (Braunholtz & Tietz, 1980).

A new approach was needed for Industry to be able to contribute materials suitable for IPM. ICI Plant Protection Division has recognised this challenge and, in cooperation with other companies including Nihon Nohyaku and Ishihara Sangyo Kaisha, is evaluating a new package of insecticides. The key to this achievement has been the identification of compounds which are selective for broad groups of insects such as Lepidoptera or sucking pests. In addition, ICI has developed formulation technology suitable for the delivery of insect pheromones which has the potential for use outside the limited scope of single species control simply by substituting other naturally occurring active ingredients.

The aim of this paper is to illustrate a range of projects, designed to evaluate the performance of these insecticides when used against major pest species and to investigate their potential for IPM.

A Package of Selective Insecticides

The following insecticides are already available from or under evaluation by ICI:

Chlorfluazuron (IKI7899, PP145):- A stomach acting, benzoyl-urea insect growth regulator. The compound causes death at moult of immature

stages and prevents adults laying viable eggs in members of the Lepidoptera, Coleoptera and Diptera.

Buprofezin (NNI-750, PP618):- A novel insect growth regulator active against immature stages of certain Homoptera. The compound also causes adults to lay eggs which are not viable.

PP761:- The sex pheromone of Pectinophora gossypiella, the pink bollworm. Applied in a slow-release microcapsule, control is achieved through mating disruption. Activity is totally specific to males of P.gossypiella.

Pirimicarb (PP062):- A fast-acting selective carbamate aphicide. This compound is active through contact, fumigant, translaminar and root-systemic routes.

All of the above are more or less specific, either through their spectrum of intrinsic activity or a combination of spectrum and their mode of action. They are suitable for use alone against a narrow range of pests or in combinations, thereby providing a broad spectrum effect while maintaining safety to non-target organisms.

Chlorfluazuron (Atabron®)

ICI has evaluated chlorfluazuron for the control of cotton Lepidoptera in Peru. The geography of Peru provides an ideal environment for the use of integrated control measures against insect pests of cotton, and it has been possible to regulate the balance between pests and their natural enemies through the judicious use of selective control agents within each closed system. From the trials performed to date, a clear pattern has emerged: chlorfluazuron gives excellent control of gross foliar-feeding Lepidoptera including Alabama argillacea and Anomis texana at rates between 25 and 150g a.i./ha, providing a technical effect equivalent to the synthetic pyrethroids and superior to lead arsenate, the standard 'soft' pesticide. Significantly, chlorfluazuron has been shown to have no effect on a wide range of beneficial insects including coccinellids, predatory mites and a number of species of predatory bug (Table 1). The use of pyrethroids, which are relatively toxic to these insects, is restricted during the first one hundred days of the cotton season, thus chlorfluazuron will provide a valuable alternative to lead arsenate for early season use. Heliothis virescens and Bucculatrix spp. are also important pests of cotton in Peru; the former in particular is not well controlled by conventional insect growth regulators. In contrast, chlorfluazuron has proved highly effective against H.virescens where hand-picking is frequently employed for the control of this pest in Peru, and can also be used for Bucculatrix control at the higher rates mentioned.

In the Far East, many crops including cotton and vegetables are grown very intensively. The frequent application of insecticides over prolonged periods and near continuous selection pressure has, not unexpectedly, led to resistance in a number of species of Lepidoptera, notably Plutella xylostella and Spodoptera exigua in vegetables, and more recently, reported problems with Heliothis armigera in cotton (Wangboonkong 1981). It is vital for the continued control of these pests that novel insecticides be made available, and used with care to ease the burden on existing products. Ishihara Sangyo Kaisha and ICI have evaluated chlorfluazuron in Thailand,

Malaysia, Indonesia and Japan for the control of insect pests on a wide range of crops. The compound has been highly effective against many species of Lepidoptera, and particularly promising results have been obtained against H.armigera on cotton, while in Thailand, yields have been increased from 0.4 to 1.4 metric tonnes/ha following season-long applications of chlorfluazuron at 50g a.i./ha. Thus, where the other control agents, with the potential to control major insect pests resistant to conventional insecticides, have given variable results (e.g. Bacillus thuringiensis, diflubenzuron), chlorfluazuron provides a truly effective alternative control measure.

TABLE 1

The effect of chlorfluazuron on pest and beneficial species of arthropods on cotton in Peru, 1983

ARTHROPOD		CHEMICAL RATE (g a.i./ha)		
		CHLORFLUAZURON	ALSYSTIN	LEAD ARSENATE
		50	125	2800
Anomis texana and Alabama argillacea*	a	272	292	202
	b	5	12	76
Heliothis virescens*	a	48	38	33
	b	9	12	10
Coccinellidae+	a	2	2	3
	b	10	14	11
Predatory mites+	a	2	2	1
	b	10	10	10
Large predatory bugs (e.g. Orius sp.)+	a	8	4	8
	b	12	24	16
Small predatory bugs (e.g. Nabus sp.)+	a	1	1	6
	b	12	12	8

* No live larvae/100 terminals
\+ No live arthropods/100 terminals
a = Prespray
b = 15 DAT

In Malaysia and Indonesia, the recent introduction of a pollinating weevil Elaeidobius kamerunicus has revolutionized the oil palm industry, replacing hand-pollination and leading to improved yields. Because oil palm is subject to attack from lepidopterous pests such as Thosea asigna, the continued success of the project relies on the identification of suitably selective control agents. Although at an early stage of evaluation, there are indications that chlorfluazuron may be useful in this context.

Buprofezin (Applaud®)

Top fruit and citrus are crops which have a long history of research and implementation of IPM. One of the reasons for this has been the effect of broad-spectrum insecticides on mites; compounds which are not applied as miticides or at miticidal rates frequently have a greater impact on predatory mites than on their prey species. The resulting imbalance can lead to mite problems of unexpected proportions.

Nihon Nohyaku and ICI have studied the effects of buprofezin when applied to citrus for the control of coccid scales and whitefly. In these studies, effective control at rates between 125 and 600ppm has been accompanied by complete neutrality to predatory mites, and other beneficials such as bees. In this environment, predatory mites may exert control over their phytophagous prey and alleviate the need for specific miticidal treatments (Fig. 1). In addition to these studies, work in Spain has demonstrated that buprofezin is harmless to Encarsia formosa and Cales noacki, two important hymenopterous parasites of whitefly (Garrido et al., 1984).

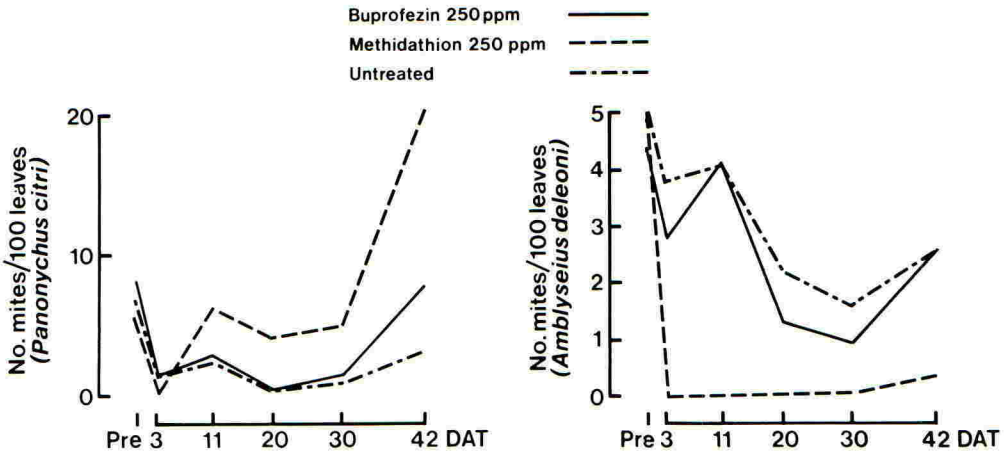

Figure 1 - Effects of insecticide treatments on mite populations in citrus (amended from "Official Trial Results for Citrus" (1981) vol. 18).

One of the most promising uses of buprofezin is for the control of rice plant hoppers and leaf hoppers where its advantages are two-fold. Firstly, the compound is effective against insects of this group which are resistant to organophosphate and carbamate insecticides, and secondly, as the compound is highly selective, natural enemies of the rice pest complex are preserved. This includes predators, e.g. Lycosa pseudoannulata, (Table 2) and parasites, e.g. Paracentrobia andoi, of mobile stages of hoppers and borers, and the International Rice Research Institute (IRRI) has recently published data showing that buprofezin is safe to immature stages of the egg-parasite, Anagrus sp. in contrast with many broad-spectrum insecticides (Mochida & Basilio, 1983). It is known that egg-parasites play an important role in the suppression of stemborer populations, thus the application of buprofezin for the control of homopterous pests will allow for maximal benefit from these parasites.

TABLE 2

Contact toxicity of buprofezin and a standard insecticide against nymphs of the predaceous spider Lycosa pseudoannulata

Treatment	CUMULATIVE % MORTALITY*				CUMULATIVE % MOULTING			
	1DAT	3DAT	6DAT	9DAT	1DAT	3DAT	6DAT	9DAT
Carbofuran 12F 750g a.i./ha	93a	93a	93a	93a	0	0	3	7
Buprofezin 50WP 750g a.i./ha	0b	0b	0b	0b	0	7	47	100
Control	0b	0b	0b	0b	13	20	43	100

* Treatment means with no letter in common are significantly different at the 5% probability level (Duncan's multiple range test) (amended from IRRI Annual Report for 1981).

PP761

For many years, entomologists have been excited by the prospects of controlling insects through the manipulation of their mating behaviour. The concept has also found favour with environmentalists due to the inherent safety of pheromones and related chemicals to non-target organisms. Until recently, success with insect control using pheromones had been limited to pests of minor importance, or involved the use of highly complex application methods and control strategies. Now, the Tropical Development and Research Institute (TDRI) and ICI have collaborated to develop a highly effective product for the control of the pink bollworm, Pectinophora gossypiella in cotton. Utilising PP761, the species' natural sex pheromone in a microencapsulated form, mating disruption is achieved with persistence of effect through slow-release of the active ingredient. The real significance of this formulation lies in its compatability with existing conventional spray equipment, so that the product can be applied in the same manner, or even in mixture with a range of insecticides, fungicides or foliar micronutrients. PP761 has been the subject of extensive large-scale field evaluations in both Egypt and Pakistan, where the pink bollworm is a predominant pest of cotton. Full details of the success of these projects are given in Critchley et al. (1984).

Pirimicarb (Aphox®, Pirimor®)

Pirimicarb is a well established, safe, selective aphicide. Numerous publications have highlighted its lack of adverse effects on non-target organisms in the laboratory and the field (e.g. Helgesen & Tauber, 1974; Vickerman et al. 1976). However, with the advent of the other insect control agents discussed in this paper, it is pertinent to consider pirimicarb in a new context: as part of a package of selective insecticides which has the potential to give broad-spectrum pest control without risk to beneficial arthropods. ICI have put particular effort into the evaluation of the impact of pirimicarb on arthropods in the cereal ecosystem (Cole & Wilkinson, unpublished). It is apparent that the compound can be used to give highly effective control of cereal aphids whilst preserving important polyphagous predators, which are thought to delay the build up of aphids in the crop early in the season (Potts & Vickerman, 1974; Sunderland, 1975) and may enhance the effects of the insecticide.

CONCLUSIONS

Many economic entomologists hold the view that the future of successful crop protection will depend on the development of Integrated Pest Management programmes. Ultimately, such strategies should provide maximum benefits to the grower by enhancing the effects of biological control agents and reducing overall reliance on conventional pesticides. Risk to the environment is reduced and through varied selection pressure, pesticide resistance may be avoided thus prolonging the effective life of valuable chemical control agents. Despite the constraints on Industry which have limited the development of selective insecticides, ICI has been active in assembling a package of compounds which, it is hoped, will be employed in many IPM programmes worldwide. In this paper, we have indicated that the correct tools are now available for IPM of major pest species. It only remains for applied entomologists to devise strategies for the optimal use of these compounds in particular crops.

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EFFECTS OF PP618 ON IMMATURE STAGES OF ENCARSIA FORMOSA AND CALES NOACKI (HYMENOPTERA: APHELINIDAE)

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ABSTRACT

The insecticide PP618 (NNI750, Buprofezin) was tested at rates of 125 and 250 ppm on immature stages of the beneficial aphelinids E. formosa and C. noacki, in order to determine any possible effects on survival, reproduction and behaviour.

By applying the criteria developed by the Working Group of the OILB (Pesticides and Beneficial Arthropods) to the results obtained, it can be concluded that PP618 is harmless to immature stages of E. formosa and C. noacki. In addition, the product had no demonstrable sterilizing activity on the adult stage. These selective characteristics of PP618 suggest that it will become a valuable component of integrated pest control programmes.

INTRODUCTION

Encarsia formosa and Cales noacki are two important aphelinid parasites of the whitefly species, Trialeurodes vaporariorum and Aleurothrixus floccosus respectively, occasionally maintaining these pests below the economic threshold.

However, it is often necessary to use chemical pesticides against whitefly, and against other pests and diseases which occur simultaneously, and it is vital to the success of integrated control that the products used are safe to beneficial predators and parasites. This compatibility between chemical and biological materials is the concern of an OILB work group on "Pesticides and Beneficial Arthropods".

In relation to E. formosa, useful publications have appeared from Delorme (1982), Garrido et al (1982) and Oomen (1983). Regarding Cales noacki, papers have been published by Carrero (1979), Garrido et al. (1982), and finally by Santabaya et al. (1980). All these references provide information on the direct effect of several pesticides on the parasites in question.

Besides the potential direct effect of a pesticide on a beneficial insect, it is also important to know the effect on its reproductive capacity, for example, whether it causes sterility or affects the number of eggs laid. In fact, little has been published specifically on E. formosa and C. noacki, apart from the papers by Delorme (1983) on E. formosa and Beitia (1984) on C. noacki.

The purpose of this paper is to present the results of studies which investigated the effect of the insect growth regulator PP618 (NNI750) on the survival and reproductive capacity of immature stages of E. formosa and C. noacki.

MATERIALS AND METHODS

E. formosa and C. noacki individuals were maintained in a breeding room kept permanently at 20°C and 65% relative humidity, with a photoperiod of 15 hours.

Since the nymphal stages of these insects can develop to adults on pieces of plant material, the pesticides were applied to individual bean leaves in the case of E. formosa and orange leaves in the case of C. noacki.

The insecticide was applied by a hand sprayer in a volume of 71.93 ml cm^{-2}.

The rates of PP618 used were 250 ppm and 125 ppm, equivalent to 0.0179 and 0.0089 mg of formulated material per cm^2.

In each trial there were three replicates and two control treatments; one sprayed with water and the other unsprayed. In each treatment 50 nymphs were sprayed.

To assess the possible insect mortality, the following technique was adopted from Garrido (1982):

1) Sufficient insects for each treatment were collected, counting them with the aid of a stereoscopic microscope, and transferred to the individual bean and orange leaves.

2) The leaves infested with the nymphal stages were attached to pieces of synthetic material such as polyvinyl or cork using pins to keep the leaves flat, thereby facilitating assessment.

3) Following this, the leaves were sprayed with pesticide or water depending on the treatment.

4) The material was then placed on a tray and left until dry.

5) The treated and untreated samples were kept in a room with controlled temperature and humidity.

6) Every two days the emergence of adults was assessed and puparia with holes were discarded. This was continued for one month after which the study was terminated. However, if emergence of adults in untreated samples was less than 95%, the experiment was repeated.

For the sterilization study the methodology of Beitia (1984) was used. The first part of the technique which refers to the application of the pesticide to the beneficial insects was as previously described.

a) Once the leaves had been sprayed with the pesticide and allowed to dry they were introduced into an open Petri dish which was placed in a wooden box measuring 19 x 19 x 30 cm and covered by a fine mesh. Previously three small plants had been placed in the box; citrus plants in the case of C. noacki and beans in the case of T. vaporariorum. The plants, which were grown in a liquid nutrient medium had been previously infested with first and second instar stages of the respective whiteflies. These stages are the most suitable for parasitism by newly emerged adults of E. formosa and C. noacki.

b) After the Petri dish with the treated beneficial insects had been placed in the box containing the plants parasitized by the respective whiteflies, all the gaps were sealed so that the adults were retained inside the box and could not escape. The boxes were then placed in the breeding room.

c) The boxes described in sections a) and b) remained in the breeding room for 20 to 25 days. Similarly, the boxes with the control treatments were placed in another section of the breeding room.

Once this time period had elapsed, the amount of parasitism was assessed. This was to determine the degree of sterilization of treated compared to untreated individuals. Another set of trials was undertaken where insects were examined more frequently (once weekly instead of after 20 to 25 days).

In order to discount any possible side effect, Beitia (1984) conducted a specific trial on C. noacki reproduction by parthenogenesis and the conclusion was that where females were not fertilized by males, reproduction did not occur.

RESULTS

Table 1 shows the mortalities in larvae of C. noacki, and Table 2 the mortalities in nymphal stages of E. formosa and C. noacki. Tables 3 and 4 refer to the sterilizing effects on both parasites.

DISCUSSION

The mortality caused by PP618 at 125 and 250 ppm to the larvae of C. noacki was 10.83 and 10.34% respectively. According to the OILB guide-lines, products are categorised as harmless to beneficial fauna (value 1) if mortalities are less than 50%. Thus, PP618 can be regarded as safe against the larval stage of C. noacki.

TABLE 1

Mortality caused by PP618 on larvae of *C. noacki*

Rate (ppm)	Mean % Mortality		
	Control	Treatment	Attributed to pesticide ± SE
125	17.9	28.73 ± 10.13	10.83 ± 10.13
250	17.9	28.24 ± 6.64	10.34 ± 6.64

TABLE 2

Mortality Caused by PP618 on nymphs of *E. formosa* and *C. noacki*

Rate ppm	Mean % Mortality on					
	E. formosa			*C. noacki*		
	Control	Treatment	Attributed to pesticide	Control	Treatment	Atributed to pesticide ± SE
125	0	0	0	0	0	0
250	0	0	0	1.92	7.32 ± 7.57	5.40 ± 7.57

TABLE 3

Parasitism of *T. vaporariorum* by nymphal forms of *E. formosa* when treated with PP618.

Rate of PP618 applied (ppm)	Total no nymphs assayed	Adults emerged	% emergence	No of descendants from nymphs	Relation between no of descendants and adults emerged
125	336	321	95.4 ± 2.1	380	1.10 ± 1.05
250	331	321	96.9 ± 1.7	586	1.78 ± 1.47
0 with water	112	110	98.2	51	0.45
0 without water	117	114	97.4	98	0.85
Total	229	224	97.8 ± 0.6	149	0.65 ± 0.28

TABLE 4

Parasitism of A. floccosus by nymphal forms of C. noacki when treated with PP618

Rate of PP618 applied (ppm)	Total no nymphs assayed	Adults emerged	% emergence	No of descendants from nymphs	Relation between no of descendants and adults emerged
125	180	177	98.3 ± 2.9	469	2.63 ± 0.6
250	180	166	92.2 ± 3.5	326	1.64 ± 0.48
0 with water	60	58	96.7	175	3.01
0 without water	60	60	100	170	2.83
Total	120	118	98.3 ± 2.4	345	2.92 ± 0.12

Furthermore, PP618 can be classified as harmless to the nymphs of E. formosa and C. noacki, according to the criteria determined for toxic hazards, since there was no mortality of E. formosa at either rate, and in the case of C. noacki it was zero at 125 ppm and 5.4% at 250 ppm.

It can be noted that the toxicity of the product to C. noacki is less when the insect is in the nymphal stage than in the larval stage.

In the sterilisation studies carried out on both parasites, which are reported in Tables 3 and 4, the emergence of adults was found to be greater than 92% in all the treatments.

By analyzing the population growth ratio for E. formosa and C. noacki it can be seen that this is greater than one for E. formosa at both rates of 125 and 250 ppm. This demonstrates that for each treated individual there is more than one descendant, proving not only the absence of a sterilising effect but that there is a tendency for the population to increase.

This suggests that PP618 does not have any major influence on the reproductive process of E. formosa when the product is applied to the nymphal stages of the insect.

Similar conclusions can be drawn for C. noacki. PP618 did not produce sterility in any of the insects assayed although a certain reduction in the reproductive potential was observed compared to the control treatments.

However, the increase in the treated populations of both insects is still positive, and both sexes are represented in the subsequent generations.

CONCLUSIONS

From the data obtained in these trials, the following points emerge:

1) PP618 at the rates used (125 and 250 ppm) was harmless to larvae of C. noacki and nymphs of E. formosa and C. noacki.

2) No sterility following treatment of nymphs of E. formosa or C. noacki was detected. The nymphs reached the adult stage and reproduced normally with the result that there was an increase in the size of the population during the course of the experiments.

3) PP618 is harmless to the immature stages of E. formosa and C. noacki and does not affect the reproduction of these insects by sterilising either of the sexes.

4) Thus, the product can be considered for use in integrated pest management schemes where these beneficial insects form an important part of the control programme.

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SELECTIVITY OF PIRIMICARB IN CEREAL CROPS

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ABSTRACT

Spring and autumn applications of pirimicarb in cereals showed few significant effects on natural enemies of aphids or on the arthropod food of wild birds during long-term comparative field trials with broad-spectrum insecticides.

BACKGROUND AND OBJECTIVES

In recent years there has been an increase in the use of insecticides in cereals. Spring applications have become more apparent in continental Europe, taking the form of pre-flowering insurance sprays against a range of insect pests, while in the autumn the increase is linked with the aphid vectors of barley yellow dwarf virus (BYDV), which has become a more serious problem with the trend towards earlier sowing of winter cereals.

An awareness of the desirability of examining the effects of pesticides on non-target arthropods, especially with new compounds or new regimes, has led to a series of field trials. Comparisons were made between recently developed pyrethroids (permethrin and cypermethrin), a long-established organophosphate (dimethoate), a specific aphicide (pirimicarb) and an untreated control. Particular attention was given to known predators and parasites of pests, the removal of which could lead to loss of natural control. Consideration was also given to the arthropod food of ground-living birds. Two main studies were carried out, the first investigating effects of spring and summer sprays, the second, those of autumn sprays.

METHODS

In the first trial there were spring or summer applications of insecticides in two successive years. In the second trial an autumn application in the first year was succeeded in the second by an autumn and a spring application. Normal field rates were used as shown in Table 1.

The sites consisted of fields of winter wheat in Hampshire, each divided into four plots of not less than 4 ha. The first trial had two and the second trial three replicate fields.

TABLE 1

Spray rates

Trial 1	Pirimicarb	125g ai/ha	(250g "Aphox"/ha)
Year 1 -	Permethrin	50g ai/ha	(200cm^3 "Ambush"/ha)
Year 2 -	Cypermethrin	25g ai/ha	(250cm^3 "Cymbush"/ha)
	Dimethoate	400g ai/ha	(1000cm^3 "Rogor" E/ha)
Trial 2	Pirimicarb	140g ai/ha	(280g "Aphox"/ha)
	Cypermethrin	25g ai/ha	(250cm^3 "Ambush"/ha)
	Dimethoate	340g ai/ha	(850cm^3 "Rogor" E/ha)

Sampling was confined to the central hectare of each plot to ensure good buffer zones. The main methods used were pitfall trapping (15 or 10 traps per plot) and vacuum sampling (9 or 3 samples per plot). These were used up to harvest in the first trial and throughout the year in the second. Other methods were restricted to times when the organisms were in evidence and consisted mainly of field counts of aphids and collection of ears for laboratory counts of thrips and aphids.

RESULTS

Trial 1 - Spring/Summer Sprays

Data from the first year only are available, which show that the effects of pirimicarb on non-target groups were few and of short duration. In comparison there were reductions of 20% of the taxa on the broad-spectrum insecticide plots, including 'beneficial' groups. 240 taxa were identified and those affected had generally recovered by six weeks after spraying. There was no subsequent aphid resurgence or reduction in arthropod food of wildlife.

The relative numbers of three of the major groups present on the four treatment plots are shown from selected sampling dates in Tables 2 to 4.

In order to ensure spraying by milky ripe (Zadoks 73), pirimicarb had to be applied when aphid numbers were relatively low. In the first year this was seven weeks later than the broad-spectrum insecticide applications and the vacuum samples showed a considerable reduction in the numbers of aphids up to four weeks after spraying. The two main species were Sitobion avenae (F) and Metopolophium dirhodum (Walker). This apparent long-term control of aphids was probably due to the fortunate timing of spraying with alate arrival and not to residual pirimicarb which has a biological half-life on crops of one to three days (Anon, 1982).

The only predatory species showing an apparent (though non-significant) reduction by pirimicarb was the linyphiid spider Erigone atra in pitfall traps, 1 week after treatment. The effect was unlikely to have been due directly to pirimicarb as numbers had returned to control levels the following week.

Effects on the hymenopterous parasitoids are of concern in cereals as many utilise aphids specifically as their hosts. There is evidence of a reduction in some groups 2 weeks after treatment (though non-significant), when the aphids had become established. The Aphidiidae, exclusively aphid parasites, were the group most affected. The chalcids, which include some aphid hyperparasites, were affected to a lesser degree. The reductions correspond with the reductions in aphids on these plots. It seems likely that numbers of aphid-specific species were lower as a result of the lower numbers of aphids rather than due to a direct effect of pirimicarb. The relationship between aphids and aphidiids in year 1 is shown in Table 5.

TABLE 2

Total adult Carabidae (Numbers per Pitfall-Detransformed) - Trial 1

Spray date	(15/5/79)		26/6/79			
Weeks post spray	(-1)-7	(2)-5	(6)-1	1	3	13
Unsprayed	6.6	4.4	29	51	40	27
Pirimicarb	7.2	2.9	28	54	38	48
Permethrin	4.5	1.7	24	36	31	43
Dimethoate	4.2	1.9	14	34	36	41

TABLE 3

Total adult Staphylinidae (Numbers per Pitfall-Detransformed) - Trial 1

Spray date	(15/5/79)		26/6/79			
Weeks post spray	(-1)-7	(2)-5	(6)-1	1	3	13
Unsprayed	2.8	4.3A	2.2	3.6	1.3	0.7
Pirimicarb	2.4	4.2A	2.0	2.8	1.3	1.0
Permethrin	3.2	4.5A	3.3	4.0	1.4	1.3
Dimethoate	3.0	1.3B	3.5	3.2	2.1	1.0

Dates in brackets relate to broad-spectrum insecticide applications.

Means with no letter in common are significantly different, P=5%.

TABLE 4

Total Linyphiidae (Numbers per Pitfall-Detransformed)
- Trial 1

Spray date	(15/5/79)		26/6/79			
Weeks post spray	(-1)-7	(2)-5	(6)-1	1	3	13
Unsprayed	5.0	3.1A	3.9	6.4	11	4.0
Pirimicarb	5.2	4.5A	3.9	4.0	10	7.4
Permethrin	2.7	0.4B	3.5	5.2	10	6.0
Dimethoate	3.2	0.8B	3.5	5.7	13	5.6

Dates in brackets relate to broad-spectrum insecticide applications.

TABLE 5

Total Aphids and Aphidiid Parasitoids (Numbers per vacuum sample-Detransformed) - Trial 1

Pirimicarb spray date (Year 1)-26/6/79						
	Total Aphids			Aphidiidae		
Sampling date	2/7/79	12/7/79	27/7/79	2/7/79	12/7/79	27/7/79
Weeks post spray	1	2	4	1	2	4
Unsprayed	22.2A	124A	440A	0.8	2.0	13.3
Pirimicarb	0.4B	13B	272B	0.1	0.5	3.9
Permethrin	10.3A	79A	474A	0.2	1.9	14.1
Dimethoate	15.6A	121A	500A	0.2	1.7	13.6

Means with no letter in common are significantly different, P=5%.

Trial 2 - Autumn sprays

The level of aphid control could not be reliably assessed as the main autumn species, Rhopalosiphum padi was scarce in both years.

Only about half the potential data have so far been analysed but of the 170 taxa identified few have revealed changes in numbers attributable directly to the chemical applications. Dimethoate had the greatest effect, pirimicarb the least. There appeared to be little or no effect on populations in the following spring, summer or autumn.

The relative numbers of three of the major groups present on the four treatment plots are shown from selected sampling dates in Tables 6 to 8.

TABLE 6

Total adult Carabidae (Numbers per Pitfall-Detransformed) - Trial 2

Spray date	12/11/81					11/11/82			
Weeks post spray	-1	3	5	29	36	-1	2	3	29
Unsprayed	1.0	1.1	0.15A	9.0	111	3.4	3.5A	3.0	12
Pirimicarb	0.7	0.6	0.07AB	10.9	117	5.9	3.2A	3.6	15
Cypermethrin	0.8	0.6	0.05B	7.4	151	3.2	1.5B	1.9	13
Dimethoate	0.9	0.2	0.00B	8.5	87	2.9	0.8B	1.2	18

TABLE 7

Total adult Staphylinidae (Numbers per Pitfall-Detransformed) - Trial 2

Spray date	12/11/81					11/11/82			
Weeks post spray	-1	3	5	29	36	-1	2	3	29
Unsprayed	1.7	1.8	0.16A	8.6	3.0	2.4	2.0	2.5	7.0
Pirimicarb	1.5	2.2	0.16A	4.5	2.1	2.6	2.1	2.9	6.3
Cypermethrin	1.2	1.1	0.06B	4.9	1.7	2.1	1.7	1.6	8.1
Dimethoate	2.3	1.4	0.05B	5.3	1.9	2.6	1.6	1.6	7.8

TABLE 8

Total Linyphiidae (Numbers per Pitfall-Detransformed) - Trial 2

Spray date	12/11/81					11/11/82			
Weeks post spray	-1	3	5	29	36	-1	2	3	29
Unsprayed	2.6	3.9A	-	5.6	-	3.5	2.9A	4.5A	2.6
Pirimicarb	3.5	3.5A	-	5.0	-	4.3	2.2A	3.5A	3.1
Cypermethrin	2.9	4.2A	-	5.6	-	3.9	1.6AB	2.4B	2.3
Dimethoate	3.4	1.2B	-	5.7	-	4.9	0.9B	1.2C	3.5

Means with no letter in common are significantly different, P=5%.

CONCLUSION

In the cereal ecosystem pirimicarb caused minimal disruption to non-target arthropod populations. When aphids are the target pests and adequate control can be achieved, pirimicarb should be preferred to broad-spectrum insecticides.

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REFERENCE

Anon (1982) Pirimicarb. The Specific Aphicide. Imperial Chemical Industries PLC