SESSION 8C

ADVANCES IN THE INTEGRATED MANAGEMENT OF PESTS

SESSION ORGANISER MR R. A. UMPELBY

POSTERS 8C-1 to 8C-15

MONITORING AND BIOLOGICAL CONTROL AS THE MAIN COMPONENTS OF IPM IN VINEYARDS

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ABSTRACT

On the base of systemic approach, monitoring and biological control of noxious organisms are considered with particular reference to vine leafrollers, *Trichogramma* and microbial preparations. Monitoring of the insect pest population includes short-term forecasting and density estimation based on the sequential sampling combined with negative-binomial distribution model. Entomophage and preparations are applied on the base of the mathematical model describing parasite-host relationship and the model of a desirability function.

INTRODUCTION

Grape vine growing is one of the most ancient cultures and vines were cultivated on the territory of the present Moldova from about 600 BC. The most important species is *Vitis vinifera*, fruits of which are used fresh or for processing. Grape moth *(Lobesia botrana)* and cochylis moth *(Clysia ambiguella)* cause a considerable damage to the grape field. To control these pests organophosphorus preparations and pyrethroids, which can cause a number of negative consequences, are applied. These negatives include outbreaks of red spider mite and scale which result from the death of their natural enemies and the depression of grape leaf photosynthesis and respiration. In addition, the cytogenetic activity on warm-blooded animals of some chemical products widely applied in vineyards has been marked.

Recent research has demonstrated the prospects for vineyard integrated pest management in which emphasis is placed on non-chemical methods, particularly, the application of parasitoid *Trichogramma* and other biological means.

MATERIALS AND METHODS

The results of more than 10 years examination of vineyards in the central and southern zones of Moldova are presented. *Trichogramma embyrophagum* is the dominating species in vineyards and it was collected from the eggs of vine leafrollers. It was mass reared on the eggs of angoumois grain moth *(Sitotroga cereallela)*, preparations on the base of *Bacillus thuringiensis* were used.

To build the logic model of the monitoring-noxious organisms biological control system the method of parastrophic matrix is utilised (Vasil'yev, Tanskiy,1978). The leafroller density estimation is founded on the approaches applied in forest entomology (Vorontsov et.al., 1983). The study of the parasite-host relationship of *Trichogramma* and leafrollers and the optimisation of the pheromone trap application to forecast pests has been carried out on the basis of the mathematical method of multifactorial biological experiment planning founded by R Fisher at the Rothamsted Experimental Station in England. To find the optimal rate of bacterial preparations the desirability function was synthesised (Mencher and Zemshman,1986).

RESULTS AND DISCUSSION

Logical model

Applying the principles of the system analysis, monitoring and biological control of noxious organisms can be considered as a complex of inter-related and interacting processes occurring in the unified plant-phytophage-entomophage system. Fig 1 shows the parastrophic matrix of this system, including 15 basic parameters obtained by the special algorithm. Element 15 was taken as a response (system output).

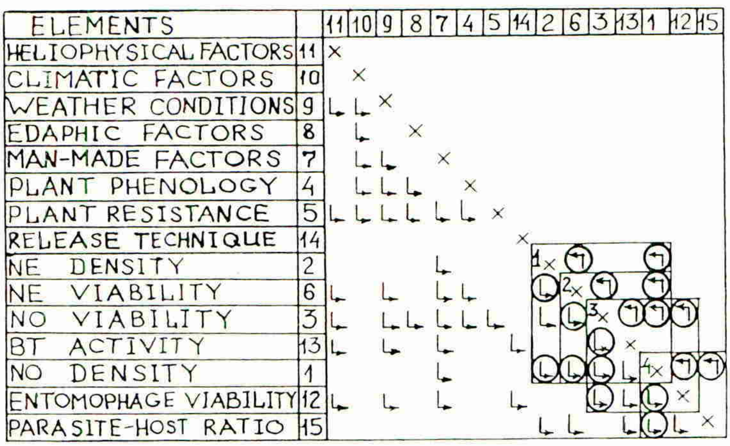

Fig 1 The parastrophic matrix of the system:

↳ the direct element effect; (↳) the reciprocal element effect; NE - natural enemies; NO - noxious organisms; BT - Bacillus thuringiensis

In the matrix four inter-related subsystems formed by the system forming elements 1,2,3,6 are clearly outlined. Element 11 (heliophysical factors), which closely related to climatic and weather conditions, soil and relief peculiarities (elements 10,9,8), is a common input in the system. System forming elements correct the system functioning in conformity with the signals received from input (managing) elements 4,5,7,10,12-14. The analysis of significant elements and subsystems of the monitoring of noxious organisms (NO) and the biological control system, with particular reference to leafrollers and a group of beneficial agents - *Trichogramma* and bacterial preparations are presented below.

Monitoring

Sampling method of vine leafrollers

As it has been shown the NO population density is a system forming element. Hence, the possibility of the adequate description functioning of the system analysed depends on the element 1 estimation significance. We have worked out plans of the sequential estimation of grape leafrollers density including the procedure of the sequential.sampling combined with the model of the negative-binomial distribution. (Teshler,1991). To facilitate the procedure of decision taking, from the results of preliminary estimation, convenient nomogrames have been built. One of them, allowing estimation of generalised harmfulness of pests (B), confined at the different phases and instars of its development is shown on Fig 2.

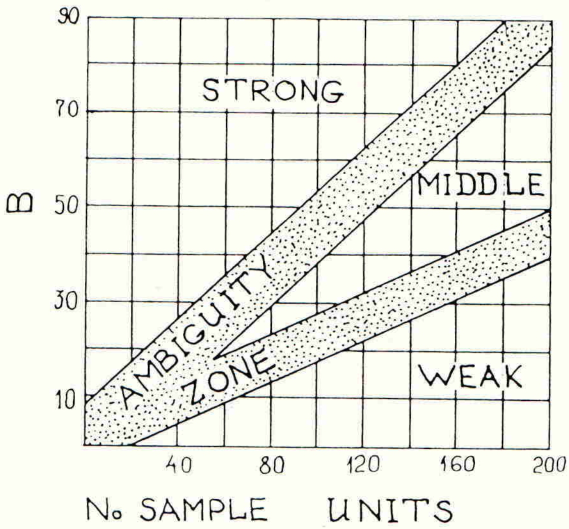

Fig 2 The interval estimation of B

In the paper (Mencher, Teshler,1991) the detailed scheme of B calculation is given, here we adduce only the final formula:

$$B = \sum_{i>1}^{L} N_i C_i$$

where N_i is the average number of eggs and caterpillars of the i-th instar with the account of their mortality; C_i is the harmfulness of caterpillars of different instars in the conventional scale; L is a number of caterpillar instars. Having made estimation and found the definite number of caterpillars and pest eggs we transfer them (with the help of the formula) into the conventional units of harmfulness B and plot them on the graph. The hit into the zone "strong" invasion indicates the necessity of carrying out protective measures; "middle" means that the insect density is near to the threshold one, it is necessary to carry out estimations more frequently; "weak" means protective measures are not necessary; "ambiguity zone" means estimates should be continued. Under field conditions it is convenient to carry out the calculation of the generalised harmfulness on the programmed calculator.

Short-term forecast of the leafroller density

The study of cross-correlation links between the male flight to pheromone traps and leafroller eggs density indicated on average, a lag of 3 days from the males flight to egg lay (cross-correlation coefficient 0.95). A mathematical model has been built allowing a forecast of the density of eggs taking into account 3-day lag. Possessing the information on the dynamics of the male flight to pheromone traps, knowing the trend of the generation development (heuistic forecast) and sex ratio we can forecast the insect egg density for the next 5 days a sufficient precision.

Pheromone traps are important elements of such forecast. The correlation between caught adults and egg density depending on the pheromone dose and trap height above the ground have been studied. The maximal correlation (r=0.8 and more) is achieved when traps are located at a height of 100-140 cm and pheromone dose at the range of 200-600 µkg.

Biological control

Studies of the parasite-host-system

The analysis of the parastrophic matrix showed that the output parameter of the system, the optimal parasite-host ratio for the entomophage, depends on a number of abiotic and biotic factors. A field model experiment, including both regulated (pests egg and *Trichogramma* density, and location over the vineyard), and non-regulated factors (weather conditions, planting density etc) has been conducted. The quadratic model of the relationship of the *Trichogramma* biological efficiency to the factors studies has been developed. For the convenience of the application the model was transformed into a mechanical nomogram including the most significant factors (Fig 3).

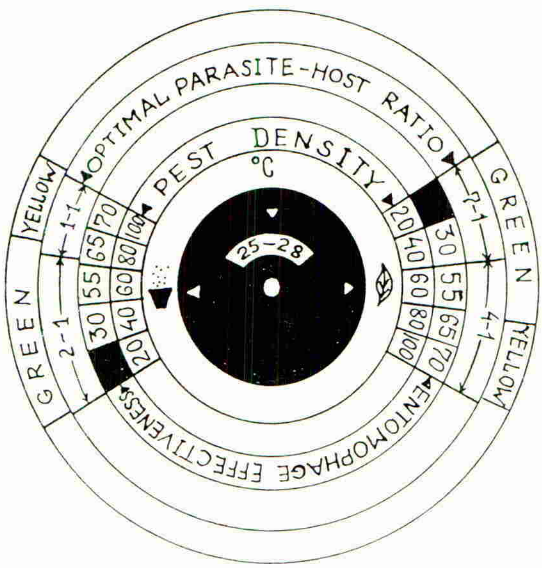

Fig 3 Mechanical nomogram

The nomogram consists of two discs rotating one relatively the other. In the window of the upper disc the observed value of the average air temperature (in this case it was established 25-28°C) is fixed. On the upper disk by symbols the way of the entomophage application in the field (mechanised tractor and hand release) is indicated. Here the scales: the pest density and entomophage biological efficiency related to it, allowing to decrease the pest density to the economic threshold of harmfulness (ETH) are located. Along the edge of the lower disc the values of the optimal parasite-host ratio are indicated. They are indicated by three colours: "red" - means the *Trichogramma* application is unlikely to be effective; "yellow" - the *Trichogramma* application should be combined with other protection measures; "green" - the entomophage application alone should decrease the pest density to the ETH.

Influence of BT on the leafrollers and Trichogramma

The effect of two bacterial preparations, BTB and Leptidocide (L), and their mixtures on the mortality of leafroller caterpillars and viability of *Trichogramma* was studied. The preparations belong to different serotypes of *B.thuringiensis*. BTB also contains a thermostable exotoxin. To solve the problem a desirability function (Fig 4) has been synthesised.

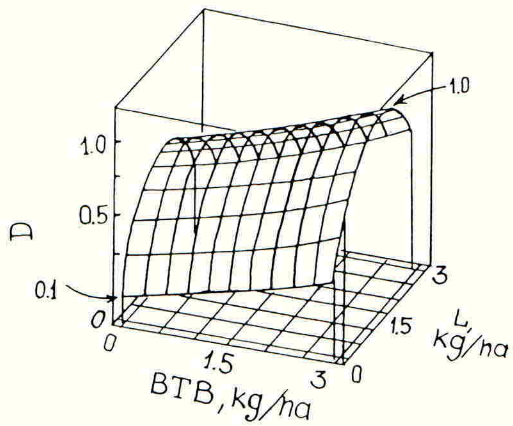

Fig 4. Isolines of the desirability function D

The function D reaches its maximum at the rate of L in the range of 1.5 to 1.75 kg/ha and BTB from 2.8 to 3.0 kg/ha. The separate application of L and BTB at maximal rates decreases the function, which is apparently connected with a harmful influence of the preparations on the *Trichogramma* (the antagonism of the joint application is not displayed). If preparations are not applied the function D decreases as well, because the caterpillars size reduction is not observed. The desirability function has given the possibility to solve the problem by compromise: knowing the weather forecast it is possible to choose preparations rate and combination which are maximally effective against leafroller caterpillars and the least harmful for *Trichogramma*.

CONCLUSION

Analysis of the monitoring - NO biological control logical model, carried out with the aid of parastrophic matrices, showed the intrinsic relations in the system, system forming elements and subsystems of the various levels and parameters of the system input and output. Consequently this analysis allowed study of the system behaviour control.

The individual elements of the monitoring and biocontrol of NO including the following stages are described:

1. The estimation of leafrollers population density was done on the basis of the sequential sampling method.

2. Short-term forecasting of leafrollers density includes two steps: heuristic forecast of the male density based on pheromone traps data; estimation of expected pest density after *Trichogramma* release during subsequent 5 days by the equation. The pheromone traps are located 100-140 cm above the ground and pheromone is used at the rate 200-600 μkg.

3. Plant protection measures were carried out on the basis of forecast data when past density exceeded its ETH. When leafrollers density exceeds ETH *Trichogramma* is applied. In other cases when the pest density exceeds the ETH and the weather is unfavourable for the entomophage, bacterial preparations are used as a supplement.

4. It is recommended to take into account the generalised harmfulness of the pest, these contained various pest instars and development phases. The estimation of that kind is done using the nomogrames realised by programmed calculator.

5. The evaluation of the optimal *Trichogramma*-leafrollers ratio is carried out by nomogram. The option of the dose and the combination of bacterial preparations effective against leafrollers caterpillars and non-harmful for *Trichogramma* is conducted using the model of desirability function.

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ALTERNATIVE CROPS AS FLORAL RESOURCES FOR BENEFICIAL HOVERFLIES (DIPTERA: SYRPHIDAE)

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ABSTRACT

Alternative or novel crops may have a role to play in biocontrol as well as producing a useful crop. Studies on five alternative crops showed buckwheat and coriander were the two most preferred by two species of beneficial hoverfly. Reasons why the flies should favour these particular crops are discussed.

When coriander was sown around a field of winter wheat in an attempt to influence syrphid distribution between fields, it failed to significantly increase syrphid diversity or species numbers within that field, this is in contrast to more positive effects when other plant species have been used by co-workers.

INTRODUCTION

Aphidophagous hoverfly larvae (Diptera: Syrphidae) have been extensively studied because of their potential as aphid biocontrol agents. Several studies have demonstrated an association between the presence of syrphid larvae and the cessation of aphid population growth (Dean, 1974; Chambers *et al.*, 1983; Holmes, 1984; Entwistle & Dixon, 1990). Proteins from pollen are needed by adult syrphids to mature their reproductive system (Schreiber, 1948) and hoverflies are often recorded feeding on wild flowers, from which they take both pollen and nectar. Understanding the selection of floral resources used by adult syrphids is important because of the potential it may have for manipulating syrphid distribution in the agroecosystem (Cowgill, 1991; Cowgill *et al.*, 1992). The study reported looked at hoverfly foraging on some potential alternative crops. Alternative crops or crops that may become more widely grown in the U.K. are shown in Table 1 with their uses.

TABLE 1. Potential alternative crops in U.K. agriculture and their uses.

Crop		
Common name	Scientific name	Use
Borage	*Borago officinalis* L.	Pharmaceutical oils
Buckwheat	*Fagopyrum esculentum* Moench	Specialist diets, Game cover
Coriander	*Coriandrum sativum* L.	Culinary, Medical
Gold of pleasure	*Camelia sativa* L.	Cosmetics oils
Honesty	*Lunaria annua* L.	Industrial oils
Marigold	*Calendula officinalis* L.	Industrial oils
Meadow foam	*Limnanthes alba* Benth.	Industrial oils
Oilseed poppy	*Papaver somniferum* L.	Culinary, Medical
Quinoa	*Chenopodium quinoa* L.	Culinary, Game cover
Tansy leaf	*Phacelia tanacetifolia* Benth.	Green manure

Alternative crops are being experimentally grown in the UK for a number of reasons. Advances in breeding technology and the development of crop management together with the European Communities Common Agricultural Policy (CAP) resulted in agricultural over-production during the 1970's and 1980's (Anon. 1988). Recent proposals to reform the CAP should reduce over-production but alternative crops could help this reduction by substituting novel crops for traditional ones without taking land out of production altogether. In the UK oilseed rape has been successfully introduced and is now a major breakcrop. More recent is the development of linseed and cold-adapted varieties of sunflower (eg. cvs Allegro and Avante) which are now increasingly grown commercially in the UK.

This study investigated the potential of a number of crops which may have commercial uses and which could be used by Syrphidae as sources of pollen and nectar.

MATERIALS AND METHODS

Flower selection by adult Syrphidae: summer 1991

Five potential alternative crops were observed for syrphid foraging activity. The crops were borage, buckwheat, coriander, marigold and sunflower. Crops were sown in individual plots 6m x 12m (no replication) under bird proof netting at Bridget's E.H.F., Winchester, Hampshire during spring 1991.

On four dates during the crops' period of flower, between July 23 and August 21, each crop was observed for hoverfly foraging activity (pollen or nectar feeding). The netting prevented the observer from walking along the plots in a standard manner, so an area of one square metre was observed for a ten-minute period, five times on each date, in each crop by rotation between 06:30 BST and 15:30 BST, weather permitting. Weather conditions were noted. Results were recorded on a micro-cassette recorder.

In order to test for any effect of the netting itself on syrphid activity a plot of buckwheat outside the netting was surveyed in the same way as the plot of the buckwheat under the netting.

Field trial of an alternative crop: summer 1992

Coriander was sown in a strip, 0.75m x 200m at 25kg ha^{-1} along the northern and eastern edges of a field of winter wheat (cv. Galahad) during spring 1992. The field was bounded along the northern edge by a hawthorn (*Crataegus monogyna* Jacq.) hedge and by a post and wire fence with a grassy base along the eastern edge. Two transects of fluorescent yellow water traps were put in the field at right angles to each of the two coriander borders. In each transect, the traps were placed at distances of 1m, 5m, 15m, 25m and 50m from the nearest coriander. The same arrangement of traps was placed in a nearby control field of winter wheat (cv. Galahad) which had a hawthorn hedge as a southern boundary and a post and wire fence with a grassy base as an eastern boundary but which was not sown with coriander. Umbelliferae and other flowers on which Syrphidae could forage were cut down around the control field. On 13 dates from June 17 to July 26, Syrphidae were collected from the water traps in each field and aphid numbers on ten marked ears of wheat around each trap were recorded. On a warm, dry sunny and still day, 24 standard census walks lasting 15 min each were performed along one 200m strip of the coriander from 06:30 to 12:30 BST. Syrphids were identified to species when possible and behaviour when first noted recorded onto a microcasette recorder.

RESULTS

Flower selection by adult Syrphidae: summer 1991

A total of 601 observations of the foraging behaviour of syrphids was recorded on six plots of five crops during four dates of the crops'

FIGURE 1: Proportions of *Episyrphus balteatus* foraging on alternative crops for each survey date.

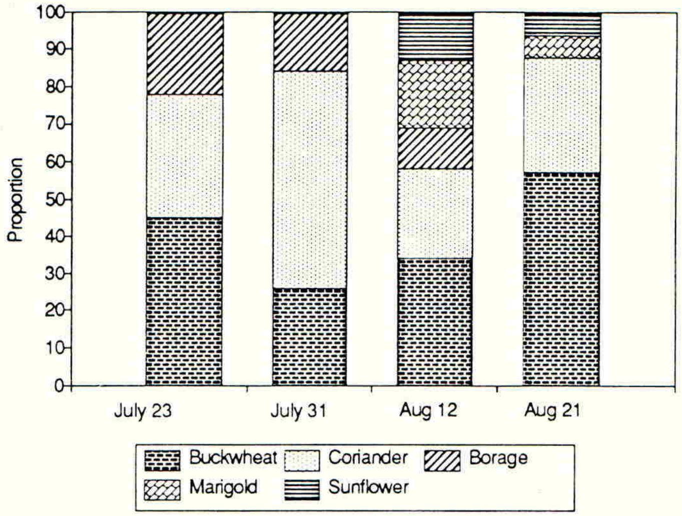
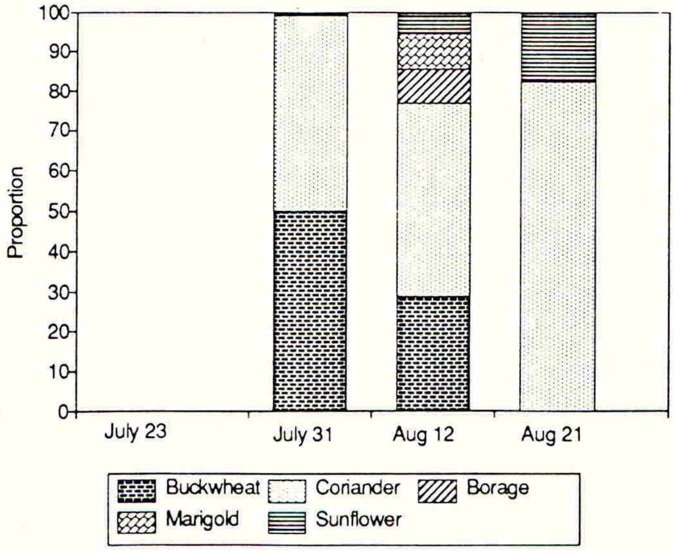


FIGURE 2: Proportion of *Metasyrphus corollae* feeding on alternative crops on each survey date. No *M. corollae* were recorded on July 23.



flowering period. 75% of the syrphids seen were those with aphidophagous larvae, the most commonly observed species being *Episyrphus balteatus* Deg. (30.8 %).

To determine whether the netting influenced the penetration of different sized hoverflies into the alternative crops under the netting, syrphids were classified into small (eg. *Melanostoma* sp. and *Syritta* sp.), medium (eg. *E. balteatus* and *Syrphus* sp.) or large (eg. *Eristalis* sp. and *Scaeva* sp.) sizes, and a G-test carried out on numbers seen foraging on buckwheat under the netting and buckwheat in the open. There was no significant association between syrphid size and the numbers recorded foraging on buckwheat inside and outside the netting. (G_{adj} = 3.27 2df, N.S.). Proportions of the two most commonly observed syrphid species recorded foraging on the crops on each date are shown in Fig. 1 and Fig. 2. No *Metasyrphus corollae* F. were recorded on July 23. Coriander and buckwheat were the favoured crops on any one date for *E. balteatus* and *M. corollae*.

<u>Field trial of an alternative crop: summer 1992</u>

The composition of syrphid species in the experimental and control fields was very similar. *E. balteatus* and *M. corollae* were the most abundant syrphids recovered from the traps, comprising 52.75% and 34.71% of all syrphids captured respectively (53.22% and 35.63% in control). 94.0% of syrphids in the experimental field were those with aphidophagous larvae (94.7% in control).

During one standard walk, 73 *E. balteatus* were recorded feeding on the coriander and another 36 were present in coriander but not feeding.

The abundance and activity of *E. balteatus* on the coriander was not reflected in water trap catches. Mean numbers of female *E. balteatus* caught in traps at the five distances from the field boundaries did not significantly differ between fields during the study (Mann-Whitney U; U=0.5584, N.S.; U=0.2051, N.S.; U=0.4811, N.S.; U=0.3627, N.S.; U=0.5562, N.S.). There were more female *M. corollae* captured at traps 1m from the boundary in the control field than 1m from the coriander in the experimental field (U= 2.3757, <u>P</u><0.05) but at all other distances there were no significant differences (U=0.2021, N.S.; U=1.2353, N.S.; U=0.1123, N.S.; U=0.2033, N.S.). Maximum mean aphid numbers occurred during wheat GS 83 (Zadoks *et al.*, 1974) in both control and experimental field. There was a significant difference between maximum mean number of aphids in the experimental field (6.4/ear) and the control field (12.9/ear) (*t*=4.2665, 19 df, <u>P</u><0.01%). The peak catch of adult syrphids in each field occurred after the aphid population in the two fields had begun to fall.

DISCUSSION

Syrphids use floral resources selectively (Ruppert and Molthan, 1990; Cowgill *et al.*, 1992) with floral features such as colour, depth of corolla tube and nutritional value of pollen important factors in determining preference. Coriander and buckwheat have flowers with shallow corolla tubes, allowing *E. balteatus* and *M. corollae*, which have relatively short tongues for syrphids (Gilbert, 1980) access to nectar and pollen. The flowers of both buckwheat and coriander are white, the colour of many of the preferred food plants of *E. balteatus* and *M. corollae* (Cowgill, 1991). The other alternative crops utilised by the syrphids in the study were mainly used for pollen feeding only. Pollen was not only taken from anthers on the sunflowers and marigolds but from leaf surfaces where pollen had fallen from anthers while bees had been collecting pollen. Competition with bees may account for lack of utilisation of borage by syrphids during the study since up to 50 bees were seen per 10 minute survey foraging in the plot of borage.

Similar (replicated) trials in New Zealand, where coriander and buckwheat were two of four alternative crop tested, showed coriander and buckwheat to be the preferred food plants of *Melanostoma fasciatum* and *M. novaezealandiae*, the two native species of syrphid with aphidophagous larvae in the New Zealand agroecosystem (Lovei *et al.*, 1992a).

Molthan and Ruppert (1989) reported an increase in syrphid numbers and diversity in herbaceously rich strips but many native wild flowers identified as attractive to economically important species of syrphid are pernicious weeds and their encouragement would be agronomically unacceptable (Cowgill, 1989). However a crop that was attractive to aphidophagous species of syrphids should have added value to any farmer where aphid outbreaks may occur.

The lack of a significant difference between the treated and control field could be due to the high mobility of syrphids. Further trials with more fields as replicates should give a clearer indication of the role alternative crops may have to play in influencing beneficial syrphid distribution on arable land.

That plants can be sown in an agricultural environment and influence hoverfly distribution has been shown in New Zealand where *P. tanacetifolia*, was sown in strips within cereal fields. Three to eight times as many hoverflies were captured in fields containing *P. tanacetifolia* than in adjacent fields without *P. tanacetifolia* strips (Lovei *et al.*, 1992b).

P. tanacetifolia has been used to influence hoverfly distribution in the agroecosytem in the U.K.. More hoverflies have been captured in cereal fields bordered by *P. tanacetifolia* than in fields without *P. tanacetifolia* borders (Hickman pers. comm.). The surface patterning of the pollen grains of *P. tanacetifolia* is very distinctive and the pollen can readily be distinguished in the guts of dissected hoverfly specimens. The pollen has consequently been used as a biological marker and it has been found that a higher proportion of hoverflies in the *P. tanacetifolia* bordered fields contained the distinctive pollen in their guts than in the control fields (Hickman pers. comm.)

The aim of providing attractive floral resources for hoverflies in an arable environment is to enhance the potential for biocontrol, by their aphidophagous larvae, by influencing oviposition. That coriander, as an alternative crop, can significantly influence the distribution of beneficial hoverflies is yet to be confirmed in the U.K.

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USE OF FIELD SIMULATORS TO INVESTIGATE INTEGRATED CHEMICAL AND BIOLOGICAL CONTROL TACTICS AGAINST THE COTTON WHITEFLY, *BEMISIA TABACI*

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ABSTRACT

The need to rationalise pesticide use and exploit non-chemical control of multiresistant whitefly populations is being addressed by evaluating insecticides against *B. tabaci* and its Aphelinid parasitoid *Eretmocerus mundus* under simulated field conditions in the laboratory. These species are cultured on cotton in large chambers, exposed to formulated insecticides at recommended rates using an integral track-mounted sprayer, and resulting effects on insect numbers are documented with minimal interference to insects or plants. Experiments conducted in the absence of pesticides are compared with those incorporating two applications of a pyrethroid (cypermethrin) or an organophosphate (profenofos). The design of simulation experiments, and their potential to assist with the choice and timing of pesticide applications on cotton and other crops is discussed.

INTRODUCTION

Problems with managing the whitefly, *Bemisia tabaci*, on cotton in several countries highlight clearly the need for reliable methods to validate and improve Integrated Pest Management (IPM) tactics. Based on events documented throughout the tropics and sub-tropics, insecticides alone offer little prospect for controlling this highly polyphagous and very damaging pest. Indeed, large-scale reliance on chemicals has often appeared counter-productive in this respect, increasing rather than reducing the severity of whitefly infestations and selecting for strong resistance to most insecticide groups (Dittrich *et al*., 1990; Byrne *et al*., 1992). Reasons for these outbreaks remain contentious, but almost certainly include over-reliance on broad-spectrum chemicals and their adverse effect on parasitoids and predators (Gameel, 1969; Eveleens, 1983).

The most widely-reported enemies of *B. tabaci* are hymenopteran parasitoids of the Aphelinid genera *Eretmocerus* and *Encarsia*. Despite doubts over the taxonomic relationships, geographical distributions and host ranges of constituent species (Gerling, 1990), one species - *Eretmocerus mundus* - has been reported from much of the Old World distribution of *B. tabaci* and has been shown, in some cases, to impose significant mortality on whitefly populations (eg Abdelrahman, 1986).

Information on how insecticides affect *E. mundus* is very fragmentory, the only comprehensive data of potential relevance being that from laboratory bioassays against *Encarsia formosa*, the standard biocontrol agent for glasshouse whitefly, *Trialeurodes vaporariorum* (Oomen, 1989). In this paper, we describe new techniques for studying interactions between *B. tabaci* and *E.mundus* in both the presence and absence of insecticides under simulated field conditions in the laboratory.

MATERIALS AND METHODS

Field simulators

'Field simulators' (Rowland *et al.*, 1990) consist of three contiguous units: a sprayer in its metal housing unit at the front; a central cage holding plants and insects; and a plenum chamber at the rear housing a 0.3m diameter fan to draw air uniformly through the cage simulating a light breeze. The cage itself (1.7 x 1.2 x 1.0 m) is glazed with perspex, but has fine steel mesh at each end to provide ventilation. Banks of fluorescent and tungsten lights to promote plant growth are mounted above the roof of each cage, and provide an 18h photoperiod within the simulators. Temperature in the surrounding room is maintained at 26+1°C.

Insect strains

The SUD-R *B. tabaci* strain used for this work was collected from sprayed cotton in the Sudan in 1987. Despite being reared at Rothamsted without further insecticide pressure, it has maintained low (3-5 fold) resistance to pyrethroids and moderate (20-40 fold) resistance to the organophosphates profenofos and monocrotophos (M. Cahill, unpublished data). *E. mundus* was collected from Israeli cotton in 1990, and has since been cultured in large numbers using SUD-R *B. tabaci* as hosts.

Establishment and monitoring of experimental populations

Experiments are initiated by releasing 100 *B. tabaci* females onto eight cotton (cv. Deltapine) plants at the 2-3 node stage spaced evenly on the floor of each cage. Adult parasitoids are added 10 days later, at an starting density of 50 females/cage (Birnie and Denholm, 1992), to coincide with the first cohort of immature whiteflies reaching the preferred stage for parasitism by *E. mundus*.

Following release, whitefly numbers are monitored at least twice-weekly by counting adults through a rigid 55 cm borescope (Olympus Keymed Ltd.) inserted through brush-bordered apertures in the cage wall (Rowland *et al.*, 1990). Adult parasitoids, which are smaller than whiteflies and better camouflaged against the leaf surface, are assessed at similar intervals by viewing insects through a small mirror held obliquely to an illuminated leaf surface. Both techniques entail minimal disturbance to insects and plants.

Application of insecticide

Insecticides are applied using an track-mounted sprayer running on rails in the roof of each cage (Rowland *et al.*, 1990). For work reported below, commercial formulations of cypermethrin ('Polytrin'; Ciba Geigy AG) or profenofos ('Curacron'; Ciba Geigy AG) were diluted with distilled water and applied at recommended field rates of 50 and 500g a.i./ha respectively, 28 and 35 days after the initial release of whiteflies into the simulators.

Design of simulator experiments

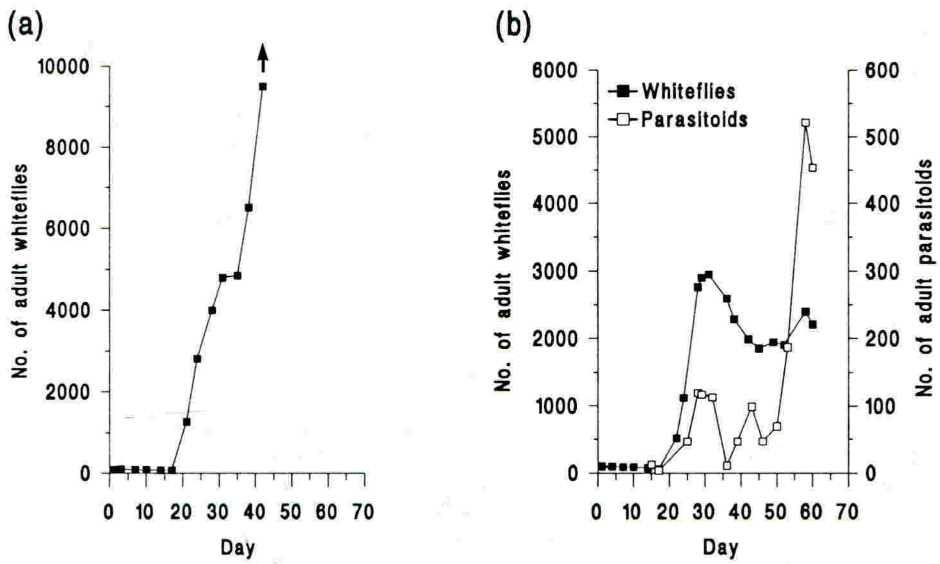
Sustaining experiments for a sufficient period (*ca.* 60 days) to discern how insecticides affect at least one post-treatment generation of pests and parasitoids imposes a major constraint on the number and scale of trials that can be conducted. Decisions regarding controls are of particular importance in this respect, since in each trial there are four levels of complexity that could potentially be compared simultaneously: (i) whiteflies alone; (ii) whiteflies + parasitoids; (iii) whiteflies + pesticide; and (iv) whiteflies + parasitoids + pesticide. Having proved highly predictable in preliminary trials, the first of these is now judged unnecessary. Combination (ii), although very repeatable over time, provides a valuable check on the comparability of trials. Combinations (iii) and (iv) appear essential for an adequate evaluation of a test compound against both species. Thus, in recent experiments, two simulators have incorporated each of combinations (iii) and (iv), with a fifth containing combination (ii) acting as the major control. To illustrate the development of this approach, all four possible combinations are presented below.

RESULTS AND DISCUSSION

No insecticide applied

In the absence of parasitoids and any insecticide application, whitefly numbers show a characteristic pattern whereby a slow initial decline in the number of the founders is followed by a sharp increase from day 17 onwards as adult progeny appear in the cage (Figure 1a). Emergence of the next generation from *ca*. day 37 onwards results in adult numbers rapidly exceeding 10,000/cage. Accumulation of honeydew then becomes a major factor limiting further growth, and greatly impedes the accuracy and ease of population monitoring.

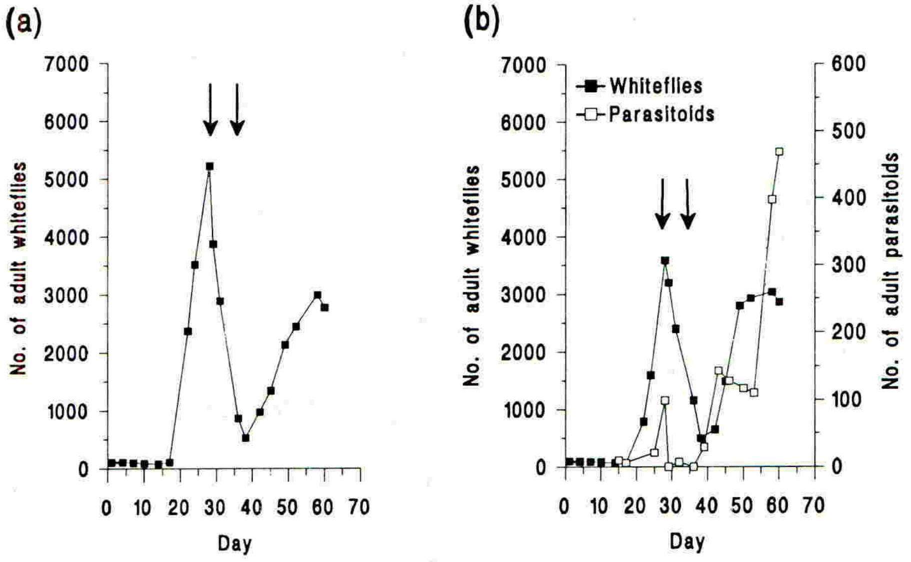
FIGURE 1. Changes in adult whitefly numbers in simulators in the absence (a) and presence (b) of parasitoids with no insecticide applied.



With the addition of parasitoids, the appearance of the first whitefly generation is delayed for ca. 2 days - an indication that virtually all receptive hosts present at the time of introduction were successfully parasitized - and there is little or no further increase in whitefly numbers over subsequent generations (Figure 1b). The first generation of *E. mundus* adults appears *ca.* day 26-28, coinciding very closely with the first wave of second generation host larvae reaching the preferred age for parasitism. This 'plateauing' of whitefly numbers appears due to the similar development times of the two species enabling *E. mundus* to track whitefly development sufficiently closely to maintain the host at a relatively constant population size (L.C. Birnie, unpublished data).

The initial extent of this suppression is very dependent on the starting density of parasitoids (Birnie and Denholm, 1992). The density used here (50 females/cage), and now adopted routinely, appears optimal for establishing *E. mundus* in the cages, yet avoiding it reducing *B. tabaci* to the extent that insecticide effects would not be readily discernible.

FIGURE 2. Effect of profenofos applied to simulators containing whiteflies alone (a) and whiteflies and parasitoids (b). Arrows denote the timing of insecticide applications.

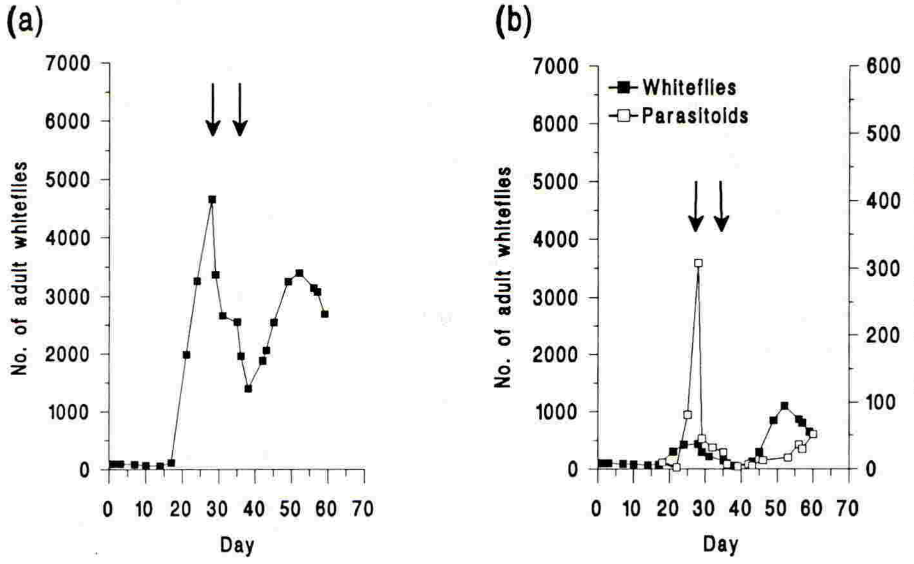


Incorporation of insecticides

Two sprays of cypermethrin or profenofos had very contrasting effects on these population trajectories. Profenofos proved the more potent compound against whiteflies alone, reducing adult numbers by *ca.* 85% after a single application (Figure 2a). In comparison, cypermethrin required two sprays to achieve a cumulative reduction of *ca.* 70% of pre-spray numbers (Figure 3a). This was consistent with earlier work attributing the greater efficacy of profenofos against SUD-R whiteflies to its translaminar and vapour action, enabling more chemical to reach the underside of leaves on which adults congregated (Rowland *et al.*, 1991). With both compounds, these effects were sufficiently transient to allow a recovery in numbers from day 40 onwards.

As expected, both insecticides caused rapid and severe mortality of adult parasitoids present at the time of treatment (Figures 2b and 3b). This effect was accentuated in the cypermethrin-sprayed cage by the very large number of parasitoids present, resulting from an unusually high level of parasitism of the first whitefly generation. Reason(s) why this occurred are still unclear. Differences in the subsequent dynamics of parasitoids were nonetheless sufficient to demonstrate a marked disparity in the effect of the compounds on the persistence of *E. mundus* in the cages. Numbers in the cypermethrin-sprayed cage remained very low for more than three weeks and then showed a protracted recovery (Figure 3b), whereas those in the profenofos-sprayed cage followed very closely the pattern in an unsprayed population (Figure 2b, cf. Figure 1b). Hence the mortality of adults at the time of spraying had little effect on the size and timing of subsequent generations.

FIGURE 3. Effect of cypermethrin applied to simulators containing whiteflies alone (a) and whiteflies and parasitoids (b). Arrows denote the timing of insecticide applications.



Causes of this difference between compounds are being investigated in smaller-scale experiments exposing life-stages of both species to direct contact with sprays and to residues of insecticides on leaf surfaces. Such work is essential to verify the apparent lack of toxicity of profenofos against immatures of *E. mundus*, and to establish the importance of exito-repellant effects in influencing the exposure of adults to cypermethrin deposits. In the meantime, our finding that cypermethrin exerts more adverse long-term effects on parasitoids is consistent with field observations in several countries (G.H. Ernst, pers. comm. 1992). It also fully supports events in Israel where the avoidance of pyrethroids on cotton early- to mid-season, with consequent reliance on pheromones plus infrequent use of organophosphates and carbamates to control bollworms and sucking pests, has greatly alleviated problems with *B. tabaci* and reduced the number of sprays required against this pest (Horowitz *et al.*, 1992).

CONCLUSIONS

Based on experience to date, the simulators offer exciting scope as IPM research tools, providing opportunities to compare chemicals with contrasting properties and active against different life-stages under realistic conditions in the laboratory. Despite obvious limitations imposed by the cost of equipment and the time-scale of experiments (Birnie and Denholm, 1992), we forsee that the present system, or derivations of it, could contribute greatly to work on several other natural enemies and phytophagous pest species.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF AN INTEGRATED CONTROL STRATEGY FOR SUMMER APHIDS IN WINTER WHEAT.

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ABSTRACT

Trials on the integration of selective aphicides with naturally occurring populations of aphid specific predators and parasites have been carried out in England from 1990 to 1992. Trials compared the efficacy of commercially recommended rates of pirimicarb and alpha-cypermethrin with substantially reduced rates when applied at flag leaf emergence or early flowering stages. The results demonstrate a good control of aphid infestations by parasitoids by the grain filling stages where aphids had overwintered on the crop, with no response to treatments. Where parasitoids were present, but visible parasitism was below critical levels, the use of low rate specific aphicides gave similar levels of control to that given by recommended rates. Where levels of parasitism were very low full rate aphicides were required to control aphid reproduction.

INTRODUCTION

The use of reduced rate selective aphicides to restrict aphid population growth with minimal effects on aphid predators and parasitoids was proposed by Poehling (1987). Field trials in Germany between 1983 and 1988 demonstrated that under certain circumstances a better economic return could be obtained by using reduced quantities of active ingredients (Mann *et al.*, 1991). A series of field trials were done in England between 1990 and 1992 applying either the full recommended rate or a reduced rate of insecticides at two timings against naturally occurring aphid populations. This was to establish whether reduced rates were applicable under English conditions and to define the circumstances under which reduced rate applications were viable.

MATERIALS AND METHODS

Sites were located in 15 farm crops as detailed in Table 1. Apart from insecticides applied during the summer, inputs were according to normal farm practice. Treatments consisted of pirimicarb (Aphox), at full (140 g AI/ha) or reduced (25 g AI/ha) rates, or alpha-cypermethrin (Fastac or Acquit), at full (15 g AI/ha) or reduced (5 g AI/ha) rates. Each treatment was applied to separate plots at flag leaf emergence (GS 37, Tottman & Makepeace 1979) or early flowering (GS 61). Sprays were applied by Oxford precision or motorised knapsack sprayer in 200 l of water/ha using medium quality spray nozzles and pressures of 2-3 bar. Plots were 4 by 24 metres with 0.5 metre paths, and were laid out in randomised blocks with 4 replications.

Table 1. Site details

Site	Variety	Sowing date	Autumn aphicide
1990			
Barham, Cambs	Hornet	2 October	none
Bridgets, Hants	Mercia	29 September	cypermethrin
Hemel Hempstead, Herts	Apollo	30 September	none
Shifnal, Shrops	Mercia	25 October	none
Surfleet, Lincs	Riband	9 October	none
1991			
Bocking, Essex	Riband	18 September	cypermethrin
Bridgets, Hants	Haven	25 September	cypermethrin
Clifton Campville, Staffs	Riband	2 October	deitamethrin
Hemel Hempstead, Herts	Apollo	20 September	cypermethrin
Swaton, Lincs	Riband	15 October	deltamethrin
1992			
Little Bentley, Essex	Beaver	30 October	bifenthrin
Bridgets, Hants	Hereward	15 October	none
Hemel Hempstead, Herts	Talon	11 October	none
High Mowthorpe, N Yorks	Beaver	6 October	none
Stretton en le Field, Leics	Beaver	14 October	none

Aphids were counted on 25 tillers per plot, selecting 5 groups of 5 tillers at random. Aphids were identified to species in the field, and numbers on the head, flag leaf and leaves 2 - 3 recorded separately per tiller. Numbers of visibly parasitised (mummified) and fungus infected aphids on assessed tillers were also recorded as were aphid predators. The amount of damage caused by cereal leaf beetle (*Oulema melanopa*) larvae and cereal leaf miners was estimated as the percentage of each leaf damaged. Aphids were counted on plots about to be sprayed, or previously sprayed at each spray timing and on all plots at the early milk stage (GS73). Plots were harvested by combine harvester and sub-samples taken for grain quality analyses, yield results will be reported in a future paper. All results were subject to analysis of variance using angular transformations for percentages and logarithmic (base 10) transformations for aphid numbers. A nested factorial design was used to segregate the effects of the different factors applied.

RESULTS

The predominant aphid species recorded were the grain aphid (*Sitobion avenae*) and the rose-grain aphid (*Metopolophium dirhodum*). The numbers of these aphids present on the plots about to be sprayed at the GS 37 assessment in 1990 are shown in Table 2, in 1991 no aphids were detected on the crops at this growth stage and in 1992 aphids were only detected at Stretton-en-le-Field, where only a few *S. avenae* and *Rhopalosiphum padi* were found, and at Hemel Hempstead with 1 per cent of tillers infested with a mean of 0.04 *S. avenae* and 0.03 *M. dirhodum* per tiller. Some spray applications were slightly delayed by adverse weather, significant delays occurred at High Mowthorpe in 1992 where the GS 37 spray was not applied and was substituted by a spray at GS 75. The numbers of aphids present when the GS 61 sprays were applied is shown in Table 3. The numbers of aphids present at the GS 73 assessments is shown in Tables 4 and 5. Percentage control of the two principal species is shown as the percentage difference in back transformed logarithmic means relative to numbers on untreated controls. The probabilities of differences in control due to the different factors applied is shown.

TABLE 2. Percentage tiller infestation, numbers of *Sitobion avenae* and *Metopolophium dirhodum* and percentage mummified at GS 37 in 1990.

Site	% tiller infestation	Numbers per tiller *S. avenae*	*M. dirhodum*	% mummified
Barham, Cambs	6	0.05	0.04	5.3
Bridgets, Hants	17	0.06	0.21	0.6
Hemel Hempstead, Herts	8	0.13	0.01	1.6
Shifnal, Shrops	5	0.09	0.22	14.6
Surfleet, Lincs	7	0.06	0.04	28.6

TABLE 3. Percentage tiller and head infestation, numbers of *Sitobion avenae* and *Metopolophium dirhodum* and percentage mummified on untreated plots at GS 61.

Site	% infested tillers	heads	Numbers per tiller *S. avenae*	*M. dirhodum*	% mummified
1990					
Barham, Cambs	17	2	0.2	0.2	6.0
Bridgets, Hants	73	15	1.3	3.0	2.0
Hemel Hempstead, Herts	6	2	0.6	0.1	3.9
Shifnal, Shrops	22	3	0.1	0.4	27.1
Surfleet, Lincs	3	0	< 0.1	< 0.1	36.9
1991					
Bocking, Essex	< 1	< 1	0	< 0.1	0
Bridgets, Hants	25	5	0.3	0.6	0.1
Clifton Campville, Staffs	< 1	< 1	0	< 0.1	0
Hemel Hempstead, Herts	< 1	0	< 0.1	0	0
Swaton, Lincs	< 1	< 1	0	< 0.1	0
1992					
Little Bentley, Essex	15	4	0.1	0.2	0.4
Bridgets, Hants	23	7	0.3	0.3	0.3
Hemel Hempstead, Herts	24	7	0.2	0.6	1.7
High Mowthorpe, N Yorks	2	1	0.1	< 0.1	0
Stretton en le Field, Leics	9	4	0.1	0.1	0

TABLE 4. Numbers of *Sitobion avenae* on untreated plots at GS 73, percentage control given by different rates and timings and the probabilities of an overall effect and of differences in control due to timing, full versus reduced rate and chemical choice).

Site	Numbers per tiller		Percentage control GS37 full	GS37 reduced	GS61 full	GS61 reduced
Probabilities	*(overall)*	*(timing)*		*(rate)*		*(chemical)*
1990						
Barham, Cambs	0.1		40	54	32	52
	(0.271)	*(0.820)**		*(0.376)*		*(0.524)**
Bridgets, Hants	3.5		43	57	86	66
	(0.046)	*(0.036)*		*(0.473)*		*(0.541)*
Hemel Hempstead, Herts	1.5		58	45	63	85
	(0.034)	*(0.044)*		*(0.385)*		*(0.091)*
Shifnal, Shrops	0.05		-64	-170	60	38
	(0.879)	*(0.003)*		*(0.293)*		*(0.010)*
Surfleet, Lincs	0			n a		
1991						
Bocking, Essex	0.1		-16	-137	-109	0
	(0.469)	*(0.738)**		*(0.983)*		*(0.106)**
Bridgets, Hants	3.6		20	22	65	17
	(0.072)	*(0.017)**		*(0.009)**		*(0.873)*
Clifton Campville, Staffs	0.7		15	15	43	54
	(0.347)	*(0.090)*		*(0.707)*		*(0.146)*
Hemel Hempstead, Herts	3.1		42	-5	31	9
	(0.482)	*(0.939)*		*(0.064)*		*(0.101)*
Swaton, Lincs	0.6		30	10	90	24
	(0.064)	*(<0.001)**		*(0.001)**		*(0.002)**
1992						
Little Bentley, Essex	3.9		43	6	53	27
	(0.010)	*(0.043)**		*(<0.001)**		*(0.558)**
Bridgets, Hants	3.9		7	-68	69	33
	(0.248)	*(<0.001)**		*(<0.001)**		*(0.035)**
Hemel Hempstead, Herts	1.5		-30	-28	33	34
	(0.808)	*(0.004)*		*(0.944)*		*(0.665)*
High Mowthorpe, N Yorks	8.7				85	77
	(<0.001)			*(0.041)*		*(0.117)*
Stretton en le Field,	9.6		57	50	80	48
Leics	*(<0.001)*	*(0.008)**		*(0.001)**		*(0.327)**

Significant interactions were found between the factors on many sites. Probability values are marked * in Tables 4 and 5 where a significant interaction was found between those factors.

TABLE 5. Numbers of *Metopolophium dirhodum* on untreated plots at GS 73, percentage control given by different rates and timings and the probabilities of differences in control due to timing, chemical choice and label versus reduced rate.

Site	Numbers per tiller		Percentage control GS37		GS61	
			label	reduced	label	reduced
Probabilities	*(overall)*	*(timing)*		*(rate)*		*(chemical)*
<u>1990</u>						
Barham, Cambs	0			n a		
Bridgets, Hants	0.3		0	43	54	66
	(0.219)	*(0.052)**		*(0.193)**		*(0.055)**
Hemel Hempstead, Herts	0.2		40	-8	45	64
	(0.368)	*(0.805)**		*(0.267)**		*(0.368)**
Shifnal, Shrops	0.2		38	11	65	-19
	(0.589)	*(0.822)**		*(0.068)*		*(0.006)**
Surfleet, Lincs	0			n a		
<u>1991</u>						
Bocking, Essex	0			n a		
Bridgets, Hants	0.8		-84	-26	-15	-37
	(0.376)	*(0.415)*		*(0.656)*		*(0.077)*
Clifton Campville, Staffs	0.8		42	40	63	30
	(0.082)	*(0.102)**		*(0.119)*		*(0.600)**
Hemel Hempstead, Herts	5.7		46	30	47	55
	(0.018)	*(0.165)*		*(0.801)*		*(0.202)*
Swaton, Lincs	0			n a		
<u>1992</u>						
Little Bentley, Essex	2.8		39	32	60	38
	(0.019)	*(0.092)*		*(0.081)*		*(0.445)*
Bridgets, Hants	1.6		22	-52	27	20
	(0.859)	*(0.287)**		*(0.261)*		*(0.225)**
Hemel Hempstead, Herts	7.1		14	4	16	17
	(0.476)	*(0.519)*		*(0.703)*		*(0.714)*
High Mowthorpe, N Yorks	1.0				77	10
	(0.002)			*(<0.001)*		*(0.686)*
Stretton en le Field,	13.3		29	-12	66	-12
Leics	*(0.024)*	*(<0.001)**		*(<0.001)**		*(0.300)**

DISCUSSION

The levels of control achieved by both full and reduced rate aphicides varied greatly between sites and years. In 1990 aphids overwintered on the four crops which had not received an autumn pyrethroid spray. Aphid numbers built up earlier in the spring and were declining by the flowering stage with increasing pressure from parasitoids at three of the sites. Aphicides had little effect on aphid numbers at these sites. Levels of parasitism were lower at Bridgets and Hemel Hempstead and aphid numbers increased to damaging levels at these sites. Similar reductions in aphid numbers were obtained from both full and reduced rate applications.

In 1991 no aphids were found to have overwintered at any of the sites, all of which received autumn pyrethroid sprays. Aphid immigration to the crops was delayed by cold, wet weather, and numbers on the crops peaked late in the grain filling stages. Natural enemy effects were less important and reduced rate aphicides were significantly less effective than full rates in controlling *S. avenae* at two sites.

In 1992 few, or no, overwintered aphids were found on the sites. Aphid immigration was earlier than in 1991 and potentially damaging aphid infestations were recorded at all sites. Natural enemy levels were much lower than in 1990 and reduced rate aphicides gave a significantly poorer control than full rates at 4 sites.

Reduced rate aphicides were shown to be effective where natural enemies were established within a field at intermediate levels which were insufficient to give adequate control unaided. Where natural enemy levels were slightly lower reduced rates were significantly less effective. Whilst 'mummy counts' are known to give a variable estimate of parasitism (Walton *et al.* 1990), the proportion of mummified aphids found during assessment gave a useful indication of aphid build-up at these sites and merits further investigation. More sophisticated techniques of electrophoresis or rearing are available but would be too slow to be of value either in experiments or commercially. Reduced rates can not be recommended with confidence unless a reliable and economic means of assessing natural enemy levels is established.

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SUPERVISED CONTROL OF FOLIAR PESTS IN BRASSICA CROPS

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ABSTRACT

Damage thresholds were tested for cabbage aphid (*Brevicoryne brassicae*) and cabbage caterpillars, mainly large white butterfly (*Pieris brassicae*), small white butterfly (*Pieris rapae*), diamond-back moth (*Plutella xylostella*) and cabbage moth (*Mamestra brassicae*) in crops of cabbage, calabrese and Brussels sprouts. In three of the seven experiments the systematic sampling method (Hommes *et al*., 1988) was adopted. In the remainder a sequential sampling method was tested (Theunissen, 1988). Spray treatments were reduced from a mean of 6.1 applications on routinely-treated plots to means of 0.85 and 1.6 for aphid and caterpillar control respectively on the supervised plots. Percentage marketable produce was greatest from routinely-treated plots. There was unacceptable internal pest damage in calabrese spears, eg small white butterfly caterpillar damage and in Brussels sprouts buttons eg cabbage aphid at three of the sites.

On the basis of this work the thresholds will be modified to reflect changing susceptibility to pests at different plant growth stages. The sequential sampling method will be used to permit more rapid assessments than are feasible with the systematic method.

INTRODUCTION

There is increasing pressure on growers to reduce insecticide input, yet produce blemish-free produce. On market brassicas in the UK there is widespread routine spraying for control of aphids and caterpillars (Thomas, Davis and Garthwaite 1992), because there are no proven and established treatment thresholds.

The aim of the work is to evaluate different sampling methods for monitoring cabbage aphid (*Brevicoryne brassicae*) and cabbage caterpillars mainly the small white butterfly (*Pieris rapae*), large white butterfly (*Pieris brassicae*), green-veined white butterfly (*Pieris napi*), garden pebble moth (*Evergestis forficalis*) diamond-back moth (*Plutella xylostella*) and cabbage moth (*Mamestra brassicae*) and to establish robust treatment thresholds. The 3 year MAFF (Ministry of Agriculture, Fisheries and Food)-funded project involves collaboration between entomologists and horticulturalists at ADAS Arthur Rickwood Experimental Husbandry Farm and HRI (Horticulture Research International) Kirton, Stockbridge House and Wellesbourne.

METHODS

Four sites were used and three types of brassicas were tested. (Table 1).

TABLE 1. Sites and brassica crops tested

	Site	Type of Brassica	
1.	Mepal, Cambs	1i.	cabbage
		1ii.	calabrese
2.	Cottenham, Cambs	2.	cabbage
3.	Kirton, Lincs	3i.	Brussels sprouts
		3ii.	cabbage
		3iii.	calabrese
4.	Cawood, N Yorks	4.	Brussels sprouts

Treatments were as follows:-

1. Untreated, control
2. Routine treatment - sprayed at 2 week intervals with a tank mix of deltamethrin (5ml AI/ha) for caterpillar control and pirimicarb (75 g AI/ha) for aphid control in 600l water/ha from 2 weeks after transplanting.
3. Supervised treatment - insecticides and rates as above, applied singly or as a tank mix only when threshold(s) exceeded.
4. Integrated treatment - _Bacillus thuringiensis_ (Thuricide 1 kg/ha) and pirimicarb (75g AI/ha) applied singly or in a tank mix, but only when threshold(s) exceeded.

Monitoring of treatments 3-4 started 2 weeks after transplanting and continued at two week intervals until harvest. Two sampling methods were tested. For the cabbages at sites 1 and 2 and Brussels sprouts at site 4 (see Table 1) the systematic method used by the IOBC Working Group (Hommes _et al_., 1988) was adopted. This method involves sampling five plants at 10 points, regularly distributed throughout the plot. In the remaining trials a sequential sampling method was used with sampling charts and lists of random plant positions. In order to check the decisions made by the sequential sampling method, a sample of 50 plants was always assessed. The results were transferred to sampling charts.

Sampling charts were constructed using theory based on Wald's Sequential Probability Ratio Test (Wald, 1947) and the practice of Dutch scientists (Theunissen, 1988). In the charts the x-axis represented the accumulated sample size and the y-axis represented the difference between the number of infested plants and the number of non-infested plants. The chart was divided into three areas by two parallel lines representing the upper and lower thresholds, the upper threshold being 10% above the lower threshold. The slopes of the lines depended on the values of the thresholds. The distance between the parallel lines depended on both the values of the thresholds and the probabilities of under or overestimating the pest population (set to 0.05).

Using the sampling charts sampling continued until:-
either 1. The upper line was crossed - treatment necessary.
or 2. The lower line was crossed - treatment unnecessary.
or 3. The maximum sample size was reached (resample a week later).

Each selected plant was examined for presence or absence of live, wingless cabbage aphid and live caterpillars. The thresholds tested were 10% infested plants for the first two sample dates and 5% infested for further samples until harvest for both aphids and total caterpillars.

Assessments of yield and percentage marketability were made at harvest.

Assessments of internal damage were made eg samples of calabrese spears and Brussels sprout buttons.

RESULTS AND DISCUSSION

Spray treatments for aphid control were reduced from a mean of 6.1 (range 3-10) on routinely-sprayed plots to 0.85 (range 0-2) on supervised plots. Spray treatments for control of caterpillars were reduced from a mean of 6.1 (range 3-10) on routinely-treated plots to 1.6 (range 0-3) on the supervised plots.

There was a very late spring migration of cabbage aphid as indicated by the Rothamsted Insect Survey (M. Tatchell, Pers.comm.). Caterpillar pests, especially small white butterfly and diamond-back moth built up slowly.

The percentage marketable produce (free from pests and pest damage) was greater from routine than from supervised plots (Table 2). This assessment of marketability did not include internal pest damage. Cabbage aphids were found under wing leaves of Brussels sprouts buttons on the lower third of the stem at 10% on the supervised plots and 0.7% on the routinely-sprayed plots. The anomalous result in trial 1i. was due to a localised and severe attack by caterpillars of green-veined white butterfly (Pieris napi). The percentage marketable produce was less on supervised plots than untreated plots and is a function of small plot size.

TABLE 2. Percentage Marketable Produce

Site and crop	untreated	routine	supervised
Mepal, Cambs			
1i. Cabbage	91	89	72
1ii. Calabrese	99	100	99
Cottenham, Cambs			
2. Cabbage	-	100	90
			IPM = 92
(Kirton), Lincs			
3i. Brussels sprouts	38	82	71
3ii. Cabbage	41	93	80
3iii. Calabrese	88	95	92
Cawood, North Yorks			
4. Brussels sprouts	81	99	99

The systematic sampling method proved more practical and less time consuming than the full 50 plant random sample. However, this method provides less information than the sequential method. In most of the sequential assessments, a decision was made after many fewer than 50 plants. The sequential sampling charts used in these experiments had some drawbacks, notably that the level of infestation that could be tolerated was set as the lower threshold and that the distance between the upper and lower thresholds was too wide, so that much higher levels of infestation were observed before treatment was applied. To overcome these problems the charts have been modified. Following the results of trial 1i. plot size has been increased to a minimum of 200 m^2.

Although in 1991 supervised control resulted in a reduction in the number of sprays, this will not always be the case. In reducing the number of spray treatments, we must accept that there may be some loss of quality.

CONCLUSION

The supervised treatments have resulted in a marked reduction in the number of sprays applied but pest attacks were delayed until July. With sampling methods and threshold levels used, in most trials there was too much pest damage at harvest, eg caterpillar damage in calabrese spears. A fully sequential sampling procedure has been adopted and the threshold values have been modified so they are related to plant growth stages (Theunissen and den Ouden, 1985).

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THE DEVELOPMENT OF PRACTICAL AND APPROPRIATE IPM METHODS FOR IRRIGATED RICE IN EASTERN INDIA.

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ABSTRACT

The paper reports on progress in rice insect pest management in the Indo-British Fertiliser Education Project. Over 100 pest and natural enemy taxa were identified. Established economic threshold levels were exceeded in 24% of the trials in farmers fields, by 7 pest types. The most frequent pests were stemborers and planthoppers. Rice IPM systems are often complex, but a practical guide to methods of pest monitoring using simple economic thresholds was developed. The guide includes step by step instructions and clear photographs of key pests and natural enemies. These IPM methods allow a reduction in insecticide use, but sustain yields, giving 20% higher net profits. Techniques for training farmers and extension workers are outlined, these concentrate on demonstrations of simple IPM methods in farmers fields.

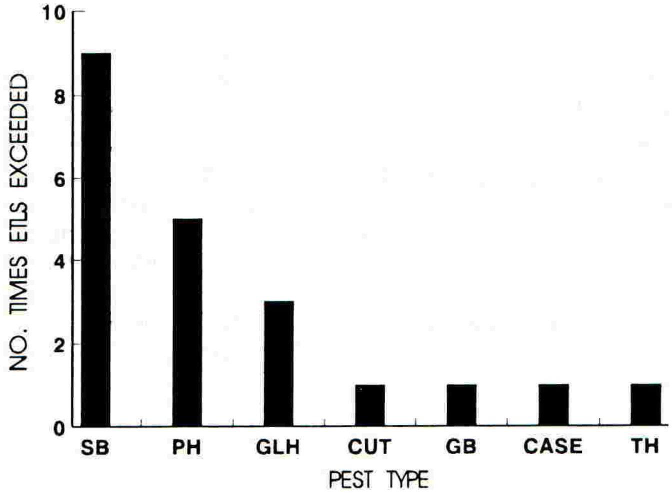
INTRODUCTION

For 10 years the Indo-British Fertiliser Education Project (IBFEP) has operated in 6 states in eastern India. A major aim was to improve the yield and profitability of irrigated rice in this important rice producing region. Rice yields in eastern India have not increased as much as in other areas in response to high yielding varieties and improved agronomic methods (Barker & Pal, 1979). As the project progressed, inputs to rice cultivation increased, and the need to improve the management of insect pests, particularly brown planthopper (*Nilaparvata lugens*), became apparent. Results from IBFEP Phase 1 (1982-7) showed that yields and pest densities were increased by raised levels of nitrogenous fertilisers. However, economic threshold levels for insect pests were seldom exceeded, emphasising the importance of need-based insecticide use (Chakraborty *et al.*, 1990). Consequently, IBFEP Phase 2 (1987-1992) included an integrated pest management (IPM) programme for insect pests of irrigated rice. The IBFEP IPM programme aimed to adapt existing rice insect pest management technology to local conditions. It operated in 6-8 villages in West Bengal and Orissa each season, but has recently expanded to cover a total of 40 villages per season in West Bengal, Orissa, Bihar and Assam. If the benefits to farmers are sustained, the programme could be enlarged to cover more villages in this large rice producing region.

THE RICE FAUNA

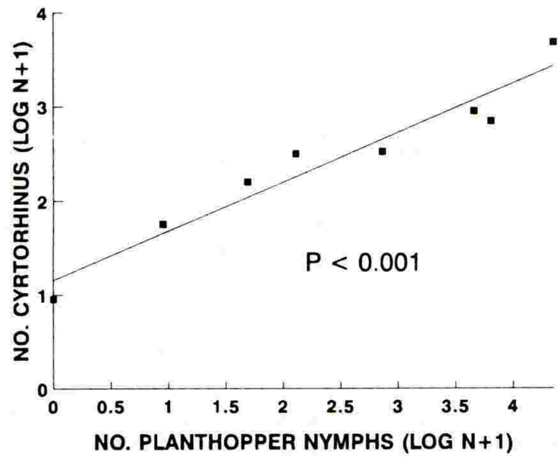
The programme identified 56 insect herbivore species found commonly in D-Vac, sweep and visual samples. Extension staff consider planthoppers (PH) (*N.lugens* and *Sogatella furcifera*), stemborers (SB) (mostly *Scirpophaga incertulas*), gall midge (*Orseolia oryzae*), leaf-folders (mostly *Cnaphalocrocis medinalis*) and gundhi bug (GB)(*Leptocorisa* spp.) as major pests. Cutworms/armyworms (CUT)(Lepidoptera; Noctuidae), leafhoppers (GLH)(*Nephotettix* spp.), hispa (*Dicladispa armigera*), caseworm (CASE)(*Nymphula depunctalis*), grasshoppers (Orthoptera; Acrididae) and thrips (TH)(*Stenchaetothrips biformis*) are considered minor pests. In the IPM programme from 1989-91, economic thresholds levels were exceeded by 7 pest types, but most frequently by stemborers and planthoppers (Fig 1). Details of the economic threshold levels are given later in the paper.

FIGURE 1. The frequency that pest taxa exceeded the economic threshold levels (ETLS), 1989-91. Pest abbreviations as in text.



In the IPM trials themselves, economic thresholds were exceeded in 24% of the 34 village sites used from 1989-91. A range of insect pests caused potential yield loss in these trials but at any one time only one pest type ever approached or exceeded the economic threshold. There was no evidence of economic damage being caused by the combined effects of several pest types that were individually at sub-economic levels. Pest types may include several similar species but usually one species predominated in any particular trial. For example, 7 species of rice stemborer were recorded but *Scirpophaga incertulas* (yellow stemborer) was the most common. Over 50 taxa of predators and parasitoids were identified, and most sites possessed a rich natural enemy fauna when insecticide use was not excessive. Taxa were identified to species where possible, but spider identifications in the regular sampling were only to family level. Very variable levels of egg parasitism of brown planthopper (*N.lugens*) and yellow stemborer (*S.incertulas*) were found between seasons and sites (e.g. 0-72% in brown planthopper). The heteropteran predator *Cyrtorhinus lividipennis* was often common, showing a positive relationship to the numbers of planthoppers (Fig. 2).

FIGURE 2. The numbers of the predator *C. lividipennis* and planthopper nymphs in D-Vac samples from 8 nearby rice fields, Orissa, 1989.



PEST MONITORING AND ECONOMIC THRESHOLD LEVELS

One of the main barriers to the implementation of IPM for farmers is that the required decision making has been too complex or laborious (Goodell, 1984; Matteson *et al.*, 1984; Norton & Way, 1990). Monitoring systems must be simple but accurate enough to improve on existing decision making by farmers. Farmers already decide whether to apply pesticides depending on how serious they perceive the pest problem to be. They normally do this from the field margin and therefore detect mainly the visually obvious pests or pest stages. The IBFEP monitoring system involves visually estimating the numbers of pests on each of 10 rice hills in a diagonal walk across the rice field. Simple step by step instructions are included in an IPM guide for extension workers and these can easily be translated into the local languages for farmers. A form has been produced to match the monitoring instructions, but it would also be possible to use clip boards and pegs. For simplicity, monitoring based on sequential sampling has been avoided. The IPM guide also includes a table of economic thresholds for several pest taxa (leafhoppers, planthoppers, combined defoliators, gall midge, stemborers and gundhi bug)(example in Table 1). Thresholds are given as numbers per hill rather than as percentages or per square metre. Economic thresholds were compiled from published figures (e.g. Anon., 1988; Kalode & Krishnaiah, 1991; Maiti, 1985; Reissig *et al.*, 1986) and after consultation with IBFEP field staff. More importantly, thresholds are subject to a continuous process of reassessment based on the results of IPM trials, and improvements can be easily added to the loose-leaf guide. For example, early season thresholds for stemborers were increased several times because no-insecticide plots produced the same profits as IPM plots receiving insecticide for stemborer. Photographs in the IPM guide show pests and damage as they appear in the field allowing easy identification. The guide is printed on synthetic paper for repeated field use and has pest and natural enemy names, alphabetically and phonetically, in 6 local languages and dialects.

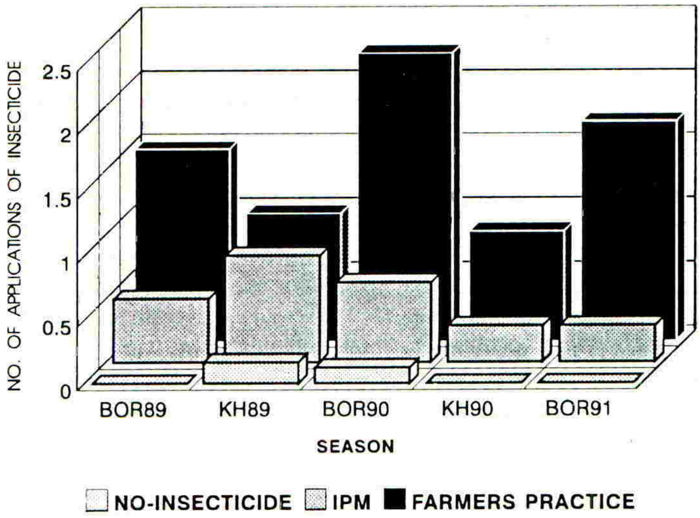
TABLE 1. Recommended economic thresholds for planthoppers (PH) and stemborers (SB) in rice in eastern India.

	Seedbed and newly transplanted	Vegetative stage	Reproductive stage	Maturing
PH	>5 adults or large nymphs per 10 plants	>15 adults or large nymphs per hill	>15 adults or large nymphs per hill	No control after dough stage
SB	>5 deadhearts per 10 plants	>2 deadhearts per hill	>1 deadheart per hill	No control necessary

USE OF INSECTICIDE IN THE IBFEP IPM PROGRAMME

Farmers use up to 5 applications of insecticides per season, but it is quite common for farmers to apply no insecticide if they perceive no pest problems. The IBFEP IPM methods have resulted in decreased applications of insecticide compared with farmers normal practices (Fig 3). These data are based on 34 IPM trials in farmers fields in separate villages in Orissa and West Bengal between 1989 and 1991.

FIGURE 3. Mean numbers of insecticide applications in IPM trials in the boro (spring) and kharif (autumn), 1989-91.

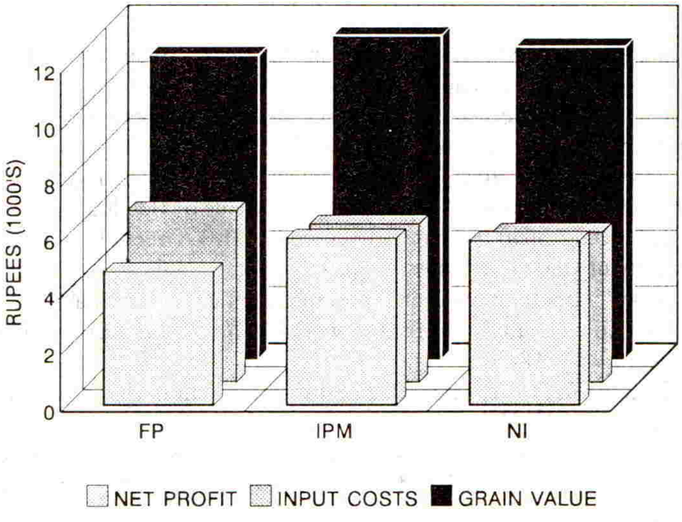


More insecticides are used in the longer boro (spring) season because crop yields are potentially much higher, warranting higher levels of agronomic inputs. The no-insecticide treatments occasionally received insecticide where seed-beds were shared. Extension staff provide advice and training in the use of crop protection chemicals but there are still some problems with underdosing, lack of adherence to safety procedures and poor methods of application (e.g. spray applied only to the top of the canopy). Most insecticides are manufactured in India but many modern chemicals are unavailable. IBFEP only recommends (and subsidises) a selection of these pesticides on the grounds of safety.

THE ECONOMICS OF IPM OF INSECT PESTS

It is important to demonstrate the advantages of IPM to entomologists, extension workers and especially to rice farmers. Farmers will only be convinced if they see improved yields or profits in their own fields using methods that they understand. The IBFEP IPM programme used simple demonstration plots in farmers fields with replicated trials at selected sites. The design followed standard procedures for IPM demonstration plots (e.g. Anon., 1988). Typical farmers cultivation practices were compared with no-insecticide and IPM treatments. The IPM and no-insecticide treatments produce profits on average 20% higher than in the farmers practice (Fig. 4, $P<0.001$). This analysis used the 20 IPM trials from 1989-91 for which full agronomic details were available.

FIGURE 4. Mean economic performance per hectare for farmers practice (FP), IPM and no-insecticide (NI) treatments in the simple IBFEP IPM demonstration trials, 1989-91.



FARMER TRAINING IN THE IBFEP IPM PROGRAMME

Training has been a major component of the IPM programme, aiming to set up a network of extension workers that can undertake farmer training. The emphasis has been on practical field training for extension workers and farmers using the demonstration plots. The plots are used to explain monitoring methods, improve farmer recognition of pests and increase awareness of the natural enemies using visually obvious predators in the field. Farmer training meetings are held at each IPM demonstration site early in the season when stemborers are often a problem, and then later to coincide with peak levels of planthoppers. The aims are to increase farmer awareness of natural enemies and to emphasise the importance of need-based use of insecticides. Demonstrations of natural enemies killing pests in small containers are used, together with other live specimens and photographs with legends in the local language. Similarly the harmful effect of some insecticides on natural enemies is demonstrated as well as emphasising the need for safe practices to avoid harmful effects on humans. The basic economics of need-based use of insecticides are presented, together with the importance of weekly monitoring for pests. The method of monitoring is explained again prior to a session of field training on natural enemy awareness and monitoring. By simplifying the methods for the management of insect pests of rice and by concentrating on field demonstrations and training it is anticipated that the transfer of IPM technology to Indian rice farmers should be more successful than in the past.

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AN ANALYSIS OF INSECTICIDE USE IN KENYA COFFEE IPM AND OUTBREAKS OF *ICERYA PATTERSONI*

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ABSTRACT

Pest control measures with particular reference to insecticide use patterns on large-scale coffee estates in Kenya were surveyed through formal questionnaires and informal farm visits. It was found that between 1970 and 1985, farmers relied less and less on insecticides for pest control as IPM principles became more widely adopted. It was therefore concluded that insecticides were unlikely to be responsible for the upsurge of *I. pattersoni* although subsequent spraying may have exacerbated the situation.

INTRODUCTION

In Kenya, coffee is attacked by a large pest complex (LePelley, 1968), but during the later part of this century the Kenya Coffee Research Foundation (CRF) has developed a viable IPM programme, based on conservation of invertebrate natural enemies, against most of the major pests (Bardner, 1985). However, from 1980, *Icerya pattersoni*, a previously rare indigenous insect, attained pest status on large-scale coffee farms in central Kenya (Wanjala *et al.*, 1986). This scale insect is usually found aggregated on the undersides of leaves but quite commonly forms colonies on branches and stems during severe attacks. In mild infestations, the scale causes leaf-fall while severe infestations result in dieback and sometimes tree death.

Kinuthia and Mwangi (1986) have shown that a sizable natural enemy complex is associated with *I. pattersoni* on coffee; this complex is dominated by a coccinellid beetle, *Rodolia iceryae*. More recent studies by Kairo and Murphy (unpublished) have indicated that the combination of *R. iceryae* along with other natural enemies is able to suppress *I. pattersoni* population outbreaks when pesticides are used at the CRF-recommended field rates. In view of these observations, the International Institute of Biological Control (IIBC) in collaboration with the CRF and farmers began a project in 1985 to research the cause of the disruption to the natural enemies; this information was to be used as a basis for evaluating and possibly adjusting current IPM programmes against other pests and thus prevent further outbreaks of *I. pattersoni*.

Although there are several factors that could have disrupted the population dynamics of *I. pattersoni*, initial attention was focussed on insecticides because of their possible detrimental effects on natural enemies. This paper reports: firstly, the results of a survey to determine general insecticide use patterns against coffee pests from 1970 to 1985 and their association with *I. pattersoni* outbreaks; secondly, observations on the effects of spraying on the population structure of *I. pattersoni* and its natural enemies.

MATERIALS AND METHODS

Farmer surveys

Surveys on pest control practices for the period 1970-85 were conducted through questionnaires and farm visits in Muranga and Kiambu districts of Kenya. This was only possible for some large-scale coffee estates which kept records of farming activities during previous years. In total, 11 estates all within the area where *I. pattersoni* was a problem and comprising about 10% of the total estate area in the region were surveyed. Informal discussions were also held with many other large-and small-scale farmers. In the questionnaire farmers were provided with a list of common coffee pests and for each year asked to indicate: occurrence, severity and control measures used, i.e insecticide or biological (it was assumed that natural enemies were responsible for control when insecticides were not used). Where used, farmers were asked to indicate type of insecticide and the spraying strategy, such as spot or blanket sprays. It was not possible to get quantitative information on rates of application and timing but the indication was that CRF recommendations were generally followed.

Determination of the population structure *I. pattersoni*

Samples of leaves were taken randomly from sprayed and unsprayed trees in four estates. These were examined and the number of different scale stages determined. For convenience, scales were divided into three easily distinguishable groups: all first instar, intermediate instars and final instar with adults.

RESULTS

Farmer surveys

Pest occurrence and control measures

For the period 1970-80, the number of instances in each estate when pest species were reported causing damage varied between nine and 11 per year. However between 1980 and 1985 the number rose to 12-13, mainly because of the emergence of *I. pattersoni* and *Aspidiotus* sp., the latter species developed as a serious pest in the late seventies and early eighties (Waikwa *et al.*, 1983). These reports were collated according to insecticide usage and Figure 1a gives the relative use annually from 1970 to 1985. Although there was an overall drop in the number of reports where insecticides were used, the steady decline was apparently reversed in 1980 owing to the emergence of the new pests. It is noteworthy that the initial decline was accompanied by an increase in reports where natural control was considered sufficient to maintain pests below damaging levels. Associated with these trends was an overall decline in the number of species targeted for chemical control (Figure 1b).

Major and minor pests and control measures

In general, there were more reports of minor pests than of serious ones. This is shown in Figure 2 which also gives the control strategies adopted for each group. An initial increase in cases where insecticides were used against minor pests between 1970 and 1974, was followed by a steady decline from 1975 to 1985. On the other hand, from 1970 to 1980 there was a steady increase in the number of reports where chemicals were not needed to maintain minor pests below damaging levels. From 1980 to 1985 a reversal of this trend occurred. Reports of serious pests on which insecticides were used showed a steady decline from 1970 to 1975 when they stabilized at 3-5% until 1980 when again there was an increase. Generally, there were very few reports of serious pests where non-insecticidal control methods were considered sufficient to maintain the pest below damaging levels.

Figure 1. Use (hatch) and non-use (open) of insecticides to control pests

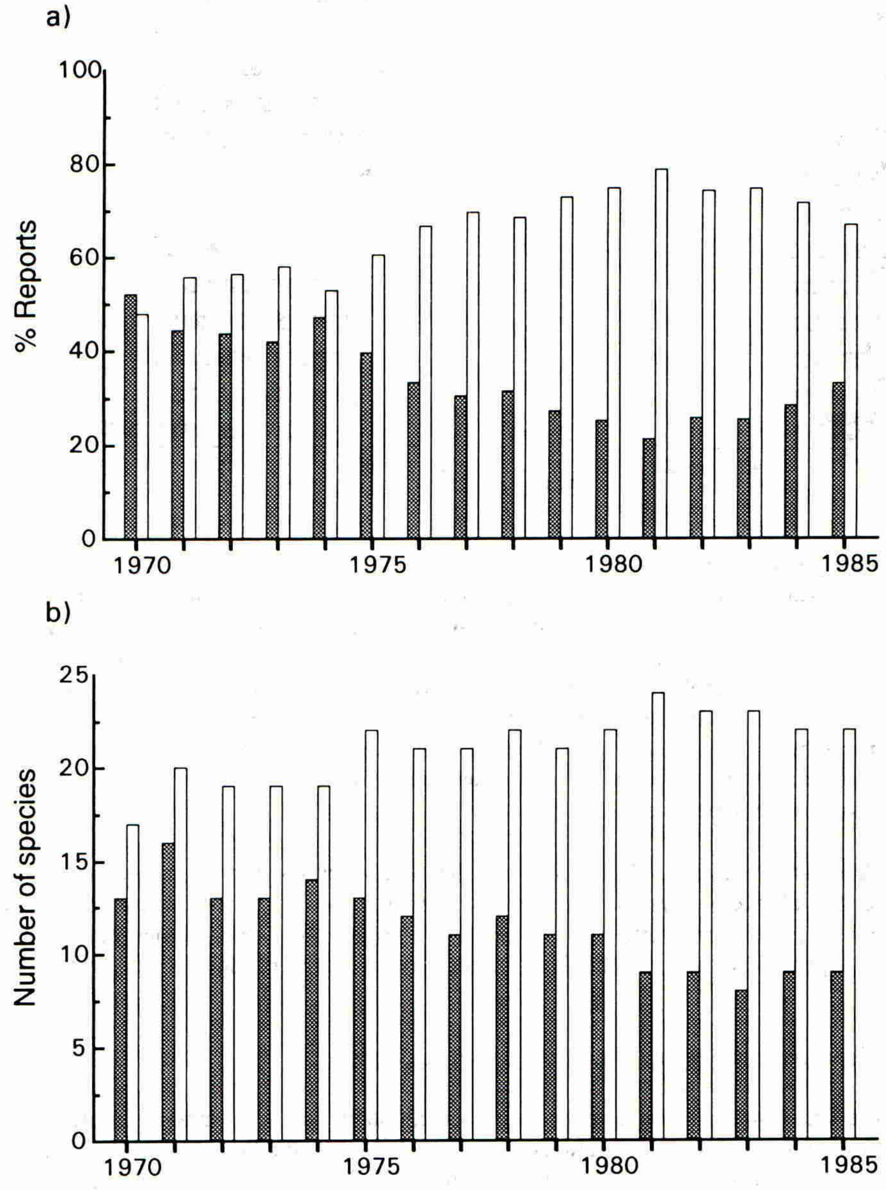
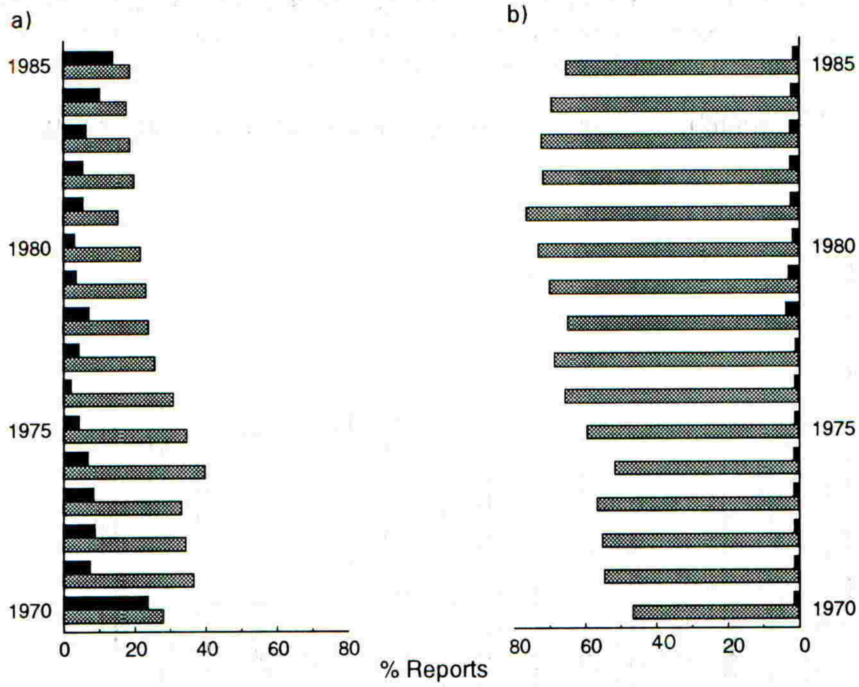


Figure 2. Control measures against minor (hatch) and serious (solid) pests using a) insecticides and b) natural enemies



Insecticide types and application

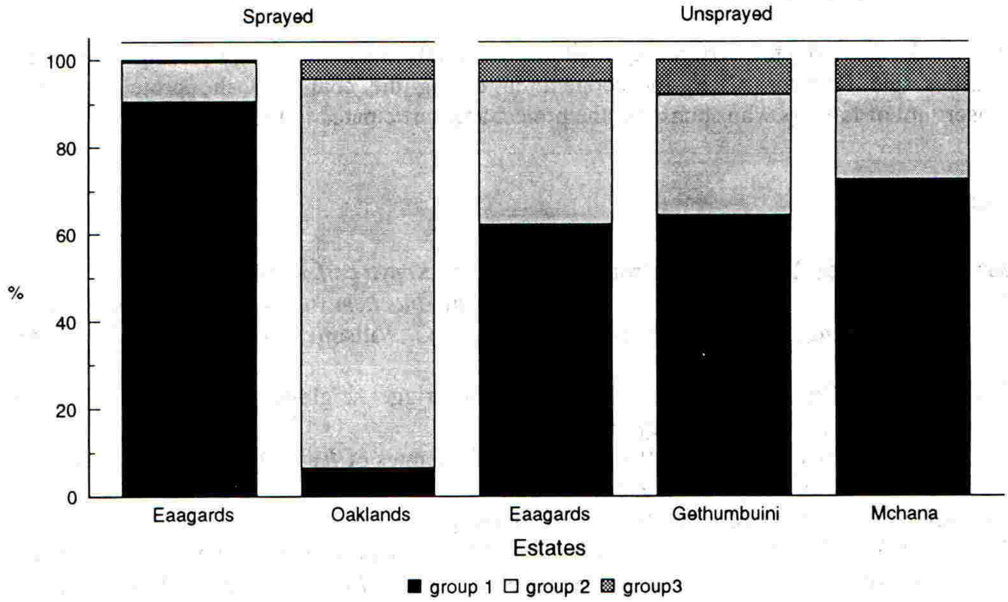
For the survey period the two most widely used insecticides were parathion and dieldrin. Use of parathion against *Leucoptera* spp. dropped gradually from 1970 and none of the estates in the survey used it after 1978. After the mid-seventies more interest was paid to disyston a systemic soil-applied insecticide, for control of these major pests. Throughout the entire survey period, dieldrin was used regularly for stem treatment against ants attending scales and mealybugs. However, organophosphate insecticides have since replaced dieldrin as agents for stem treatment. With the advent of new pests in the 1980s, there was an increased use of diazinon and azinphos methyl.

With regard to insecticide application, the mid-seventies saw a gradual decline in routinely applied blanket sprays and the adoption of more carefully timed tactical spot sprays. Most of the estates ran some form of pest monitoring programme which sometimes involved pest scouts. Apparently, pest thresholds recommended by CRF (Bardner, 1975) were found useful.

Structure of sprayed and unsprayed *I. pattersoni* populations

There was a predominance of first and second stage scales in sprayed estates which basically formed single stage generations as opposed to the situation in unsprayed estates where generations overlapped (Figure 3). Insecticides had a synchronising effect because while most stages were killed by the spray, unhatched eggs still within the ovisac survived protected by the mother scale.

Figure 3. Proportion of different scale groups in sprayed and unsprayed estates



DISCUSSION

In general, the results of the survey showed that, for the period 1970-80, farmers gradually used less and less insecticides to control fewer and fewer pest species. Moreover, during this period, insecticide applications decreased for both `severe' and `minor' pests. Given that *I. pattersoni* has been present on coffee since the turn of the century (D.J. Williams, pers. comm.) and that the types of insecticides used on estates were not dramatically changed for the period 1970-85, it seems unlikely that the outbreaks of *I. pattersoni* in 1980 were induced through the effects of insecticides on natural enemies. Indeed, it is concluded that the spraying regimes used in IPM programmes against other coffee pests in central Kenya are probably compatible with most invertebrate natural enemies in the coffee estates. The role of other factors such as foliar feeds, increased leaf retention owing to fungicide use and irrigation are currently under investigation.

The use of spot applications of organophosphates against *I. pattersoni* from 1980 onwards did little to abate the pest. In fact, the data reported here suggests that the insecticides, through inducing synchronized generations in the pest, may have indirectly reduced the effectiveness of stage-specific natural enemies (Godfray and Chan, 1991). Because of its relative ineffectiveness, spot spraying against *I. pattersoni* was reduced in the mid-eighties and more emphasis was placed on conserving natural enemies found associated with the scale. In the late-eighties, a reduction in the number of outbreaks was noted (T. Michaelides, pers. comm.). However, the pest did not decline to its pre-eighties population levels.

ACKNOWLEDGEMENTS

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THE EFFECT OF MANAGED FIELD MARGINS ON HOVERFLY (DIPTERA: SYRPHIDAE) DISTRIBUTION AND WITHIN-FIELD ABUNDANCE

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ABSTRACT

Hoverfly activity around two floristically different types of field margin was monitored over a two-month period. Margins were either managed and drilled with a mixture of native wildflowers, or left unmananaged. Hoverfly activity was estimated using fluorescent yellow water traps in transects at right angles to the field margins.

The establishment of wild-flower strips around field margins influenced the local abundance of syrphids leading to increased hoverfly activity within the adjacent crop, thus enhancing the potential for syrphids to have a major influence on the regulation of aphid populations.

INTRODUCTION

Through the careful management of field margins it is possible to establish a diverse floral sward which is visually attractive and has the potential to prevent ingress of pernicious weeds, as well as provide a habitat for beneficial insects and spiders (Marshall & Nowakowski, 1992). The potential benefits of managed field margins for beneficial entomofauna are, at least, twofold: the sites may provide an improved habitat for overwintering polyphagous beetles (Harwood in prep.), whilst providing a pollen and nectar source for foraging adult hoverflies in the summer. By contrast unmanaged wild field margins may often be dominated by a few agriculturally unacceptable weed species which may spread into the adjacent crop reducing yields and offering a limited resource to beneficial insects.

Both male and female adult hoverflies feed on pollen and nectar. Nectar (or aphid honeydew) is used as a source of energy. Schneider (1948) established that female hoverflies require amino acids available in pollen protiens for the maturation of their reproduction system. Many syrphid larvae (e.g. *Metasyrphus corollae* and *Episyrphus balteatus*) are predatory on cereal aphids have the potential to limit aphid population growth (Chambers & Adams 1986, Entwhistle & Dixon 1990). By improving the provision of floral resources in land which may often hve few naturally occuring wildflower species it may be possible to enhance natural syrphid populations within cereal fields and thus enhance their intrinsic biocontrol potential.

MATERIALS AND METHODS

Wildflower margins

Three pre-established experimental floral margin strips were used for the study, strips A and B were in their first year of establishment (drilled September 1991), with strip C in its third year (drilled September 1989). Commercially available seed mixtures were used, the compositions of which are shown in tables 1 and 2. These mixtures were chosen to produce a sward of non-invasive indigenous wildflowers and grasses which would be visually attractive, whilst containing a range of species with flowering times spread throughout the summer.

Strips were approximately 220m long and either 3m (strip C) or 5m (strips A and B) wide, and were positioned at the edge of fields of winter wheat, following the line of existing farm tracks. Five representative unmanaged margins (dominated by *Crataegus monogyna, Urtica dioica* and *Galium aparine*), surrounding three different winter wheat fields were chosen for comparison with the wildflower strips.

TABLE 1. Seed mixture used to establish grass and wildflower strips A and B (percentage of total by weight).

Species	%	Species	%
Achillea millefolium	2	*Leucanthum vulgare*	4
Agrostis castellana	10	*Malva moschata*	3
Cynosaurus cristatus	40	*Plantago lanceolata*	5
Festuca rubra		*Prunella vulgaris*	3
subsp. *commutata*	10	*Rumex acetosa*	3
subsp. *purinosa*	10		
subsp. *rubra*	10		

TABLE 2. Seed mixture used to establish grass and wildflower strip C (percentage of total by weight).

Species	%	Species	%
Achillea millefolium	0.2	*Knautia arvensis*	1.9
Agrostemma githago	4.3	*Leontodon hispidus*	0.8
Agrostis tenuis	3.5	*Leucanthemum vulgare*	0.3
Alopecurus pratensis	7.0	*Lotus corniculatus*	1.0
Anthemis arvensis	0.3	*Malva moschata*	1.2
Anthilhilis vulneraria	1.4	*Onobrychis spp.*	2.7
Anthoxanthum odoratum	5.25	*Phleum pratense*	
Centauria cyanus	1.0	subsp. *bertolonii*	1.75
Centauria nigra	1.0	*Plantago media*	0.5
Centauria scabiosa	1.5	*Poa pratensis*	7.0
Cerastium fontanum	0.2	*Primula veris*	0.8
Cynosaurus cristatus	3.5	*Prunella vulgaris*	0.8
Daucus carota	0.8	*Ranunculus acris*	1.0
Festuca rubra		*Rhinathus minor*	1.3
subsp. *commutata*	14.0	*Rumex acetosa*	0.8
subsp. *purinosa*	21.0	*Sanguisorba minor*	2.1
Galium verum	0.8	*Silene alba*	0.8
Geranium pratense	1.2	*Silene dioica*	0.5
Hypocheirus radicata	0.8	*Tricetum flavescens*	7.0

Trapping methods

Six lines of six fluorescent yellow water traps extending out from the field margin into the crop were used to assess hoverfly activity around either unmanaged or managed margins. The traps were positioned at ear height (65 to 95cm),at distances of 1, 5, 10, 25, 50, and 100m from the field margins. Traps were filled with a water/detergent solution with 10ml/l glycerol and 10ml/l ethalene diol added as an humectant / preservative. Trapping commenced 1st June 1992 and ended 24th July 1992. Traps were emptied twice weekly. Hoverflies caught were identified to species and sex in the field when emptying traps. Data was log transformed and tested for goodness of fit to a normal distribution using a chi squared test. One way analysis of variance was used to examine differences between treatment and non-treatment traps.

RESULTS

Treatment differences

Table 3 summarises the catches of yellow water traps in fields with wildflower margins (treatment transects) and in those with unmanaged field margins (control transects). Greater total numbers of most syrphidae were trapped in treatment transects (from managed margins) compared with control transects (unmanaged margins) e.g. *Metasyrphus corollae* ($\underline{P}<0.01$, F=9.009), *Melanostoma scalare* ($\underline{P}<0.01$, F=9.671), genus *Platycheirus* ($\underline{P}<0.01$, F=15.107) and *Eristalis* spp. ($\underline{P}<0.01$, F=16.828). There was however no significant difference between treatment and control catches for *Episyrphus balteatus*. The total number of aphidophagous syrphids caught was significantly higher in the treatment transects than in the control transects ($\underline{P}>0.05$, F=4.481). Figures 1-4 give a graphical representation of mean trap catches per trap day within treatment and control fields with respect to trap date and distance into the crop for total aphidophagous syrphids and for *Eristalis* spp. (which are not aphidophagous).

FIGURE 1. Aphidophagous hoverfly catches (per trap day), on successive dates, in transects extending from floral strips into winter wheat.

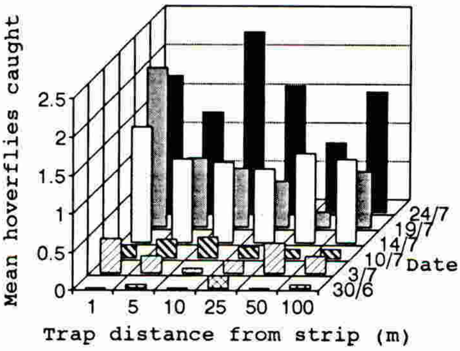

FIGURE 2. Aphidophagous hoverfly catches (per trap day), on successive dates, in transects extending from unmanaged field margins into winter wheat.

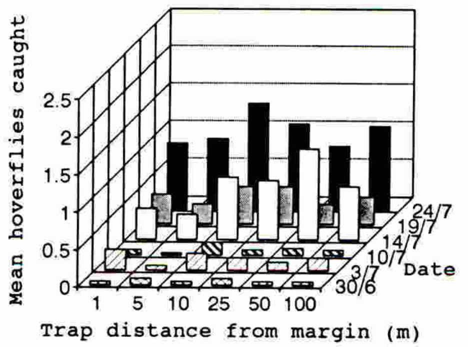

FIGURE 3. *Eristalis* spp. catches (per trap day), on successive dates, in transects extending from floral strips into winter wheat.

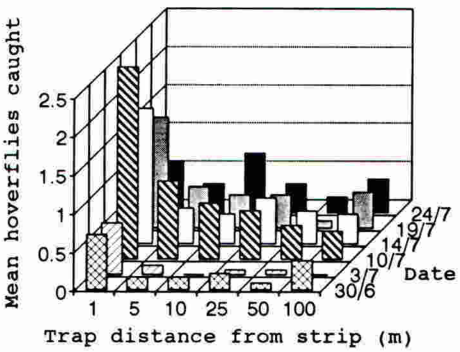

FIGURE 4. *Eristalis* spp. catches (per trap day), on successive dates, in transects extending from unmanaged field margins into winter wheat.

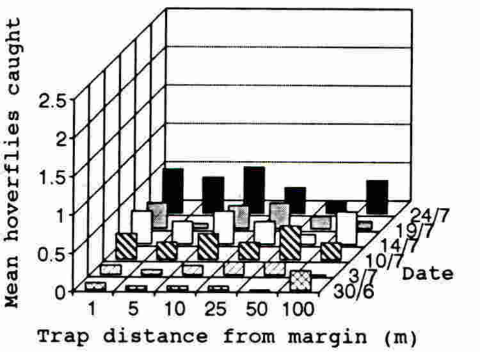

TABLE 3. Mean hoverfly catches in yellow water traps in transects extending into fields of winter wheat, with 95% confidence intervals (n=6).

Trap distance from margin (m)	1		5		10		25		50		100	
	$\bar{x}$	±	$\bar{x}$	±	$\bar{x}$	±	$\bar{x}$	±	$\bar{x}$	±	$\bar{x}$	±
WILDFLOWER MARGINS												
Episyrphus balteatus	16.17	9.04	8.67	6.69	11.00	6.70	8.67	4.07	9.33	10.15	8.33	5.58
Eristalis spp.	58.17	57.03	20.17	11.62	15.33	7.90	12.83	6.94	7.50	4.24	11.67	10.02
Metasyrphus corollae	9.50	3.97	7.00	5.39	8.67	5.54	6.83	2.24	3.17	2.24	8.33	7.17
Melanostoma scalare	8.00	5.10	7.00	6.47	8.33	6.95	8.17	4.17	6.83	6.59	7.50	6.66
Platycheirus spp.	1.33	1.68	1.67	2.87	2.50	2.63	2.17	2.04	1.67	1.95	2.00	1.76
Total aphidophagous	38.67	9.99	26.17	12.25	33.17	18.64	27.50	11.14	21.50	15.78	28.00	19.97
UNMANAGED MARGINS												
Episyrphus balteatus	9.00	4.30	5.67	6.22	10.33	8.31	12.50	8.88	11.33	7.01	8.17	5.07
Eristalis spp.	10.67	10.04	5.67	4.44	10.17	7.72	7.67	8.12	7.33	5.21	7.50	8.07
Metasyrphus corollae	1.67	1.58	3.50	2.55	3.67	3.43	4.67	3.49	7.83	3.78	5.00	2.66
Melanostoma scalare	2.17	0.79	2.67	3.91	4.83	3.41	4.50	2.28	6.00	4.49	5.50	2.87
Platycheirus spp.	0.17	0.47	0.50	0.88	0.83	1.23	0.50	0.88	1.50	2.63	0.33	0.54
Total aphidophagous	14.67	3.30	14.00	12.10	20.83	11.06	23.17	11.45	27.83	13.15	19.67	7.14

Hoverfly distribution

Regression analysis of [log (n+1)] transformed total trap catches vs [log distance from strip] revealed a significant negative gradient in the treatment transects for *Eristalis* spp. ($\underline{P}$<0.001, r (corrolation co-efficient) = -0.58). Both *Episyrphus balteatus* ($\underline{P}$=0.053, r=-0.32), *Metasyrphus corollae* ($\underline{P}$=0.076, r=-0.29) and the total for aphidophagous syrphids caught ($\underline{P}$=0.058, r=-0.31) approached a significant negative gradient. The transects of the control fields did not give any significant negative gradients.

DISCUSSION

A significantly greater number of hoverflies were caught in treatment transects than in control transects, including many species with aphidophagous larvae. This suggests that wildflower strips are able to increase within-field populations of hoverflies in adjacent fields, which in turn may increase oviposition of aphidophagous hoverflies within the field and hence enhance aphid predation. Possible mechanisms include increasing the reproductive success of the hoverflies through the provision of pollen, increasing larval survival through the provision of alternative hosts or by attracting hoverflies from other areas. The results from the regression analysis indicate that in treatment transects hoverfly activity is greatest close to the wildflower margins, whereas conventional unmanaged field margins showed no increased activity; this was most apparent for *Eristalis* spp., as is suggested by figures 1 to 4. During the experimental period hoverflies were observed feeding, courting and mating within the wildflower margins before ovipositing in the crop. The importance of the wildflower strips may not be solely in providing a pollen resource. Continued studies will assess the behaviour and resource use of hoverflies within the wildflower strips and the effect of enhanced syrphid numbers on within-crop oviposition.

ACKNOWLEDGEMENTS

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BRENT GOOSE DAMAGE TO OILSEED RAPE AND IMPLICATIONS FOR INTEGRATED MANAGEMENT

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ABSTRACT

The Brent goose (*Branta bernicla)* is a protected species, which feeds inland on agricultural land while over wintering in England. Using a paired-plot design, yield loss of oilseed rape due to feeding by the dark-bellied subspecies of the Brent goose was measured on five fields in Essex, UK. A mean of 11% loss in dry weight of seed was found, with a maximum of 27% in the worst-affected field. Early damage (before January) was associated with the greatest loss in yield. Intensive scaring in this period, along with the provision of alternative feeding areas and luring of birds using decoys, is suggested as an integrated management system likely to reduce damage.

INTRODUCTION

Approximately half the world population of the dark-bellied subspecies of Brent goose (*Branta bernicla bernicla*) overwinter on the south coast of England, in a zone streching from the Wash to the river Exe. In the winter of 1962/63 these British birds numbered approximately 15,000 (Ogilvie & St. Joseph, 1976). Since then, numbers have increased dramatically and in 1990/91 they reached 115,000 (Kirby, 1991) Traditionally the birds fed on vegetation in the intertidal zone of saltmarshes, mudflats and estuaries but since the early 1970s, large numbers have fed inland (St Joseph, 1979) on winter wheat and barley and, most recently, oilseed rape (*Brassica napus*).

Work on Brent goose damage to winter wheat funded by the Ministry of Agriculture, Fisheries and Food (MAFF), demonstrated an average 7% yield loss (Summers, 1990). Grazing of grassland by geese can lead to a reduction in biomass of live matter in the sward (Summers & Stansfield, 1991).

Faced with this damage, most farmers attempt to scare geese from their fields. The most common method used employs gas guns reinforced by shooting small numbers under licence from MAFF. Other techniques include the use of model birds in an alert position (Inglis and Isaacson, 1978) and the constant presence of a person on an all-terrain vehicle, backing up his scaring by shooting (Vickery & Summers, in press). Summers &

Hillman (1990) found that suspension of red tape across wheat fields reduced damage by Brent geese as long as there were untaped fields on which the birds could feed. Such 'alternative feeding areas' have been recommended for some time (Owen, 1973), though usually specially managed grass is the suggested forage (Countryside Premium for Set-aside Land; Anon, 1989).

Many of Britain's Brent goose sites hold internationally important numbers over the winter (Kirby *et al.*, 1990) and the species is protected under both EC and UK legislation, (Wildlife & Countryside Act, 1981). There is therefore an obligation to conserve Brent geese and seek solutions to the problem of the conflict with agricultural interests.

This paper describes a study to measure the loss in yield of oilseed rape due to Brent goose grazing in south-east Essex, UK, during the winter of 1990/91. Implications of the results for the integrated management of Brent geese are discussed.

METHODS

In October 1990, six fields of oilseed rape which had suffered goose damage in previous years were selected. In order to determine loss in yield, grazed areas were compared with ungrazed. In each field ten 2m x 2m wire exclosures were set up, and each one paired with two unenclosed plots available for geese to graze. The exclosures were erected in late October before the start of grazing and removed in April when all grazing had ceased.

During this five month grazing period, all 180 plots were monitored every 14 days. This involved counting and removing all goose droppings within a 1.5m radius of marker sticks. The number of droppings counted is a measure of grazing intensity. After the cessation of grazing the exclosures were replaced with marker flags. The height of the plants was measured at all plots every two weeks from March until the crop was harvested in August. At harvest, a sample $1m^2$ was cut from the exclosed and grazed plots and the stems were counted. These samples were dried and threshed and from each the total dry weight of seed, 1000-seed weight, and percentage oil content were measured.

RESULTS

One field, 'Abbots', was not grazed but full data was collected. The timing and intensity of grazing differed among the five grazed fields, 'Big' and 'Little' field being grazed early in the season and 'Sea' field having the highest intensity of grazing (indicated by number of droppings, Figure 1.).

Plants from exclosed plots were taller than plants from grazed plots ($P<0.05$; one-tailed Wilcoxon signed-rank test) on most dates on which measurements were taken. This height difference persisted to 15 May in 'Big' and 'Little' fields. There was no difference in plant height inside and outside exclosed areas in 'Abbots' field where there was no goose grazing (Figure 2.), suggesting that any effect of exclosures on the growth of the rape plants was negligible.

When yield inside exclosures was compared to that in grazed plots for the five fields used by geese, there was an overall loss in yield of 11%; $P<0.01$, one-tailed Wilcoxon signed-rank test (Table 1). This was greatest at 'Big' and 'Little' fields where there was 27.5% and 26.2% yield loss respectively ($0.02>P>0.05$).

TABLE 1. Mean yield, 1000-seed weight oil content and number of stems of rape plants in exclosed (ungrazed) plots and mean percentage yield loss (%diff) at grazed plots (Wilcoxon signed-rank test).

field	dry weight(g)		1000-seed weight(g)		%oilcontent		number of stems	
	mean	%diff	mean	%diff	mean	%diff	mean	%diff
Sea	397	-4.1	4.55	3.3	44.85	0.4	48.4	2.8
Upper	321	-5.7	4.19	-1.5	43.22	-1.3	31.5	9.8
Banana	266	13.0	4.64	5.1	44.13	-1.3	48.5	-3.0
Big	377	26.2*	4.17	0.0	43.71	-0.1	68.6	7.7
Little	333	27.5*	3.85	0.9	44.06	-0.5	53.0	8.5
Abbots (no grazing)	202	-53.6	4.72	-1.2	44.20	-1.4	48.7	-12.1
All grazed fields	301	11.1**	4.22	1.5	44.28	-0.5	44.8	5.0*

* significant at the 5% level
** significant at the 1% level

A negative %diff value indicates that yields within exclosures were lower than in unprotected plots.

DISCUSSION AND CONCLUSION

A mean of 11% loss in total dry weight of rape seed was found for the five fields grazed by geese. Analysed separately, two of these fields showed a significant yield loss (means of 26% and 27%) and this was probably due to feeding by Brent geese. There was no reduction in 1000-seed weight or oil content.

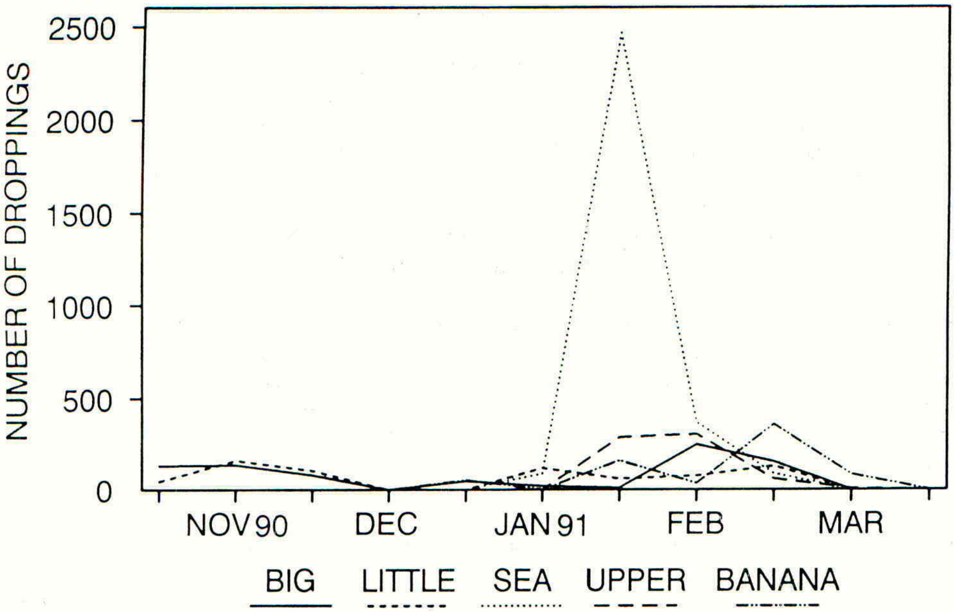

Figure 1. Number of Brent goose droppings on each field from November 1990 to April 1991

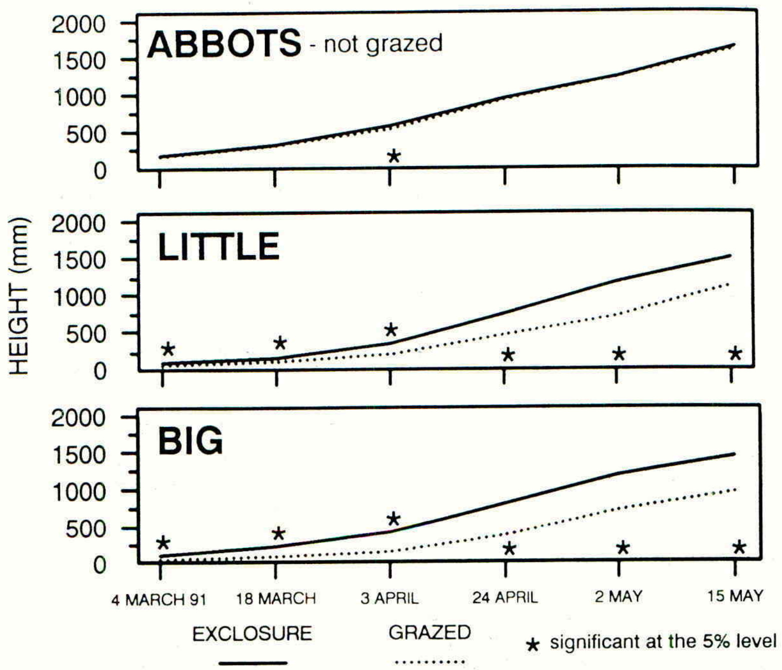

Figure 2. Mean height of oilseed rape inside and outside exclosures after intensive goose grazing had ceased.

The two worst-affected fields were those that were grazed early in the season (before January), but not those on which the most goose droppings were deposited. Although this study indicates that early damage is most important, further controlled experiments are required in order to determine the stage of growth at which rape is most vulnerable to damage by Brent geese.

If early damage causes greatest loss in yield, we would recommend that farmers concentrate scaring measures at the beginning of the season. Scaring is most successful if the birds have somewhere else to feed and the provision of alternative feeding areas is likely to form the basis of any integrated management system of Brent geese. A model is currently being constructed to help identify the most suitable fields for conversion to alternative feeding areas. Field experiments are also underway to determine optimum management of grass/clover swards to satisfy the birds' behavioural and nutritional requirements.

In addition to grass/clover, sacrificial crops could be sown on alternative feeding areas. Autumn-sown wheat and barley have been used by some farmers and the levels of damage recorded have indicated that oilseed rape might also be sufficiently attractive. Such crops are required to grow throughout the winter, be palatable and nutritional to the geese and support high numbers of birds per unit area.

The area required to accommodate a population of Brent geese, numbering several thousand at some sites, is greater than one farm could provide. There is therefore a need for farms within 'normal flying distance' of a roost to cooperate. The number of alternative feeding areas, their size, situation and management, the integration of these areas of grass and sacrificial crops into normal farming practices and the use of scaring and luring to move the birds, are among the problems being addressed by current research at the Central Science Laboratory.

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RECENT ADVANCES WITH THE MATING DISRUPTION TECHNIQUE IN APPLES AND GRAPES - FACTORS INFLUENCING THE SUCCESS OF PHEROMONES

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ABSTRACT

In Germany, the mating disruption technique using sex pheromones has been employed commercially against grape-berry moth (Eupoecilia ambiguella Hbn.) since 1986. Meanwhile in other countries this technique for other species have been introduced: - on oriental fruit moth (Grapholita molesta Busck.) in peaches (Spain, France, Italy) as well as on codling moth {Cydia pomonella L., (Austria, Italy)} and summer fruit tortrix moth {Adoxophyes orana F.v.R., (Italy)}. In the UK the introduction of mating disruption is being delayed by regulatory injunctions. Based on the experience gathered from numerous trials, it has been possible to reduce the dosage rates far enough to make the mating disruption technique economic and therefore commercially acceptable. In order to safeguard the optimum performance of this technique, any high initial population densities have to be reduced by using an appropriate insecticide. To obtain maximum success, the immigration of mated females from surrounding areas not treated with pheromones has to be reduced. This can be achieved by using the method on large areas, on a cooperative basis between grower communities.

INTRODUCTION

The development of the mating disruption technique using sex pheromones has made great advances over the last years. The first commercially available pheromone developed by BASF, "RAK 1 - Eupoecilia ambiguella Hbn.", was presented at the Brighton Conference in 1986 (Neumann et al., 1986). In the meantime other pheromones have been introduced on the market. Table 1 lists the formulated pheromones being developed or marketed by BASF at this time.

Table 1: Pheromones being tested and on the market

Pheromones	Target Species	Crop	Country * Sales	Testing
Z9-12Ac E7Z9-12Ac	Eupoecilia ambiguella Lobesia botrana	Grapes	DE,AT,CH	FR,Slovenia DE,AT,CH,FR ES,IT,GR
Z8/E8-12Ac E5-10Ac/ES-10oH	Grapholitha molesta Anarsia lineatella	Peaches	FR,ES,IT IT	 ES,FR
E8E10-12oH	Cydia pomonella	Apples	IT	DE,BE,NL,FR CH,AT
Z11-14Ac	Adoxophyes orana Pandemis spp. Archips spp.		IT	DE,BE,NL,FR
Z3Z13-18Ac	Synanthedon myopaeformis	Apples		DE,BE,NL,FR AT,IT,ES

* Abbreviations: AT - Austria, BE - Belgium, CH - Switzerland, DE - Germany, ES - Spain, FR - France, GR - Greece, IT - Italy, NL - Netherlands

Of the listed pheromones still in the testing stage, registration in Germany is planned for 1993 for Z3Z13-18Ac and E7Z9-12Ac. The pheromone for A. lineatella Z. is being used commercially in Italy, even though optimum application rate and composition have not yet been completely evaluated. Fruit growers and government advisors wish to use it as a safeguard in order to minimize the risk of A. lineatella, which occurs irregularly. In the UK, where fruit growers also show great interest in the use of pheromones, there are more impediments, even for the experimental use of pheromones, due to registration restrictions. Documents on toxicology are needed for the pheromone relevant in UK, Z11-14ac, which are not yet available. Codling moth and summer fruit tortrix usually occur simultaneously in the apple orchards in most parts of England, so tests against codling moth alone is not considered practical.

CONDITIONS AND PREREQUISITES FOR SUCCESSFUL USE OF THE MATING DISRUPTION TECHNIQUE

More than 5000 ha of trial area were available to work out the prerequisites for the success of the mating disruption technique. First of all, adequate pheromone rates must be used.

Adequate means such quantities that will ensure the resulting pheromone atmosphere in the vineyard or orchard will be/remain concentrated enough to be effective. This must take account of strong and persistent winds (such as in the mistral of the Rhône Valley) and/or when population densities are somewhat higher (though still within the prescribed range). The dosages used in the trials and in practice range between 30 and 50 g a.i./ha per month. For the codling moth in England, for example, that corresponds to a total dose of 80 to 100 g a.i./ha.
The actual amount of pheromone that diffuses, however, is dependent on the prevailing weather conditions. The release rate would probably be lower in very low temperatures. The applied quantity must be diffused at a steady rate, to maintain the correct pheromone concentrations at flight peaks. An even pheromone density in the orchard is best achieved with a symmetrical arrangement of 500 dispensers/ha {4.5 m x 4.5 m, (Karg, G et. al., 1990)}.

The plantations in which the pheromones are to be used should consist of trees of the same height, stretching for at least 50 m. Narrower plot widths would require dispenser densities above 500/ha. The number of dispensers also must be raised when the trees are taller than 3.5 m, since the moths are active in a larger air volume space in which the correct pheromone concentration must be maintained. There is always some degree of wind blowing along the borders of a plot, which may result in a lower pheromone concentration. To counteract this, the dispensers around the edges should be spaced only 2 m apart.

Immigration of mated females from neighboring areas can be limited by treating the adjacent crops (grapes, apples) with a pheromone buffer about 30 m deep.

As was already noted at the 1986 Brighton Conference (Neumann et. al., 1986), the decisive factor for the success of mating disruption is the population density. It must be sufficiently low, but currently there is no way to measure it. Instead we must go by the infestation level of the previous generation (meaning the juvenile phase of the adults that are to be controlled by the pheromones in question). The preceding larval generation should not exceed the infestation thresholds listed in Table 2, if future pheromone treatments are to be successful.

Table 2: Suggested thresholds for employing the mating disruption method

Species		Threshold at previous generation
Grape-berry moth	Eupoecilia ambiguella Lobesia botrana	5 % (Lobesia), 10 % (Eupoecilia) infested inflorescences, 5 % infested grapes (both spp.)
Codling moth	Cydia pomonella	1 % infested fruit
Fruittree tortix	Adoxophyes orana Pandemis spp. Archips spp.	1 % infested fruit or 5 % infested shoots

It is imperative to monitor pheromone treated areas to allow corrective spray of an appropriate insecticide if the infestation threshold is exceeded. This is not only necessary during the initial pheromone treatment, but may also be needed in the future.

There is always the possibility of immigration of mated females from surrounding plots, which can bring the infestation above the threshold, creating poor conditions for subsequent pheromone applications (Neumann, 1992/93). For this reason cooperative efforts between neighbouring vinegrowers and fruit growers are recommended.

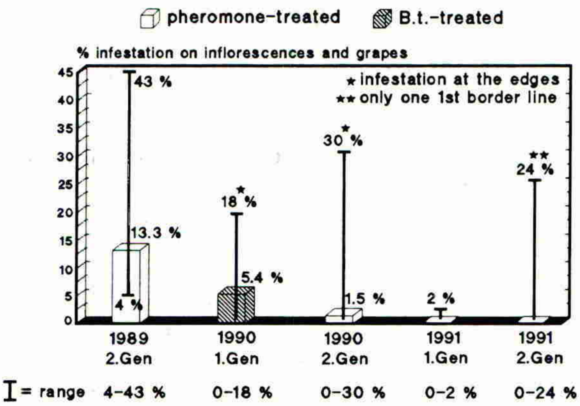
RESULTS

Exemplary results in grapes in Germany and apples in South Tirol demonstrate the substantial influence of population density.

Grapes

In 1989 the mating disruption technique for E. ambiguella was not being used successfully at the Rotenberg trial site (7 ha) near Stuttgart, Germany, because infestation/population density was too high (Figure 1). Targeted insecticide applications (twice with Bacillus thuringiensis) were effectively used to reduce the infestation density in the 1st generation of 1990. The subsequent pheromone treatment against the 2nd generation further reduced the population density (Kast et al., 1991). The results of the pheromone treatments in 1991 confirmed that the mating disruption technique is able to hold population densities at a low level. The thresholds of damage of 10% (1st generation) and 5% (2nd generation) were not exceeded.

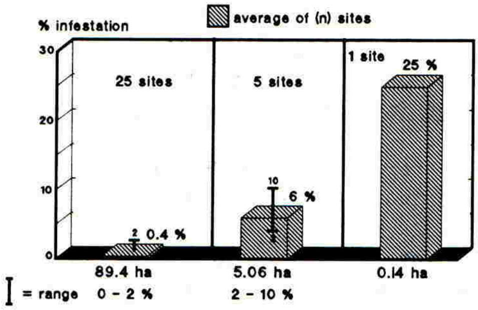
Figure 1: Effect of the population density of E. ambiguella on mating disruption



Apples

In South Tirol, pheromones were used on 109 hectares against codling moth and summer fruit tortrix. Of this, 14.7 ha belonged to organic-farming operations that use no conventional insecticides. The other 94.6 ha belonged to farms using integrated pest management. The infestation was monitored regularly by members of the South Tirol Advisory Ring.
None of the observed plots showed an infestation of fruit at harvest above 2% (threshold of damage). Even fruit orchards with 10 leafroller Adoxophyes orana larvae/100 shoots in the spring were adequately protected by the pheromones (W. Waldner, 1991).
Figure 2 summarizes the control of codling moth in the IPM plots.

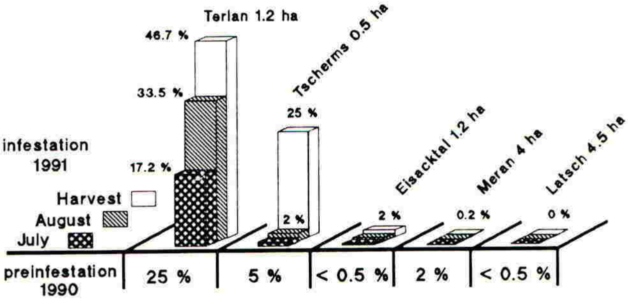
Figure 2: Control of codling moth by mating disruption, South Tirol 1991



Average infestation on a total area of 94.6 ha.

The threshold of damage (2% in South Tirol) was not exceeded on 94.5% of the total IPM area. Where an infestation above 2% developed this was because of inadequate number of dispensers, or border areas were neglected, or plots/areas were too narrow or initial infestation levels were too high. Figure 3 presents both, some positive results as well as examples of high infestation arising from high initial populations. In most cases this also included the areas of organic production.

Infestation development of codling moth in variable sites due to different preinfestation levels



CONCLUSION

Ten years of experience with experimental and commercial use of the mating disruption technique with pheromones have identified the major factors for dependable use of the technique. The initial population density is the factor with the greatest influence on the success of the method. Growers are not able to control this factor. The user must be willing to be flexible when using the technique, since this biotechnical method strongly depends on the monitoring of the infestation level, to always ensure the correct conditions for continued success during subsequent pheromone treatments. By adhering to the listed conditions, this technique is able to achieve very positive results under practical conditions, comparable to those with highly active insecticides.

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SYSTEMS ANALYSIS AS AN AID IN INTEGRATED PEST MANAGEMENT OF THE PEAR SUCKER

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ABSTRACT

Effective integrated pest management of the pear psyllid, *Psylla pyricola*, is dependent upon determining the necessity of chemical intervention. Selective pesticides currently available which are toxic to nymphal psyllids but not to predatory anthocorid bugs, need to be accurately timed for effective control of the pest. A simulation model, which describes mathematically the population dynamics of the psyllid, has been developed to predict the phenology of the pest. Successful validation of the model over three years has led to the model being integrated into a computerised advisory system for the management of apple and pear pests. The package, PEST-MAN, allows users to analyze output from the models to determine optimal control strategies.

INTRODUCTION

The dominant pest of pear in the UK is the pear psyllid, *Psylla pyricola*. Some of the psyllids overwinter as adults on neighbouring hedgerows or apple trees, while others remain in pear orchards. Early in the year most of the adults return to pears and lay eggs on the bark of the trees. The pest then passes through three generations on pear before returning, as adults, to the overwintering sites. Pear sucker damages pear production either as a result of fruit-disfiguring sooty moulds which develop on the honeydew deposited by the nymphal stages or as a vector of a mycoplasma-like organism causing the disorder 'pear decline'.

From the 1950's pear psyllids were controlled using organophosphate (OP) insecticides. However, during the late 1970's resistance to OP insecticides became widespread in psyllid populations and growers found it difficult to control pest outbreaks. Pear growers are now encouraged to adopt integrated pest management (IPM) control strategies for pear psyllids. Pear IPM is dependent upon the maintenance and encouragement of populations of predatory anthocorid bugs, in particular *Anthocoris nemoralis* (Solomon, et al., 1989). It is possible to use a broad spectrum pyrethroid insecticide early in the season before the beginning of egg-laying by overwintered adult females, as at this time few anthocorids are present in the crop. Later in the season more selective insecticides are recommended which are toxic to nymphal psyllids but not to the beneficial fauna present. Therefore, essential to the success of pear IPM is the effective timing of pesticides to coincide with the susceptible stages of the pest. Predicting suitable 'windows' in the life cycle of the pest is difficult empirically, but can be done effectively using computer models.

Simulation modelling and systems analysis have been widely used to investigate and advise on insect pest management (e.g. Ruesink, 1976). The discipline involves a dynamic process of data collation, model formulation and experimentation (Morgan, Carter & Jepson, 1988). The development of a simulation model, whereby elements and interconnections of the pest complex are considered and quantified, exposes the absence of critical information. New experiments are conducted to fill the gaps and complete the model. On completion, the model needs to be rigorously validated to ensure its accuracy. Satisfied with the quality of the output, it is then possible to experiment with the model to further our understanding of the dynamic behaviour of the system. Improved management of the pest can be sought by altering a few key decisions and analysing the consequences.

This paper describes the development of a simulation model that predicts the phenology of the psyllid *P. pyricola*. Suitable periods for the application of selective pesticides, when immature psyllids are present will be predicted.

METHODS

Psyllid population development model

The model incorporates psyllid diapause termination, development, survival, reproduction and sex determination (Figure 1). Data input

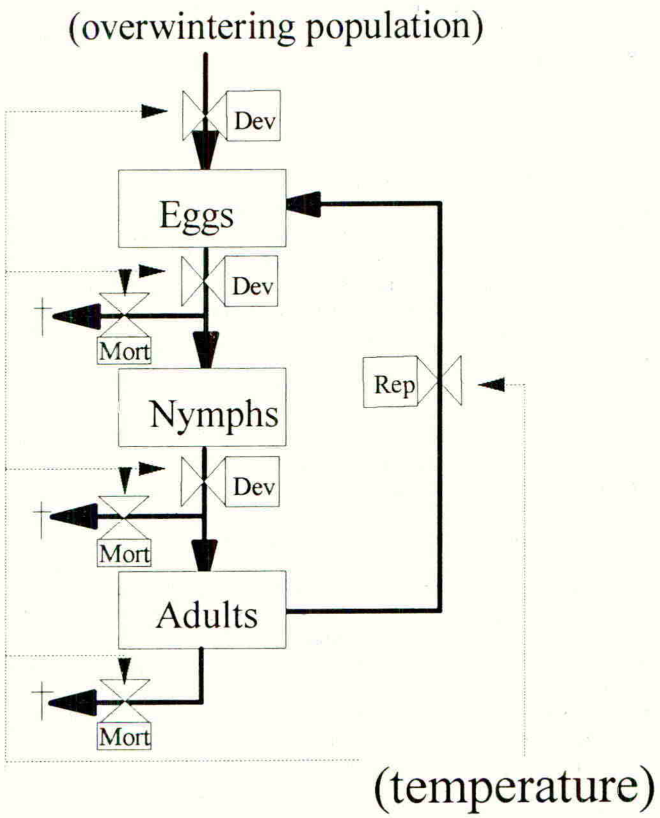

Figure 1. Relational diagram for pear sucker model.
NB Rectangles represent state variables, valve symbols represent rate variables, and driving variables are enclosed in parenthesis. Flow between state variables are represented by solid lines and the influence of driving variables represented by dashed lines.

includes daily maximum and minimum temperatures and latitude of experimental orchards. Output includes daily totals of all life stages of the psyllid.

Validation data

Weekly samples of psyllid populations were taken for 3 years. Adult psyllid samples were taken using a limb jarring technique described by Burts & Brunner (1981), whereby 40 pear limbs were beaten and the dislodged insects caught in a funnel trap. The sex of adult psyllids caught was determined in the laboratory and their numbers counted. Numbers of eggs and immature nymphal stages were recorded from leaf samples, 50 leaves being chosen randomly throughout an orchard.

RESULTS

Using regression techniques to determine the accuracy of the model's predictions, forecasts of the timing of both the emergence and peak of adult numbers were similar to the observed ($p<0.01$). Similarly, the model reliably predicted the emergence of all nymphal generations ($p<0.001$).

Suitable windows for the use of a selective insecticide depends on the existence of periods when most of the psyllid population are in the nymphal stage, with very few adults present. For the three years 1989-91 these windows existed towards the end of the nymphal periods of the first and second generations (Figure 2); by the time of the third generation of

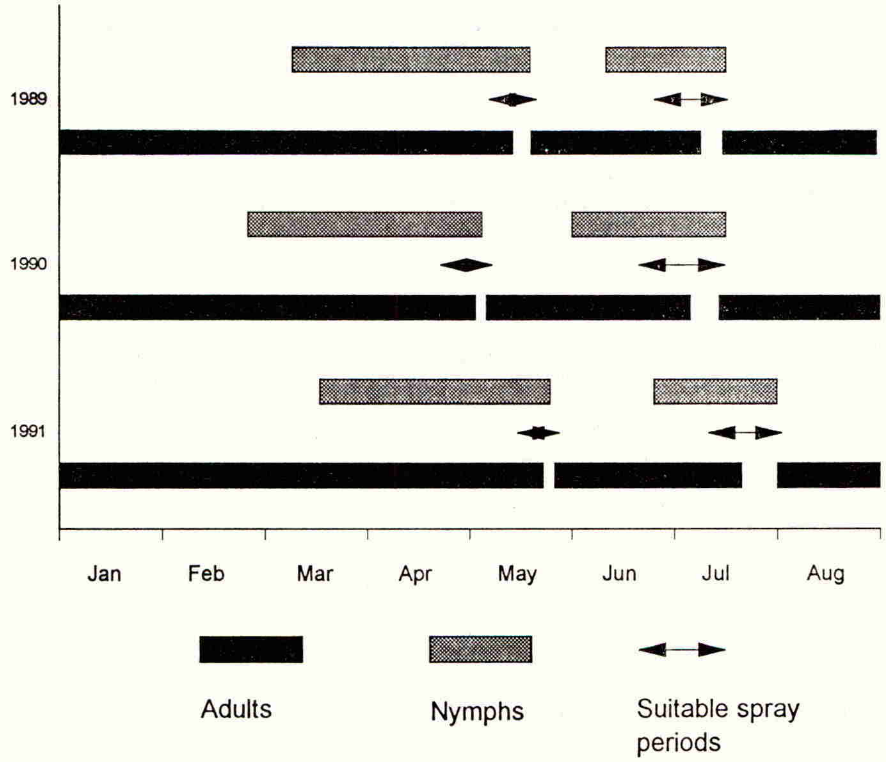

Figure 2. Suitable spray periods.

nymphs (not shown in Figure 2) there was sufficient overlap of adults of the second and third generations to obscure any potential windows for the treatment of nymphs.

DISCUSSION

The model accurately predicted the phenology of immature and adult stages of *P. pyricola*. No attempt was made to describe psyllid population dynamics quantitatively as insufficient data were available to formulate the necessary mortality rates.

Given the accuracy of the model, suitable spray periods for selective pesticides were derived. The predictions highlighted periods when nymphal stages of psyllid were accessible to pesticides and adults were not. The occurrence and duration of these periods varied between years as a result of the differing phenology of psyllids in response to the differing temperatures. Therefore, it is important to input accurate temperature data into the models (Morgan, 1990). Another potential problem of forecasting for pest management is the reliability of predictions of weather conditions. One possible solution would be to use five-year mean temperatures, with associated errors, to predict the best and worst case short-term forecasts (Rabbinge & Rijinski, 1983).

As a result of the satisfactory validation of the model, development is under-way to integrate the program into a computerised advisory system for apple and pear pests. PEST-MAN, as the advisory package is known, uses an intuitive style of presentation, involving simple pull-down menus, help statements and colour graphics, to allow users to quickly familiarize themselves with the system and to make the necessary advisory decisions for their pest problems.

ACKNOWLEDGEMENTS

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SALICYLIC ACID AS AN ENDOGENOUS SIGNAL OF RESISTANCE INDUCTION IN PLANTS

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ABSTRACT

Treatment of carrot suspension culture (*Daucus carrota* cv Kintoki) with a fungal cell wall preparation of *Chaetomium globosum* induces chitinase and the export into the extracellular space. The induction of chitinase activity, however, was preceded by the appearance of salicylic acid in the cells and to a greater extent in the extracellular space. Salicylate treatment of carrot suspension cultures induced chitinase activity more rapidly than the fungal cell wall inducer. Culture medium of induced cells, containing salicylic acid, was able to increase chitinase in suspension cultures without a direct contact between cells and fungal cell wall ("indirect induction"). Moreover experiments with reagents that influence the intracellular level of calcium ions, such as verapamil, EGTA (ethylene glycol-bis(ß-aminoethylether)-N,N,N',N'-tetraacetic acid) and the calcium ionophore A23187 indicated that Ca^{2+} may play an important role in induction and release of salicylic acid and chitinase during resistance induction.

INTRODUCTION

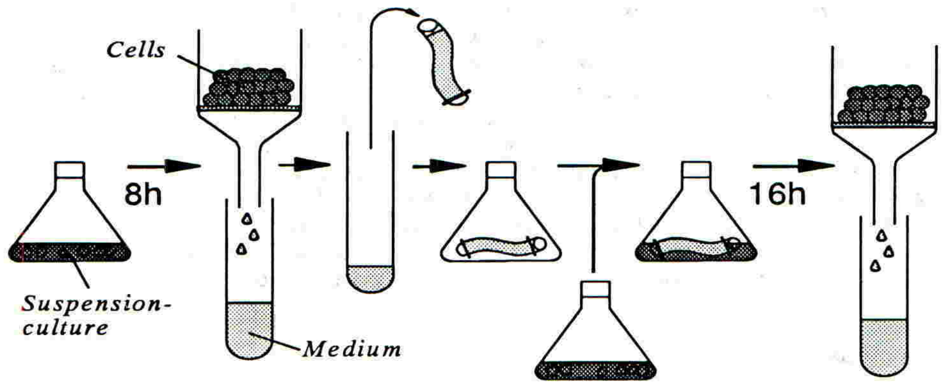
Infection of plants can activate a number of plant defense mechanisms against pathogen reproduction and secondary infection. Resistance mechanisms like for example the formation of antimicrobial phytoalexins, the reinforcement of plant cell walls and the induction of certain hydrolytic enzymes (for review see McIntyre 1982). Similar to a previous infection, the pretreatment of plants with organic or inorganic substances is able to induce plant resistance. In addition to local responses induced resistance is often widespread within the plant and provides protection against a wide range of pathogens. Hence, it is likely that a superposed factor is controlling resistance induction. In the present report we describe salicylic acid as an inducer of resistance and as a possible plant substance for signal transmission. For the detection of resistance chitinase provides a good indicator, due to the marked increase after infection.

Recently, Métraux et al. (1990) observed an increase of salicylic acid concentration in phloem sap of cucumber plants before the establishment of systemic acquired resistance by inoculation with pathogens. Salicylic acid is known as an exogenous inducer of several pathogenesis related genes, thus it was thougth to be a signal molecule in the induction of induced resistance. As an approach to elucidate the role of salicylic acid in resistance induction we developed a test system for indirect-resistance-induction in cell suspension cultures.

MATERIALS AND METHODS

CARROT CELL CULTURE AND INDUCTION SYSTEMS

Cultured cells (*Daucus carrota* L. cv Kintoki) were grown according to Okamura et al. (1979). For "indirect induction", 25 ml cell culture was incubated in a 100 ml Erlmeyer-flask on a reciprocal shaker, after 8 h cells and medium were separated by vacuum filtration. Culture medium was sterile filtrated by a syringe filter. Ten milliliters of culture medium were transferred into a dialysis tube and added to 25 ml carrot culture. Chitinase and salicylic acid were determined (see below) after further 16 hours of incubation and after the pretreatment (8 h). (Scheme 1).



SCHEME 1. Indirect Induction

CHITINASE-ASSAY AND SALICYLIC ACID DETERMINATION

A colorimetric chitinase assay was performed according to Pegg (1988). *Protein* was determined according to Bradford (1976). - For salicylic acid determination, cells and medium of 20 ml of suspension culture were separated by vacuum filtration. Cells were homogenized with 10 ml of 5% sodium-bicarbonate and centrifuged (15 min at 10,000·g). The supernatant and culture medium were acidified with 6 N HCl. To dissolve salicylic acid, 10 ml diethylether were added. A 5 ml aliquot of ether phase was transferred and allowed to evaporate. Dried organic compounds were redissolved in 50 µl methanol and analized by high performance liquid chromatography (hplc - Hitachi 655/655-60 Data Prozessor) equipped with a C-18 reversed phase column (Unisil Q 6x150 mm), at 305 nm. For the liquid phase, a gradient from 95% to 30% of water and acetonitrile, each containing 0.1% trifluoroacetic acid, was used.

INDUCERS AND CHEMICALS

- Mycelial-Wall (MW) of the fungus *Chaetomium globosum* Kinze ex Fr. were prepared according to Kurosaki and Nishi (1984). - Salicylate: Stock solutions of sodium salicylate in distilled water were prepared to obtain finale concentrations between 10^{-6} to 10^{-1} $mg \cdot ml^{-1}$ in the suspension cultures.

- Verapamil ([8-N,N-(dimethylamino)]octyl-3,4,5-trimethoxybenzoate), a Ca^{2+}-channel blocker was used to suppress an increase of cytoplasmic calcium. - EGTA (ethylene glycol bis (ß-aminoethyl)-N,N,N',N'-tetraacetic acid) a specific chelator for Ca^{2+}, was used to remove remaining calcium after washing the cells with calcium free medium. - Ca^{2+}-Ionophore A23187, a specific carrier for calcium across membranes. - D-Phenylalanine is a competitive inhibitor of PAL for the physiological substrate L-phenylalanine, thus it was used to prevent salicylic acid formation. - Phenylpropiolic acid is an inhibitor of PAL too, and was used in comparison to D-phenylalanine.

RESULTS

TIME COURSE OF CHITINASE ACTIVITY AFTER INDUCER TREATMENT

The treatment with mycelial wall, salicylate or calcium ionophore induced a marked increase of chitinase activity in carrot culture medium (Fig. 1). In contrast to that, there was no change in chitinase activity in control cells. In salicylate treated cells a peak of chitinase activity was detectable 5 hours after treatment.

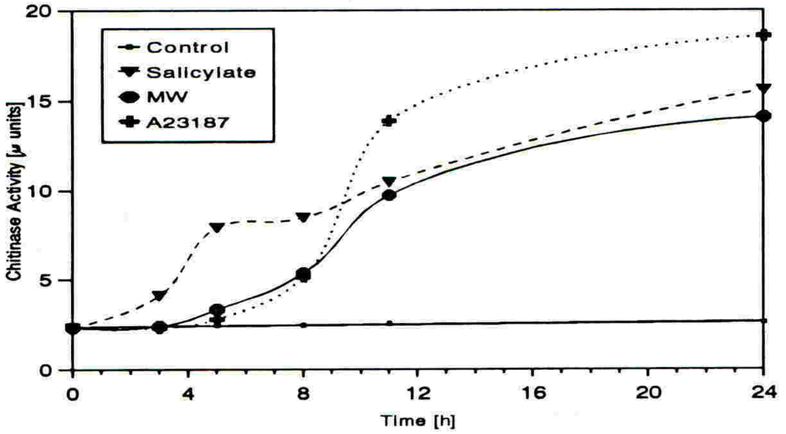


FIGURE 1. Time course of chitinase activity of medium from carrot suspension cultures after inducer treatment. Abbreviations: MW = mycelial wall (0,2 $mg \cdot ml^{-1}$); salicylate (12 μM); Calcium-Ionophore A23187 (10 μM). Replicates: n=3

SALICYLIC ACID CONTENTS AFTER MYCELIAL WALL INDUCER TREATMENT

The treatment of carrot suspension cultures with mycelial wall induced a rapid increase in salicylic acid concentration particularly in the extracellular space (Fig. 2). Eight hours after treatment, concentrations up to 120 ng per milliliter of culture could be detected. In contrast salicylic acid in untreated control suspension cultures was almost not detectable during the experiment.

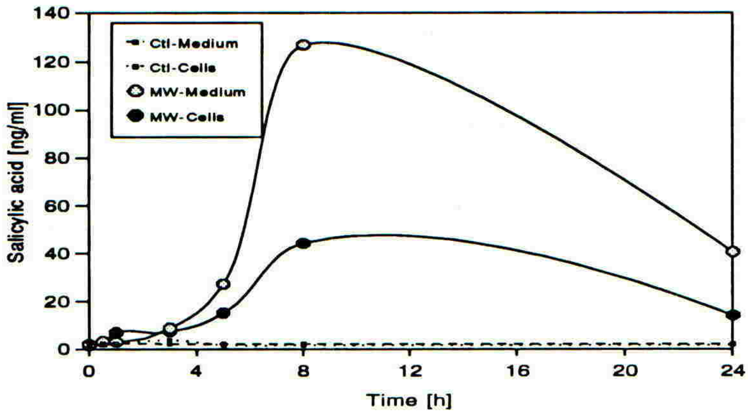


FIGURE 2. Time course of salicylic acid contents of carrot suspension cultures after mycelial wall inducer treatment. Abbreviations: Ctl-Medium/Ctl-Cells = medium/cells of untreated control cultures; MW-Medium/MW-Cells = medium/cells of mycelial wall (0.2 mg·ml^{-1}) treated cultures; n=5

DEPENDENCE OF SALICYLIC ACID AND CHITINASE INDUCTION ON Ca^{2+}-FLUX

Simultaneous application of the mycelial wall inducer plus the calcium channel inhibitor verapamil or the calcium chelator EGTA suppressed the increase of extracellular salicylic acid contents and chitinase activity particularly in the extracellular space as compared to cells exclusively treated with inducer. On the other hand the calcium ionophore A23187 induced salicylic acid and chitinase similarly to mycelial wall treatment (Fig. 3).

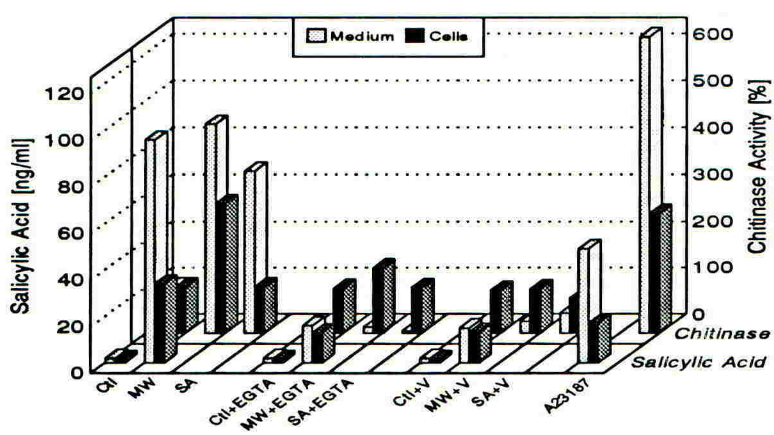


FIGURE 3. Salicylic acid contents and chitinase activity of carrot suspension cultures after induction, in presence of calcium antagonists. Abbreviations: Ctl = untreated control; MW = mycelial wall (0.2 mg·ml^{-1}); SA = salicylate (12 μM); EGTA = calcium-chelator EGTA (2 mM); V = calcium-channel blocker verapamil (100 μM); A23187 = calcium ionophore A23187 (25 μM). Replicates: n=5

INDIRECT INDUCTION: SALICYLIC ACID CONTENTS AND CHITINASE ACTIVITY

Culture medium of inducer-treated cells (Scheme 1) triggered an increase in chitinase activity in other cells, when in contact through a dialysis tube (Fig. 4). A good correlation between SA contents in the dialysis tube and chitinase induction in the surrounding culture cells could be observed. - For additional control, carrot cells were incubated with the inducer and an inhibitor of phenylalanie ammonia lyase. The inhibitors phenylpropiolic acid and D-phenylalanine prevented salicylic acid production and chitinase activity increase.

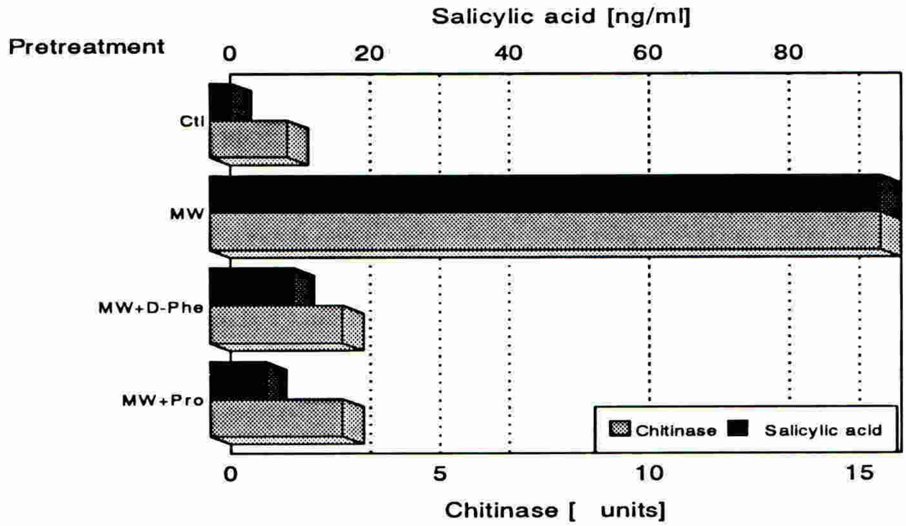


FIGURE 4. Chitinase activity of "indirect induced" carrot suspension cultures and salicylic acid contents of medium of preculture, used for indirect chitinase induction. Abbreviations: Ctl = untreated control; MW = mycelial wall (0.2 mg·ml^{-1}); D-Phe = D-phenylalanine (4 mM); Pro = phenylpropiolic acid (0.5 mM). Replicates: n=3

DISCUSSION

The primary interaction of an inducer with the target site located in the plasma membrane requires a translating system between the external signal and the internal information controlling plant physiology. Salicylic acid (SA) is an endogenous compound known to induce resistance in plants, thus SA was recently discussed as a potential substance involved in the reaction chain of resistance induction (Malamy et al. 1990). In the present report chitinase activity was used as a resistance indicator. Salicylate and a fungal cell wall preparation of *Chaetomium globosum* were used to induce resistance. The treatment of carrot suspension cultures with mycelial wall caused an increase of chitinase activity accompanied by a rapid chitinase efflux. Salicylate treatment caused a more rapid chitinase increase and efflux (Fig. 1). Preceding to the chitinase increase, inducers triggered SA appearance and its release into the extracellular space (Fig. 2). The optimal extracellular concentration of SA for chitinase induction was at the range of extracellular concentration induced by mycelial wall treatment (0,1 g·ml^{-1}). The use of inhibitors of phenylalanine ammonialyase (PAL) a key enzyme in salicylic acid synthesis indicated that an increase in intra- and extracellular concentration depends on *de novo* biosynthesis of SA. - Verapamil, a calcium channel blocker also inhibited the amount of SA. A comparable inhibition profile could be detected for chitinase (Fig. 3). The calcium ionophore A 23187 was able to substitute the inducer in salicylic acid and chitinase induction. The results suggest, that Ca^{2+}-influx is essential for SA and chitinase induction and export during resistance formation.

To investigate whether salicylic acid, produced from inducer-treated plant cells, is able to induce resistance we developed a biotest system for "indirect induction". Culture medium from induced carrot cells induced chitinase activity and salicylic acid in other carrot cells without a direct contact to the inducer mycelial cell wall. Experiments with inhibitors of salicylic acid synthesis indicated that salicylic acid is a signal in the resistance induction chain. Recently Malamy et al. (1990) described an increase of salicylic acid contents of tobacco leaves resulting from tobacco mosaic virus (TMV) infection and correlating with the expression of pathogenesis-related proteins. Métraux et al. (1990) reported an increase of salicylic acid contents in the phloem of cucumbers and its correlation with systemic acquired resistance responding to a challenge with TMV or the fungal pathogen *Colletotrichum lagenarium*. All investigations indicate independently that salicylic acid is likely to be a missing link in the transduction chain of inducer interaction and plant response. Further research will be done to elucidate whether the calcium ions and salicylic acid involved in plant resistance induction are a part of a common eucaryotic signal transduction via protein phosphorylation.

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ACTIVITY OF *Bacillus thuringiensis* var. *kurstaki* AGAINST *Helicoverpa zea* AND *Heliothis virescens* (LEPIDOPTERA: NOCTUIDAE) ON COTTON

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ABSTRACT

Activity of *Bacillus thuringiensis* against 1st instars of *Helicoverpa zea* (Boddie) and *Heliothis virescens* (F.) was studied on cotton. In the laboratory, percent mortality of *H. zea* and *H. virescens* increased significantly (P=0.05) with increases in *B. thuringiensis* rate. Mortalities of *H. virescens* were significantly (P=0.05) higher than of *H. zea* at 0.56 and 1.12 kg/ha rates of *B. thuringiensis* 4 and 7 days post-treatment. LD_{50} values were 2-, 2.5- and 1.6-fold higher for *H. zea* than the *H. virescens* 4 and 7 days post-treatment and at pupation, respectively. Most mortality occurred by 4 days post-treatment. Results from the field for 3 and 7 days post-treatment indicated a pattern of mortality similar to laboratory data 4 and 7 days post-treatment.

INTRODUCTION

Helicoverpa zea (Boddie), the corn earworm, and *Heliothis virescens* (F.), the tobacco budworm, are important pests of cotton in the United States. Pyrethroids are considered to be the most effective insecticides against both species. In recent years, *H. virescens* has developed resistance against pyrethroids (Luttrell *et al.*, 1987) and this has prompted development of resistance management strategies including avoidance of use of pyrethroids in early season. Current pest management strategies are directed toward the use of biological insecticides in early season.

Commercial *Bacillus thuringiensis* Berliner var. *kurstaki* preparations have been on evaluation for use in early season control of *H. zea* and *H. virescens* on cotton. Most field studies show that *B. thuringiensis* reduces heliothine spp. populations on cotton (Bell & Romine, 1980; Ali & Watson, 1982) but overall control has not been adequate under high population pressures. Laboratory studies show that *H. zea* is more tolerant to *B. thuringiensis* than *H. virescens*. MacIntosh *et al.* (1990) reported that LC_{50} for purified proteins from *B. thuringiensis* were higher for *H. zea* than for *H. virescens* for HD-73 and HD-1.

These studies report on the activity of a series of *B. thuringiensis* rates against *H. zea* and *H. virescens* on cotton.

MATERIALS AND METHODS

Studies were conducted during 1991 on the Arkansas Agricultural Experiment Station Research Farm, Fayetteville, Ark. Cotton (DPL 50) used in these studies was thinned at pre-squaring stage to obtain a density of approximately 74,100 to 98,800 plants/ha. Effective growth of plants was maintained by furrow irrigation as needed. Plants were 64±10.6 cm (mean±SEM) tall, had 11.9±0.37 main stem nodes, 18.7±6.3 squares, 1.3±0.8 blooms, and 0.4±0.18 bolls per plant at the time the studies were conducted. Both *H. zea* and *H. virescens* larvae were from a laboratory colony maintained at the University of Arkansas. Javelin WG (Sandoz Inc., San Diego), containing 6.4% of the active ingredients with *B. thuringiensis* var. *kurstaki* delta endotoxin potency of 52863 *Spodoptera* Units/mg, was the formulation used.

Laboratory Study

A randomized complete block with four replications was used to determine the activity of *B. thuringiensis* and cypermethrin, a standard pyrethroid insecticide, against *H. zea* and *H. virescens* on cotton terminals. Cotton plants in the field were sprayed with five doses of *B. thuringiensis* (0.56, 1.12, 2.24, 4.48 and 8.96 kg/ha of commercial product), cypermethrin (0.05 kg [ai]/ha as Cymbush 3EC), or water (control plants). Applications were made with a CO_2 powered backpack sprayer equipped with two TX-6 nozzles per row. Treatments were applied in a volume of approximately 93 l/ha and at a nozzle pressure of 275.6 kPa.

Terminals were collected and brought to the laboratory in plastic bags. Twenty five, two-day-old larvae (1st instar) of *H. zea* or *H. virescens* were placed individually on a terminal in 30-ml plastic containers lined with moist filter papers. Terminals were searched for larvae after 48 h to record the mortality and surviving larvae were transferred to semisynthetic diet (Burton, 1969) in 30-ml plastic containers. Larvae were observed 4 and 7 days post-treatment and then every 4 to 5 days until pupation.

Field Study

Plots consisted of two rows, 3 m in length each, with 7-m and 3-row buffers between the ends and sides of the plots, respectively. No blanket insecticide treatments were made before or during the experiment. Plants in all plots were artificially infested with one-day-old *H. zea* or *H. virescens* larvae (7 larvae/plant). Larvae were placed on plant terminals with a camel's hair brush.

Plots were arranged as a split plot in a randomized complete block with four replications. Two species (*H. zea* and *H. virescens*) were the main plots with seven treatments (0, 0.56, 1.12, 2.24, 4.48, or 8.96 kg/ha of *B. thuringiensis* and 0.05 kg [ai]/ha of cypermethrin) as subplots. Plots were treated one day after the release of larvae on plants. The application method was similar to that described above.

Three and 7 days post-treatment, 10 plants in approximately 1 row meter from each subplot were cut and transferred to the laboratory in plastic bags. Each of the 10 plants was thoroughly searched for larvae. All the surviving larvae were transferred individually to semisynthetic diet in 30-ml plastic containers. Larvae were held at 28°C and mortality was recorded every 4 days until pupation.

Mortality data were analyzed by analysis of variance procedure. LD_{50} values were calculated by using the probit procedure. Because of the variation in survival of larvae in controls of the species, field data were standardized by transforming them to survival ratios (survival ratio=no. of larvae in a treatment/no. of larvae found in the control).

RESULTS AND DISCUSSION

Laboratory Study

Interactions between species and treatments for 4 and 7 days post-treatment periods were significant (F=2.71; for 4 days and F= 2.5 for 7 days post-treatment; df=5, 33; P=0.05). Within a species, mortality increased with application rate of *B. thuringiensis* 4 and 7 days post-treatment (Table 1). Comparisons between species showed significantly higher mortality in *H. virescens* than in *H. zea* at 0.56 and 1.12 kg/ha rates of *B. thuringiensis* at 4 and 7 days post-treatment. *Helicoverpa zea* mortality at 1.12 and 2.24 kg/ha rates corresponded to *H. virescens* mortality at 0.56 and 1.12 kg/ha rates, respectively, both for 4 and 7 days post-treatment. However, no treatment differences were detected between species at *B. thuringiensis* rates of 2.24, 4.48, and 8.96 kg/ha 4 and 7 days post-treatment. Within species, percent mortality rose with increased *B. thuringiensis* rates even though mortality did not differ between species at pupation. The highest rate of *B. thuringiensis* (8.96 kg/ha) caused mortality similar to cypermethrin in *H. virescens* at all post-treatment periods and 7 days and pupation in *H. zea*.

LD_{50} values for *H. zea* were 2-, 2.5- and 1.6-fold higher than *H. virescens* for 4 and 7 days post-treatment and pupation, respectively (Table 1). Based on 95% CI, LD_{50} values for *H. zea* were significantly higher than *H. virescens* only at 4 days post-treatment.

Most mortality in both species (60 to 91% in the *H. zea* and 76 to 98% in the *H. virescens*) occurred within four days of treatment (Fig. 1). Between species, cumulative percent mortality was significantly higher for *H. virescens* than for *H. zea* for all *B. thuringiensis* rates tested at 4 days post-treatment. All *H. virescens* mortality occurred by 16 days post-treatment. Some *H. zea* larvae survived up to 40 days post-treatment indicating more chronic type of activity.

Field Study

Significant interaction between species and treatments for 3 and 7 days post-treatment was not detected (F=1.86 for 3 days and F=0.22 for 7 days post-treatment; df=5, 30; P=0.05). Between species, comparisons showed a significantly higher survival in *H. zea* than the *H. virescens* for 1.12 and 2.24 kg/ha rates of *B. thuringiensis* 3 and 7 days post-treatment. Results from the field for 3 and 7 days post-treatment mimic the pattern of mortalities in our laboratory data on cotton terminals 4 and 7 days post-treatment.

The course of mortality is an important factor in insect control (Fast & Regniere, 1984). Although mortalities were similar between species at high rates, lethal times were significantly shorter for *H. virescens* than *H. zea* at all *B. thuringiensis* rates tested 4 days post-treatment. Fast & Regniere (1984) reported that exposure time of *B. thuringiensis* can affect LT_{50} as much as LD_{50} and may have a greater relevance to field efficacy, because larvae that live longer will have better chances of recovery as the environmental degradation of the material progresses and chances of further ingestion of active material are decreased.

These data indicate that at currently recommended rates of *B. thuringiensis* for cotton, mortality in first instar *H. zea* larvae will be lower than that in *H. virescens*. LD_{50} values indicate that the current *B. thuringiensis* recommendations closely relate to mortality data of the *H. virescens*. These results signify the importance of the knowledge of heliothine species composition for effective use of *B. thuringiensis* in their control on cotton. Initial mortality is the most important factor in control; therefore, field recommendations should be based on *H. zea* mortality data in areas where these species occur on cotton at the same time. However, because of cost constraints, using appropriate insecticide-*B. thuringiensis* mixtures in early season cotton may prove to be more effective than *B. thuringiensis* alone in areas where *H. zea* is the most abundant species.

ACKNOWLEDGMENTS

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TABLE 1. Percent corrected mortality of *Helicoverpa zea* and *Heliothis virescens* on cotton terminals treated with various rates of *B. thuringiensis* and cypermethrin at various post-treatment intervals[a]

Treatment	Rate/ ha[b]	Mean percent mortality ± SEM					
		4 d post-treatment		7 d post-treatment		pupation	
		H. zea	*H. virescens*	*H. zea*	*H. virescens*	*H. zea*	*H. virescens*
B. thuringiensis	0.56 kg	29±1.9f[c]	* 42±3.5e	37±7.7g	* 52±1.1ef	52±9.1d	56±9.7d
B. thuringiensis	1.12 kg	39±3.4ef	* 56±4.9cd	41±5.3fg	* 57±5.0de	58±5.3cd	63±1.9cd
B. thuringiensis	2.24 kg	58±6.0cd	65±3.0c	61±7.9de	66±2.0d	74±7.3bc	71±2.5bc
B. thuringiensis	4.48 kg	61±3.0c	71±5.0c	62±2.0de	74±4.2cd	77±1.7b	79±5.7ab
B. thuringiensis	8.96 kg	84±9.4b	84±1.6b	86±7.4a-c	84±1.6bc	90±7.0ab	86±2.3a
Cypermethrin	0.05 kg[d]	97±1.9a	88±3.3ab	98±1.2a	88±3.3ab	99±1.0a	89±4.1a
LD_{50}[e] (95% CI)		1.77 (1.4-2.2)	0.88 (0.5-1.2)	1.43 (0.5-2.7)	0.58 (0.3-0.9)	0.57 (0.3-0.8)	0.35 (0.1-0.6)

[a] Cotton was sprayed in the field, and terminals were brought to the lab. Two-day-old larvae were allowed to feed on terminals for 48 h and then transferred to semisynthetic diet.
[b] *B. thuringiensis* formulation contained 6.4% active material with delta endotoxin potency of 52863 *Spodoptera* Units/mg.
[c] Means within a period for 4 and 7 days post-treatment or within a column at pupation followed by the same letter are not significantly different (P=0.05, LSD). *, Astrisk indicates significant difference between adjacent means.
[d] Cypermethrin, amount of active ingredients [ai].
[e] kg/ha formulated material.

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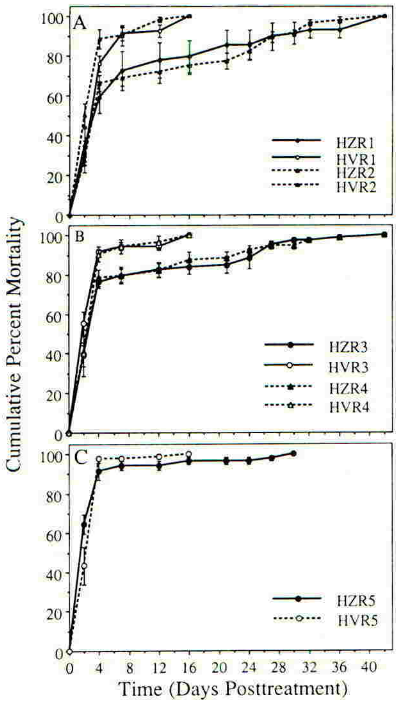

Fig. 1. Cumulative percent mortality (± SEM) versus time (days post-treatment) for 1st instar *H. zea* and *H. virescens* larvae fed cotton terminals treated with various rates of *B. thuringiensis*. Legends HZR1 through HZR5 and HVR1 through HVR5 represent 0.56, 1.12, 2.24, 4.48, and 8.96 kg/ha rates of *B. thuringiensis* for *H. zea* and *H. virescens*, respectively.

THE SPHINX PROJECT - A COMPUTER BASED IPM SYSTEM FOR COTTON

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ABSTRACT

The Sphinx Project is a cooperative effort which began in 1989 between Ciba-Geigy, Ltd. and the Egyptian Ministry of Agriculture. The major objective of the Sphinx Project is to assist production of cotton in Egypt through development of a computerized IPM database.

This paper introduces the Sphinx Project. It includes descriptions of guidelines followed in development of the project; the database and data reporting system; and benefits of the project.

INTRODUCTION

Egypt has a history of following IPM practices in cotton. The early season manual collection of Spodoptera littoralis egg masses is the primary means of controlling this pest (McKinley et al., 1989).

A lot of data are collected annually in the present Ministry of Agriculture (MAG) pest management program. However; minimal data are collected about crop development, beneficial insects and some insect pests. Also, data collected in the MAG program can not always easily be transferred to computers, and information is often not readily available to other departments in MAG.

The MAG aims to standardize data collection procedures in cotton and to develop a computer based system which can serve decision makers in the field and national policy makers in Cairo. The Sphinx Project is a cooperative effort between Ciba-Geigy and the Egyptian Ministry of Agriculture, which has as its major objective the development of a computerized integrated pest management database.

SPHINX PROJECT ORGANIZATION

The Sphinx Project is planned to last up to 10 years and will have 5 phases. Phase 1, the present phase and the phase discussed herein, has as its objective the collection and retrieval of data from cotton, its pests, beneficials and agricultural practices. Work will progress through 4 additional phases ending with the use of simulation models and expert systems.

A local steering committee was established in Egypt in 1989. The function of this committee is to coordinate, evaluate and approve Sphinx Project activities, and to set guidelines for operation.

The steering committee selected the El Mansoura district of Dakhalia Province as the location for the Sphinx Project. This province, located in the Nile Delta, is a major cotton production area. In 1992 a second area, located in Assiut Province, in Upper Egypt was added.

SPHINX PROJECT IPM DATABASE

General Characteristics

The Sphinx database is designed as a national database for cotton production. Information such as fertilizer use, irrigation, pesticide use, and cotton fruiting, will be available to any organization in the MAG. This gives it a multi-purpose and multi-level role in the MAG.

The basic principles of IPM are the same for any crop pest. This is considered in development of the Sphinx IPM computer software. The system, although developed for use in cotton, is designed for adaptation to other crop systems with minimal effort.

Information Categories

Data in the Sphinx Project database are grouped into several information categories. Data are collected from these categories in both the MAG program and the Sphinx Project. However, the Sphinx Project includes data about crop development, and pest and beneficial populations which are not collected in the MAG program.

Site information
Data collected include field identification, field size, crop rotation, crop variety, planting date, emergence date, stand density, and weather data.

Cultural Practices
These data are closely related to site information, and include land preparation, irrigation, fertilization, and non-chemical methods of pest control.

Pesticide Use Information
These data include target organism, compound used, rate of application, and time of application.

Cotton Plant Phenology and Insect Information
Data collected under these two categories include pest and beneficial insect numbers, insect damaged and non-damaged fruit, and pheromone trap data.

SPHINX PROJECT - PRESENT STATUS

Phase One Goals

Phase one of the Sphinx Project began in 1990 and will be completed in

1993. Goals for this phase are to develop and test standardized data collection procedures, and a computerized database management and reporting system which can be used at all levels in MAG to assist in IPM decisions.

Data Collection

Seventeen data forms are used in the collection of data. These data forms and scouting procedures are described in a manual.

Plant phenology and beneficial insect sampling procedures are similar to those in area-wide IPM program in Arkansas, U.S.A. (Nicholson, et. al. 1984).

Training

An intensive training program has been developed for data collection in the Sphinx Project. A one week training session is held before cotton is planted. MAG specialists introduce MAG data collection staff (cotton scouts) to the fundamentals of IPM, pest and beneficial insect life histories, insect identification, and recognition of damage. Also, the Sphinx manual and scouting system is discussed in this session. After cotton is planted, a training team works daily with the MAG cotton scouts to discuss data forms, data collection procedures and possible problem situations.

Data Entry

The data entry program is menu driven and user friendly. Minimal training is necessary for data entry teams. Although data entry screens on the computer are in English, it is not necessary for data entry personnel to read English well. Data entry screens have the same format as the Arabic data forms. Data entry follows the sequence of the data forms, and entry is from right to left.

Data Reporting

Sphinx Project reporting will function at three levels in MAG; district, province and national. Over 40 tabular and graphic reports are available (Table 1). At district level, data coming from the field passes as reports to administrators and decision makers at this and higher levels. It is necessary for the data to be available in several formats. Some persons who receive reports determine if treatments are necessary, others may use the information to evaluate efficacy of pesticide applications, while others may use the information to set national pest management strategies.

The reporting program is menu driven, and is designed to be both powerful and user friendly. The tabular reports summarize data on any user defined time interval which may be one day or the entire season. Seasonal trends in pest populations or plant phenology can be presented graphically in a daily or weekly format. Seasonal development of cotton fruit during 1991 for the El Mansoura district are shown in Figure 1. In addition, maps showing crops planted, and percent area above threshold for some pests can be generated.

District Reports

One set of reports which is generated daily has become a useful tool for decision makers in the district. These reports list all fields which exceed MAG thresholds for pests or combinations of pests. Figure 2 is an example of a daily report which has been modified for demonstration purposes. Officials review these reports and dispatch their assistants to evaluate the potential problem fields. No management decisions are made until the fields are checked by a supervisor.

Province Reports and National Reports

Province level reports as now generated are summaries of the district reports. These provide province officials with an overview of the pest and crop status in districts. Before 1992, the Sphinx Project operated in only one district of one province. Therefore, there has been no potential for development of national reports. Complete reporting needs will not be identified until the project includes several districts in more than one province.

TABLE 1. Number of reports available to MAG decision makers.

FORM NUMBER AND TITLE	DIST.	PROV.	GRAPHICS
1 BASIC INFORMATION	1	1	1
2 CORRECTION FOR FORM 1	-	-	-
3 INTERCROP INFORMATION	-	-	-
4 LAND PREPARATION & ROW SPACING	-	-	-
5 WEEKLY FERTILIZATION	1	1	-
6 WEEKLY IRRIGATION	1	1	-
7 DAILY PEST CONTROL & AGRICHEM. USE	2	2	-
8 DAILY SPODOPTERA EGG MASS COLLECTION	2	2	1
9 STAND COUNTS	1	-	-
10 SIGNIFICANT DATES	1	1	-
11 NODE LOCATION OF FIRST FRUIT	1	1	-
12 YIELD AND HARVEST DATE	1	1	-
13 PHEROMONE TRAP LOCATIONS	-	-	-
14 PHEROMONE TRAP CATCH RECORDS	1	1	1
15 WHOLE PLANT EXAMINATION	1	2	5
16 SHAKE CLOTH & PLANT/LEAF EXAM.	1	2	8
17 INSPECTION FOR % BOLLWORM INFEST.	1	2	2
SPECIAL - FIELDS ABOVE THRESHOLD	1	1	1

BENEFITS OF THE SPHINX PROJECT

The Sphinx IPM system is still under development. The Sphinx data collection system provides quantitative field level information on pest populations and damage, fruiting condition of the crop, and cultural practices. The Sphinx reporting system will make this information available to decision makers in an efficient, rapid and highly usable form.

The Sphinx IPM system will enable decision makers to:

(a) Efficiently apply pest control measures by considering action thresholds and by correct timing.

(b) Evaluate efficacy of pest control measures.

(c) Replace laborious hand produced reports with quickly produced computer reports.

(d) Evaluate agricultural practices such as date of planting, fertilization, irrigation, and pesticide use.

(e) Examine the fruiting condition of the crop and intensity of pest populations.

FIGURE 1. Province and District graphics showing fruiting development.

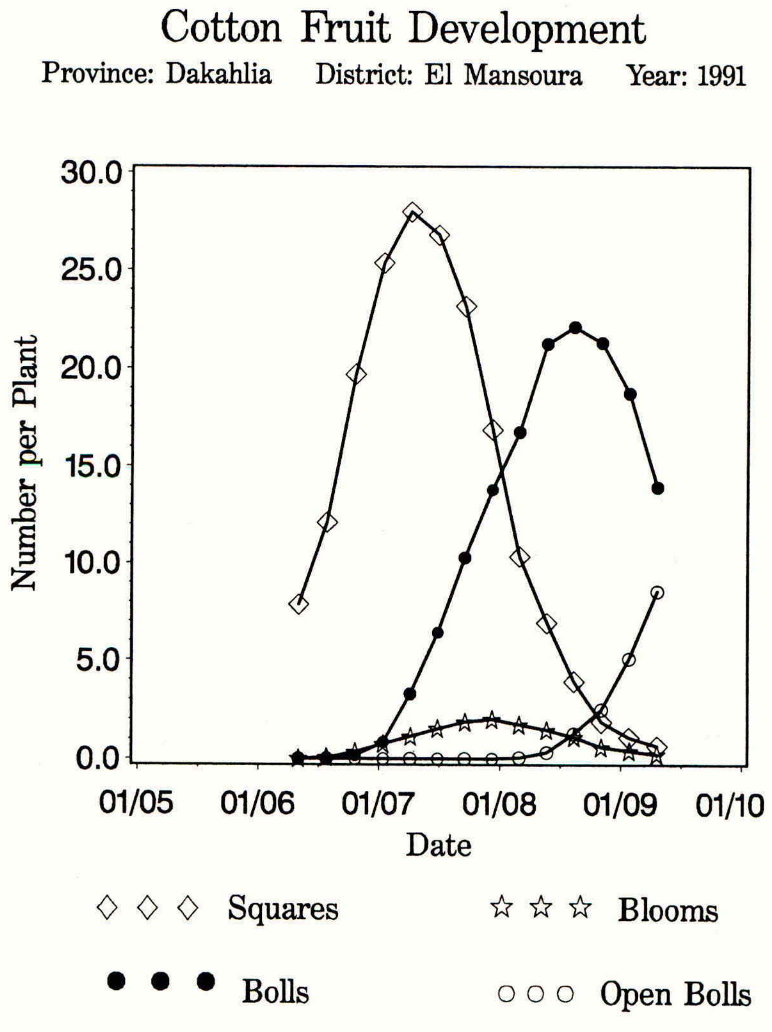

FIGURE 2. District report indicating samples exceeding MAG thresholds.

SPHINX PROJECT Date of Data Entry: 19/05/92

FORM 16 SHAKE CLOTH AND PLANT/LEAF EXAMINATION

Date: 19/05/92

Basin: 36 Cooperative: 23 District: 1 Province: 1

EARIAS	MOLE CRICKET	CUT-WORM	THRIPS IMM.	THRIPS AD.	JASSID	WHITE FLY	SPIDER MITE	APHID	FIELD NUM.
0	0	0	1	2	0	0	38$	1	1
0	0	0	4	0	0	0	35$	0	3
0	0	0	5	8	4	0	33$	0	4
0	0	0	7	2	3	0	33$	0	6
0	0	0	8	2	3	0	44$	0	7
0	0	0	8	1	0	0	33$	0	8
0	0	0	4	8	0	0	38$	0	9
0	0	0	8	2	1	0	32$	0	11

$ - field above threshold

ACKNOWLEDGEMENTS

The Sphinx Project is a team effort. Over 50 members of Ciba-Geigy (Basel and Egypt), and approximately 100 members of the MAG have been involved with this project. Any success of the Sphinx Project is the result of their efforts and goodwill.

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LOW RATE MULTIPLE APPLICATION OF BT+OVICIDE FOR *HELIOTHIS* CONTROL IN COTTON

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ABSTRACT

A logical and important insect management strategy is to assist the cotton plant in retaining its early, most profitable and/or valuable fruit. Since physiological stresses are usually neither evident nor occurring at that growth stage, insect damage is the dominant cause of fruit loss. Thus, for cotton insects, a good integrated pest management program is a combination of both preventative and corrective tactics to save early squares and bolls.

A preventative, early season *Heliothis* spp. control program incorporating the use of *Bacillus thuringiensis* (BT) larvicides, combined with "soft" ovicides, and applied at low rates on a regular 3 to 6 day schedule, was evaluated in several large plot tests in 1991. The program prevented "below threshold" damage and subsequent delays in harvest of the bottom bolls, and thus reduced the "in season" numbers of 2nd and 3rd generation bollworms. By employing preventative, early season applications of BT, and BT plus ovicide (thiodicarb) at ovicidal rates, beneficial insects were preserved and overall economic returns increased over those of a conventional insecticide program.

INTRODUCTION

Preventative strategies utilize control methods which manage pests before they reach economic threshold treatment levels. Such strategies put the grower "ahead of the game," but few end users (growers/consultants) knowingly focus on whether an application for insect control is based on corrective or preventative tactics. When a systemic insecticide is used at planting for thrips (*Thrips tabaci*) control without treatment thresholds, or when diapause and pinhead square applications are made for boll weevils (*Anthonomus grandis*), based on trap catches, preventative tactics are being employed. However, fleahopper (*Pseudatomoscelis seriatus*) and bollworm (*Heliothis zea*) spray applications are corrective and are based on sweep net and/or whole plant inspections or terminal counts. An efficient cotton insect management program is a combination of both tactics (Roach *et al.*, 1989; Durant, 1991).

Insect threshold treatment levels can change throughout the growing season or may have to be adjusted due to environmental, toxicological (resistance) and economic restraints (Cox *et al.*, 1991). For example, if 10 pests per 100 terminals result in threshold damage, 1 pest per 100 terminals will cause 10% as much damage. Obviously, less than threshold numbers of certain pests cause economic damage. If the preventative system reduces or avoids threshold damage without significantly increasing costs, then it will increase yield and economic returns. Potentially, it would seem that this is preferred to the corrective approach. A preventative early season *Heliothis* management program would incorporate the use of *Bacillus thuringiensis*, var. *kurstaki* (BT) larvicides combined with "soft" ovicides applied on a regular, short interval (3 to 6 day) to prevent "below threshold" damage and subsequent delays in harvest. Such a program would reduce numbers of 2nd and 3rd generation worms during the early and mid-season. With preventative, economical, low rate, early season applications of BTs and BT plus ovicides, beneficial insects can be preserved. It has been determined that spray application regimes based on egg thresholds produced the greatest economic returns (Bacheler & Bradley, 1989). Tests have shown that the efficacy of BTs and amitraz (OVASYN®) was significantly reduced when treatments were delayed until "traditional" larval thresholds were reached (Durant, 1991). BT and ovicide applications timed to coincide with peak moth flights (trap captures) and egg lays can be successful in controlling the early and mid-season bollworm complex when applications are timed correctly.

Studies have demonstrated that *Heliothis virescens* can detect and will avoid high dosage levels of BT (Gould & Anderson, 1991). Therefore, increasing the dosage of certain BTs may not necessarily increase its effectiveness. Since BTs in cotton are typically degraded in 3 to 7 days, and a vigorously growing cotton plant continuously sprouts new leaves, it would seem advantageous to apply lower dosages more frequently.

In 1991, 11 large scale field tests of approximately 16 hectares each were conducted in the Texas Coastal Bend and Wintergarden areas, the Louisiana Delta, the Mississippi Delta and hill areas, Georgia and South Alabama in the United States. The tests were conducted with BT at low rate multiple applications in short intervals (3 to 6 days) compared to conventional cotton insect control programs, in which applications of broad spectrum synthetic organic insecticides (SOIs) were made based on local larval and egg thresholds criteria. Worm pressure was light in most test locations except Texas.

MATERIALS AND METHODS

The Texas Coastal Bend test at Waller is presented herein as an example of the BT Low Rate Multiple Application (LRMA) concept for an improved Integrated Pest Management program.

At this site, DPL 51 cotton was drill planted on 40 hectares on May 15, 1991. 5.75 kgs of aldicarb (TEMIK® 15G) per hectare was applied at planting. An approximate stand of 83,000 seedlings per hectare emerged on about May 20th. Two Harstack (cone) moth traps were placed 91 meters from the field ends and were baited with *Heliothis zea* and *Heliothis virescens* pheromone lures which were replaced biweekly. Counts of moths in traps were made at 1 to 4 day intervals depending on the severity of infestation. Number of bollworm eggs and larvae per acre were normally counted twice weekly. Frequency of field monitoring of egg lays was increased when trap captures began to increase.

Boll weevil "trap" rows of cotton were planted 3 weeks before the main crop. The objective was to avoid spraying the entire field by attracting, containing and killing the "overwintered" boll weevils in the earlier squaring "trap" borders. Boll weevil traps were placed in the field in July and August.

The LRMA BT program was at 150 g (4.8 BIU) of BACTEC BT per hectare for two (2) applications, four (4) applications at 300 g (9.6 BIU) plus thiodicarb (LARVIN®) at 90 g and two (2) applications at 600 g (19.2 BIU) plus thiodicarb (LARVIN®) at 142 g. The conventional SOI program was seven (7) applications of Lambda-cyhalothrin (KARATE®) at 37.5 g active per hectare.

TABLE 1. Insecticide costs per hectare in a LRMA BT program.

Treatment/hectare	$ Cost per hectare (US Dollars)
2 Apps. 150 g BT (@ 4.93 each)	9.86
4 Apps. 300 g BT (@ 9.86 each) + 90 g thiodicarb (@ 2.83 each)	50.76
2 Apps. 600 g BT (@ 19.72 each) + 142 g thiodicarb (@ 4.45 each)	48.34
TOTAL	$108.96

TABLE 2. Insecticide costs per hectare in a conventional SOI program.

Treatment/hectare	$ Cost per hectare (US Dollars)
7 Apps. 37.5 g thiodicarb (@ 16.34 each)	114.37
TOTAL	$114.37

Heliothis spp. treatment thresholds were based on state extension levels which call for treatment when there are 4 to 5 small worms (plus eggs) per 100 terminals checked and 5% of the squares and small bolls damaged by small worms. Treatment was made when worm or larvae counts averaged 12500 or more small larvae per hectare. In the microbial treated plots, control measures were delayed if four or more key predators were found for each small larvae.

Boll weevil treatment levels were reached when a random sample showed 10% or more weevil punctured squares. Plant bug and fleahopper treatment levels were 7 to 8 bugs per 100 sweeps with a sweep net or visually 5 bugs per 100 terminals during the first 2 weeks of squaring. Thresholds were increased to 15 bugs per 100 sweeps in the third week of squaring and to 30 plant bugs per 100 sweeps after first bloom.

Number of bollworm eggs and larvae per hectare were normally counted twice weekly. "Plant mappings" began at squaring and were taken each two weeks thereafter. The cotton was defoliated on September 15.

Ground insecticide treatments were applied with a MELROE Spray Coupe equipped with three (3) TX6 nozzles per row, one above/over and two angled at 45° to each side of the row at 4.22 kg/cm^2 and calibrated to deliver 66 liters of spray solution per hectare. Aerial applications were made with a Turbo Thrush at 200 kph and 38 liters per hectare. Yield data was obtained by machine harvesting, October 1 and 15.

Economic returns per hectare were calculated using the Mississippi State Budget Generator (MSBG) computer program (Spurlock, 1985). Actual kgs of lint and seed turnout were used. Grade discounts or premiums were used in determining sales price from a base contract price of $1.48 per kilogram. Seed was priced at $61 per metric ton. Insecticide costs were based on 1991 prices actually paid by the grower. The cost of BT was estimated at $31.97 per kilogram.

RESULTS AND DISCUSSION

Plant bug (*Lygus lineolaris*) and fleahopper populations were low (1 per 3 meters of row) to moderate (3 per 3 meters of row) throughout the season, never exceeding the recommended treatment threshold. Tobacco budworm (*Heliothis virescens*) and bollworm (*Heliothis zea*) larval densities remained below 2 per 100 terminals until early August at which time they increased to 5 larvae per 100 terminals (5% infestation). The egg population remained low, less than 5 per 100 terminals, during June and July followed by a marked increase to 8% in early August. Worm and egg counts remained high during the first week of August then subsided to below threshold treatment levels. About this time, most of the surrounding corn fields had matured and dried. Based on moth trap counts, *Heliothis zea* comprised the majority (>90%) of the observed eggs.

Bollworm infestation and damage reached its highest during the first week of August. Boll weevils began to increase at this time and peaked on August 29. Season averages of egg counts, larvae counts, damaged squares and damaged bolls are presented in Table 3.

TABLE 3. Seasonal Average in LRMA BT and Conventional SOI program.

Percent per 25 plants	LRMA BT	*STD.DEV*	*CO VAR.*	SOI	*STD.DEV*	*CO VAR.*
Eggs	4.8	*4.55*	*0.23*	20.0	*4.84*	*0.86*
Larvae	2.5	*1.66*	*0.91*	4.4	*2.63*	*0.64*
Damaged Squares	4.0	*2.45*	*0.67*	7.8	*4.12*	*0.46*
Damaged Bolls	0.2	*0.00*	*0.00*	2.0	*3.10*	*0.21*

In Table 4, plant mapping results of July 24 showed that the LRMA BT plot had an approximate 88% fruit set whereas the conventional SOI treated plot had only a 45.3% fruit set. By August 16, LRMA BT plots had 67% fruit set vs. 43% for the conventional plots. By September 23, this LRMA BT fruit set advantage, compared to the conventional plots, had narrowed to 16.25%. An August increase in boll weevil numbers and subsequent damage in LRMA BT plots would largely account for this change in fruit set. Boll weevil trap counts increased from an average of 8 per trap in late July to an average of 17 per trap in late August.

TABLE 4. % Total fruited sites in LRMA BT and Conventional SOI program.

Percent per 75 plants	LRMA BT	SOI
July 24	88	45
August 16	67	43
September 23	58	42
STD DEV.	*12.57*	*27.86*
CO VAR.	*0.45*	*1.25*

When comparing the September average percent fruit set by position, the LRMA BT treatment exhibited a 34.3% average advantage at the Node 2 position; whereas, there is only a 1/2% difference in Node 1 fruit set. It appears that the conventional plot was insufficiently protected while attempting to set this fruit. At harvest, LRMA BT retained its 16.25% advantage.

On September 23, the LRMA BT plot had 95% open or cracked bolls. It was ready for defoliation and harvest one week earlier than conventional treatments. This week of earliness has a theoretical economic value of $93.03 per hectare (Parvin, 1991).

Economic Results

The LRMA BT treated plot yielded 907 kgs of lint per hectare whereas the conventional plot yield was 850 kgs. The LRMA BT plot had an average grade of 63 and sold for $1.48 per kilogram; whereas, the conventional plot had a grade of 57 and sold for $1.43 per kilogram. The difference in per hectare profit from operations was a $165.00 per hectare advantage for the LRMA BT treated plot.

When the theoretical value of earliness, $93.03 per hectare is added to the net operating profit of $165.00, the LRMA BT plot theoretically returned the grower an approximate $258.03 more per hectare than the conventional program.

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SESSION 9A

ASSESSMENT OF THE NON-TARGET EFFECTS OF AGROCHEMICALS

CHAIRMAN DR P. GREIG-SMITH

SESSION ORGANISER MRS R. HIGNETT

INVITED PAPERS 9A-1 to 9A-4

THE EFFECTS OF HOME PROCESSING ON RESIDUES OF FUNGICIDES ON CITRUS FRUIT: WASHING ORANGES

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ABSTRACT

The effect of culinary washing procedures on the levels of residues of the fungicides imazalil, 2-phenylphenol and thiabendazole on postharvest treated oranges has been studied. Washing was performed using a variety of wash solvents which are readily available in the home, such as water, washing-up liquid and vinegar. Analysis of the solvents after washing showed that up to 40% of imazalil and 30% of thiabendazole had been removed whereas only traces (<1%) of 2-phenylphenol residues were detected in any of the wash solvents used.

INTRODUCTION

Following harvest, citrus fruit for the fresh fruit market are commonly washed, waxed and treated with formulations containing fungicides, such as imazalil, 2-phenylphenol and thiabendazole which provide protection from fungal attack during transport and storage (Dezman et al., 1986). Residues of these fungicides are, therefore, present on citrus fruit as purchased by the consumer. Studies on the penetration of postharvest fungicides into the fruit showed that residues were highest on the surface of the fruit and in the peel, and much lower in the flesh (Abd-Allah et al., 1974; Lafuente et al., 1987; Tadeo et al., 1988).

When citrus fruit are consumed the peel is normally removed and most of the fungicide residues present will also be discarded, although small amounts may be transferred to the flesh during peeling (Königer and Wallnöfer, 1990). However, as many recipes for home-made marmalades, chutneys, cakes, desserts, etc include whole fruit or the zest of sweet oranges and/or lemons, it is important to acquire information on the effects of various culinary processing procedures on these residues.

The limited information available on the fate of fungicide residues on citrus fruit following processing prompted this investigation into the effectiveness of a variety of household wash solvents in removing imazalil, 2-phenylphenol and thiabendazole residues from the peel of oranges.

EXPERIMENTAL

Oranges

Late Valencia oranges known to have been commercially waxed and treated with imazalil, 2-phenylphenol and thiabendazole were used. The oranges (five boxes, in each approximately 76 fruit weighing 15kg) were obtained almost immediately after import into the UK, around four weeks after picking. For each experiment fruit were selected randomly from each of the five boxes.

Washing procedures

Five types of washing treatments were performed. In each case 16 oranges were washed individually. The basic washing procedure at 20°C ± 1°C was as follows:-

Each orange was immersed in a volume of wash solvent (550–600ml). The solvent was gently agitated by means of a magnetic stirrer set at constant speed for 15 minutes. The temperature of the wash solvent was recorded at the beginning and end of each wash with the following modifications:-

i) A wash with water (glass-distilled) at both 20°C and 50°C.

ii) The application of 0.25ml and 0.50ml of washing-up liquid to the surface of the peel of the orange using a soft brush prior to the wash.

iii) A wash in dilute distilled malt vinegar (45/560 V/V).

The washed oranges were dipped in 10 litres of water for 15 minutes to rinse off the washing-up liquid or vinegar. Wash solvent from individual oranges was pooled. Suitable aliquots of both wash solvents and rinse water were taken for analysis.

Extraction of residues from unwashed oranges

25 individual oranges were peeled. The peel was chopped up and combined to form one composite sample. Similarly the flesh from each fruit was macerated together to form a second composite sample. Portions of the composite peel and flesh were taken for analysis which corresponded to the original proportions of each present in the whole fruit.

The peel, macerated with anhydrous sodium sulphate, was added to the flesh to form a reconstituted sample of whole fruit. This sample was soaked overnight in acetone and filtered under suction. The filtrate and filter cake were extracted with dichloromethane. A second extraction was performed after the addition of 1M sodium hydroxide solution to produce an alkaline pH. The dichloromethane extracts of filtrate and filter cake were combined.

Clean-up of residues

Thiabendazole and imazalil in the combined extracts were partitioned into 0.1M sulphuric acid (extract A). The organic layer containing 2-phenylphenol was retained (extract B) whilst the acidic aqueous extract A was made alkaline with sodium hydroxide solution (pH 11.5) and the imazalil and thiabendazole partitioned back into dichloromethane.

Extract B was evaporated carefully to dryness and the residue dissolved in methanol/water (90/10 V/V). After the addition of dilute sulphuric acid, the 2-phenylphenol was partitioned into hexane. The dichloromethane extract containing the imazalil and thiabendazole, and the hexane extract containing the 2-phenylphenol were both carefully evaporated to dryness and the residues dissolved in a suitable volume of methanol for analysis using high performance liquid chromatography (hplc).

Extraction of residues from wash solvents and rinse water

Extraction of the three fungicide residues from the wash solvents and rinse water was also performed using dichloromethane. Again, two extractions were undertaken, one at the original pH of the wash solvent and the second after adjustment to pH 11. Addition of sodium chloride was used to prevent the formation of emulsions, particularly when washing-up liquid was present in the wash solvent. Dichloromethane extracts were evaporated just to dryness and the resultant residues dissolved in a suitable volume of methanol ready for hplc analysis.

Hplc analysis

Aliquots (20µl) of the methanolic extracts of orange, wash solvents and rinse water were injected onto a 250 x 4.6mm Hichrom RPB, 5µm column via a 10 x 4.6mm id guard column of the same packing material. A mobile phase of methanol/water (75/25 V/V) was employed with a flow rate of 1ml/min at ambient temperature.

Imazalil residues were detected with a UV detector at wavelength 204nm. 2-Phenylphenol and thiabendazole were monitored using a fluorescence detector. For extracts of whole oranges, thiabendazole residues were monitored at excitation 296nm, emission 350nm and 2-phenylphenol residues at 285nm and 350nm, respectively. For wash solvents and rinse water, the 2-phenylphenol and thiabendazole residues were both measured at excitation 285nm and emission 350nm. Quantitation was achieved by comparing peak heights from chromatograms of sample extracts with peak heights obtained using standard solutions of known concentrations. Results were based on triplicate analyses and duplicate injections of each extract and standard.

Recoveries

Recoveries of the three fungicides from whole oranges were determined by monitoring levels in unspiked and spiked portions of the whole fruit and wash solvents, respectively, (see Table 1). For whole fruit spiking levels were around 5 times the reporting limits as employed by MAFF (HMSO, 1989).

TABLE 1. Recoveries of three fungicides from whole Late Valencia oranges

Fungicide	Spiking Level (mg/kg whole fruit)	n	% Mean Recovery
Imazalil	2.5	3	80
2-Phenylphenol	5.0	3	93
Thiabendazole	2.5	3	100

Recoveries of the three fungicides from wash solvents were all >90%.

RESULTS

Chromatograms of extracts from unwashed Late Valencia oranges and from extracts of a wash solvent are shown in Figures 1 and 2, respectively.

Results of the analyses of whole fruits are given in Table 2. They are based on the mean value of triplicate determinations and are expressed in mg/kg on a whole fruit basis.

TABLE 2. Mean residue levels in unwashed Late Valencia oranges

Fungicide	Mean Residue Level (mg/kg whole fruit)	Range (mg/kg whole fruit)
Imazalil	1.32	1.20 - 1.38
2-Phenylphenol	0.84	0.76 - 0.89
Thiabendazole	2.46	2.36 - 2.53

Results of the analyses of wash solvents and rinse water are given in Table 3.

TABLE 3. Levels of imazalil, 2-phenylphenol and thiabendazole residues in wash solvents and rinse water after washing Late Valencia oranges

Washing Procedure	Levels of Fungicide Residues*		
	Imazalil	2-Phenylphenol	Thiabendazole
Water wash (20°C)	0.25 (19%)	<0.01 (<1%)	0.27 (11%)
Water wash (50°C)	0.55 (42%)	<0.01 (<1%)	0.69 (28%)
Wash with washing-up liquid (0.25ml)			
wash solvent	0.25 (19%)	<0.01 (<1%)	0.42 (17%)
rinse water	0.13 (10%)	<0.01 (<1%)	0.15 (6%)
total	0.38 (29%)	<0.01 (<1%)	0.57 (23%)
Wash with washing-up liquid (0.50ml)			
wash solvent	0.44 (33%)	<0.01 (<1%)	0.59 (24%)
rinse water	0.12 (9%)	<0.01 (<1%)	0.17 (7%)
total	0.56 (42%)	<0.01 (<1%)	0.76 (31%)
Wash with diluted vinegar (vinegar/water 45/560 V/V)			
wash solvent	0.42 (32%)	<0.01 (<1%)	0.43 (18%)
rinse water	0.13 (10%)	<0.01 (<1%)	0.11 (4%)
total	0.55 (42%)	<0.01 (<1%)	0.54 (22%)

* Level of residues expressed as mg/kg on whole fruit basis and as % of total residue on fruit in parenthesis. Each result represents the mean calculated from the analysis of three aliquots of combined wash solvent and rinse water, respectively.

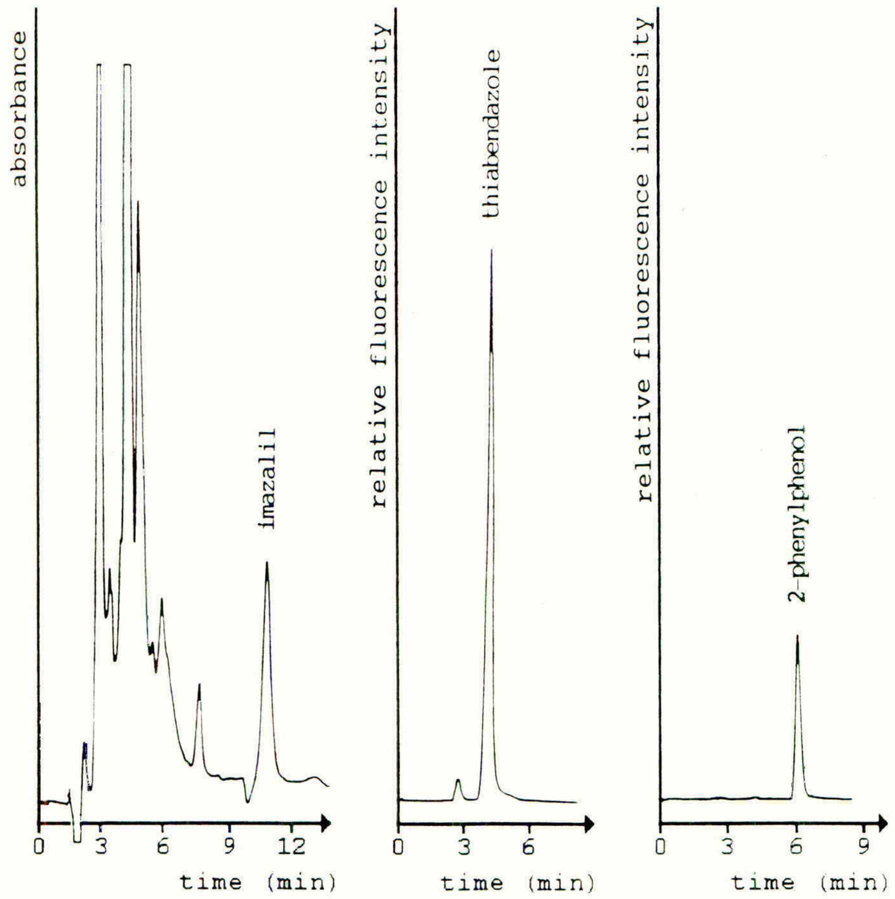

FIGURE 1. Chromatograms of extracts of unwashed Late Valencia oranges

Hplc conditions: 250 x 4.6mm id Hichrom RPB 5µm with 10 x 4.6 mm id guard column (same packing material); methanol/water 75/25 V/V; injection volume: 20µl; flow rate: 1 ml/min at ambient temperature; detection: imazalil UV at 204nm, 0.02 aufs; thiabendazole at excitation 296nm, emission 350nm and 2-phenylphenol at excitation 285nm, emission 350nm, respectively.

Retention times:	thiabendazole	4.07 min
	2-phenylphenol	6.39 min
	imazalil	10.94 min

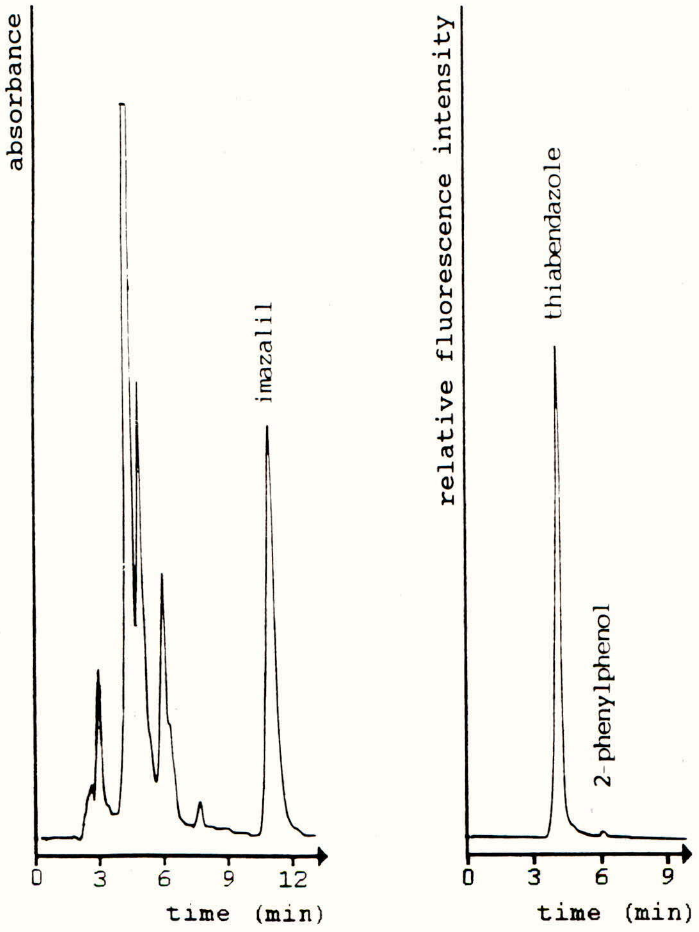

FIGURE 2. Chromatograms of extracts of water used for washing Late Valencia oranges at 20°C

Hplc conditions as in Figure 1, except for detection: thiabendazole and 2-phenylphenol at excitation 285nm and emission 350nm.

Retention times:	thiabendazole	4.03 min
	2-phenylphenol	6.33 min
	imazalil	10.93 min

DISCUSSION

Almost half of the imazalil and one third of the thiabendazole residues could be removed from the peel of Late Valencia oranges. However, residues of 2-phenylphenol were not reduced significantly by any of the washing solvents tested. Washing with hot water at 50°C, washing-up liquid or dilute vinegar at room temperature produced very similar results for all three fungicides.

Further work is required to determine how different varieties of orange, the age of the fruit after harvest and particular wax formulations effect the removal of fungicides using the above washing procedures.

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THE EFFECTS OF PESTICIDES ON BENEFICIAL ARTHROPODS

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ABSTRACT

Beneficial arthropods are defined as mutualists, natural enemies and "others". Assessment techniques for mutualists, at least in the case of the honey bee, are agreed and have proved to be workable and useful in practice; i.e. both hazardous and non-hazardous products have been identified and successfully labelled. Systems for the assessment of natural enemies and other species are currently under discussion and are considered in more detail here. The success of developments in this area to date appear to have been hampered by an excess of interest in methods at the expense of defining what is a significant effect on these beneficials in the field. Agreement on this will facilitate agreement on how lower tier experiments are to be conducted.

INTRODUCTION

This paper will consider what beneficial arthropods are, why they should be studied at all, how it is currently done, what problems this creates and a proposed solution. In the interests of brevity, only work on natural enemies and "others" will be considered. This is merely a reflection of the confusion surrounding their assessment and the interpretation of these assessments compared to those for honey bees, as representatives of mutualists. Honey bee assessment schemes are already in operation and have proved to be successful in that both hazardous and non-hazardous products have been identified and successfully labelled.

WHAT ARE BENEFICIAL ARTHROPODS

Beneficial arthropods can be considered as three groups, mutualists, natural enemies and others (Brown 1989). Beneficial arthropods are extremely diverse and come from all insect orders, with the possible exception of the Mallophaga (biting and bird lice) and the Anoplura (sucking lice) who are unloved beyond the ranks of medical and veterinary entomologists. In addition, there are numerous examples of beneficial spiders and mites.

Mutualists

In this context, mutualists are largely pollinators of plants but a wide diversity of mutualisms between arthropods and other species exist. Typically, these are more frequent in the tropics than in boreal ecosystems (Farnworth & Golley 1974), perhaps because of the greater "predictability" of these systems (May 1983). These species are either (a) introduced seasonally into crops, (b) managed or (c) wild and unmanaged. Examples of seasonally introduced pollinators (a) are the honey bee (Apis melifera) in oilseed rape or pome fruit or the bumble bee (Bombus terrestris) in green houses for egg-plant, peppers and tomatoes. Managed wild pollinators (b) include Megachile rotunda and Nomia melanderi in seed alfalfa in the USA and unmanaged wild species (c) include a wide range of Bombus species in temperate fruit and oilseed crops and ceratopogonid Diptera in tropical cocoa. In this category the released and now established oil-palm pollinating weevil Elaeidobius kamerunicus should also be considered, though during the process of its establishment in Malaysia it was considered a pest by some plantations.

Natural enemies

Natural enemies are either native or introduced and feed on pest species to the extent that pest populations are decreased. The degree to which this happens is the subject of much heated debate, however there are clear cases where some pests are held entirely in check by natural enemies and others where they are not. Natural enemies come from the spiders and mites as well as from a variety of insect orders, especially the Hymenoptera, Coleoptera, Diptera and Neuroptera. Thysanoptera and Dermaptera are also believed to important predators in a number of crops around the world.

Others

The "others" category is the service industry of the environment. There are two main groups, which sometimes overlap, they are decomposers and food species. Decomposers are a wide range of cryptosigmatid and astigmatid mites, primitive insects and numerous higher insect larvae that process plant material, greatly increasing its surface area and therefore its ease of degradation and mineralisation by micro-organisms. The food species are those arthropods which are sufficiently numerous and juicy to act either as a principal food source for birds (eg Sotherton & Moreby 1992) or as an alternate food source for polyphagous predators such as carabid beetles. High populations of food species in a field may sustain a relatively high density of such polyphagous predators which may influence pest populations by taking occasional individuals during the winter time that found colonies of pests later in the crop growing season. Alternatively, as pest populations develop, polyphagous predators may "switch" (Rauscher 1978) from food species to them however, switching can be a double-edged sword as it is always possible for the beneficial food species to be more attractive in quantity and quality than the pest so that the polyphagous predators will switch to it entirely and be distracted from controlling the pest. For completeness, the others category must also contain industrial insects of which the principal example is the Silk Moth (Bombyx mori). This species will not be further discussed here as the issues surrounding it are specific to particular forms of orchard cultivation in Japan and are adequately covered by local regulations.

WHY SHOULD THEY BE STUDIED

From the view-point of environmental protection, it is not unreasonable that beneficial arthropods should be studied. They necessarily spend much time in agricultural fields and plantations and are an integral part of the agricultural ecosystem, in some cases conferring positive benefits to the grower through enhanced pollination or the suppression of injurious species. Beneficial arthropods are one of the most highly exposed groups of non-target organisms in comparison with many of the species that are routinely tested in pesticide registration. However, the fact that beneficial arthropods are so intrinsically linked with agricultural fields has been one of the very reasons why testing has been slow to develop. In the past, much concern has centered around effects in non-target habitat. It has been accepted that pesticides are a cultural practice and as with any other practice taking place in a field there will be consequences for the residents. The view was that if there were any adverse effects then these were an efficacy disadvantage of the product and not an environmental issue per se. Currently, this view is changing in Europe as agricultural fields are no longer perceived by the community at large as units of production but as an environmental resource to be managed. As a result of this changing view, standardised testing systems are now being developed for the species involved. In the USA, development of interest in beneficial arthropod testing has been overtaken by interest in other areas of the environment, namely aquatic, avian and more recently plant testing. Though the FIFRA code contains some beneficial arthropod testing requirements, they are officially on hold and are unlikely to be re-activated before 1997 due to the current volume of activity associated with the current registration and re-registration programmes.

Should the agrochemical industry view growth in this regulatory area as an opportunity or as a threat ? The industry supports the rigorous testing of products, believing that each should be assessed on an individual basis consistent with the current state of scientific knowledge (ICI 1992). This newer area of testing is introducing greater costs in registration than in the past and could in theory lead to the restriction of some outlets. However, it must be remembered that synthetic pyrethroids were not approved for summer use in cereals in the UK for the entirety of the 1980's because of concerns over the effects on beneficials. In practice it appears that this testing is leading to changes in label safety-statements. Such changes allow customers to be better advised about products and this allows them to make a more informed choice. A confident industry should see this as an opportunity, however, excessive or unsubstantiable claims about the safety of individual products will not only ultimately discredit those products, as the claimed benefits will not be delivered, but the industry as a whole.

CURRENT APPROACHES

Germany

From the 28 July 1989, the German Plant Protection Law was enacted which required natural enemy beneficial arthropod testing on registration applications from 1 December 1989. Due to the continuing re-registration process, this meant that data was required on all products where exposure of beneficials was likely to occur. The general approach is described by Bode, Brasse & Kotke (1989) and Brasse (1990); it is adapted from the IOBC system (eg Hassan et al.1987). Crops were considered to be one of seven types (Table 1) and example natural enemies were to be tested, a minimum of two per crop and a maximum of six species where multiple crop uses were applied for. Originally IOBC guidelines were used as a basis and since 1989, a number of more detailed BBA guidelines on testing individual species have been issued. These tests were also required to GLP, this caused some difficulties as many of the laboratories in which they were done were unable to operate GLP procedures. If a trigger value of >30% effect was exceeded, the product would be considered harmful to that species unless this could be refuted in higher tier studies, for which there are no set protocols at present.

United Kingdom and EPPO/CoE

Aldridge & Carter (1992) have presented the proposed UK approach to natural enemy testing as being based on the EPPO model (Fig 1), Carter et al.(1992). Choice of species is flexible, as are methods. Trigger values are as recommended by IOBC. Currently this model has been simplified to allow for two choices at each decision point rather than three. The honey bee data requirement stage has been dropped and the tier I screen altered to be a minimum of two species, typically four but no more than six.

BART group

The beneficial arthropod registration testing (BART) group has proposed the sequential testing scheme shown in Figure (2). This requires the testing of between two and four species, representative of the taxonomic diversity, importance and sensitivity of beneficials (Barrett 1992)

Figure 1. Simplified flow chart of EPPO/CoE sequential testing scheme

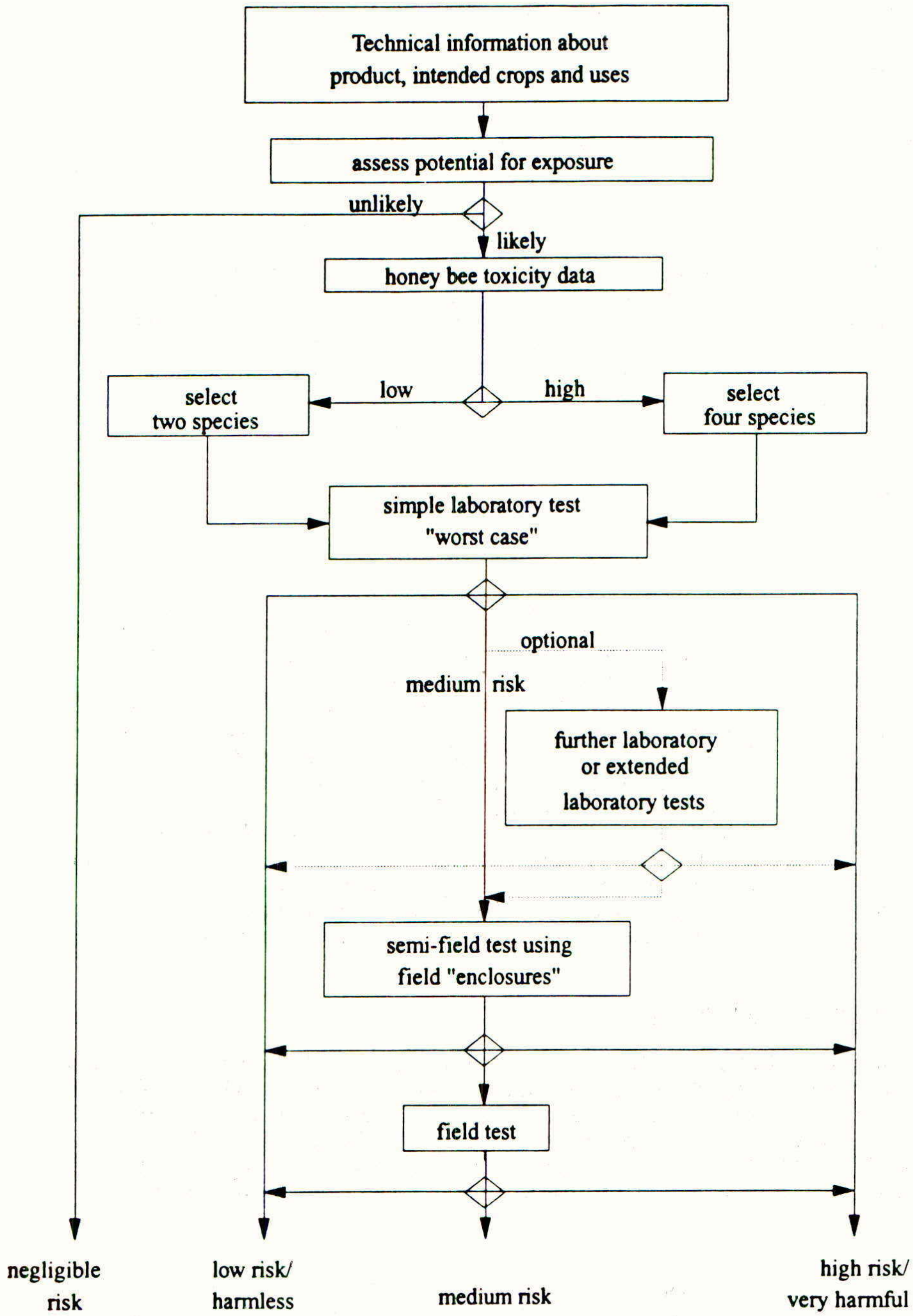
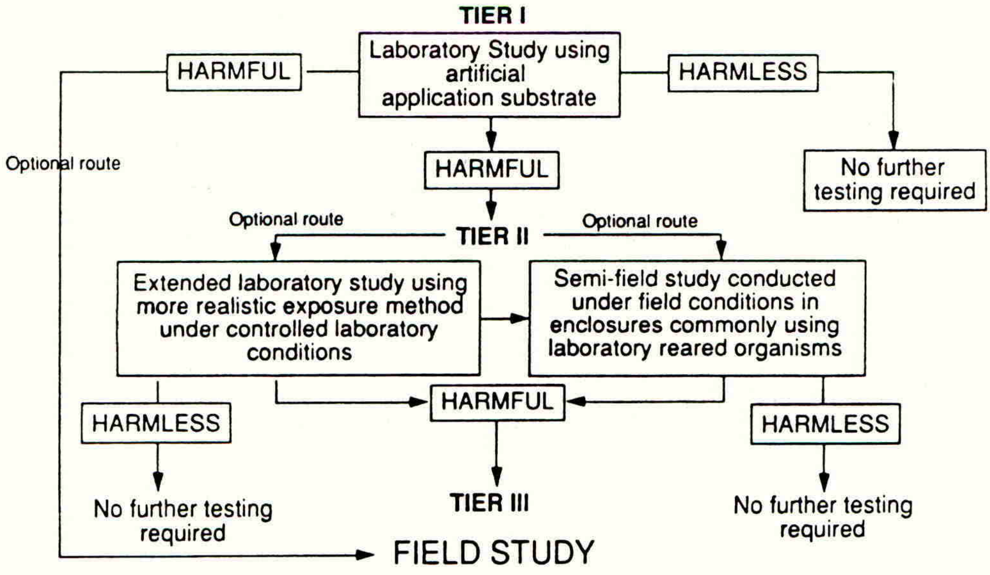


TABLE 1. The crop or habitat types and example natural enemies for testing under the German Plant Protection Law 1987.

Crop or Habitat	Example Natural Enemies
Infested with aphids	Chrysopa sp Coccinella sp Syrphus sp Aphidoletes sp
Infested with Lepidoptera	Trichogramma sp Coccygomius sp
Infested with spider-mites	Amblyseius sp Typhlodromus sp Phytoseiulus sp Anthocoris sp
Greenhouse crops	Trialeuroides vaporariorum
Infested with vegetable Diptera	Phygadeuon sp Aleochara sp
Exposed Soil	Phygadeuon sp Aleochara sp Carabidae
Infested with Pine Sawflies	Drino sp

Figure 2. The BART gourp testing scheme



EEC

The system finally adopted under Annexes 2, 3 and 6 of Council Directive 91/414/EEC Concerning the Placement of Plant Protection Products on the Market 15 July 1991; is thought ultimately to be an amalgam of EPPO/CoE, BART and German BBA proposals.

PROBLEMS

Trigger values

All the systems discussed take the IOBC trigger value of >30% effect at tier I and II, triggering field work. In practice, this means that all insecticides will inevitably progress to field experiments with at least some species. This has caused considerable concern within industry as there is little agreement about the design and interpretation of such field studies. The system appears to be driven from the "bottom up" in terms of methodology, rather than "top down" in terms of deciding what the ultimate criteria of acceptability or non-acceptability are in the field.

What is an acceptable effect ?

There is no agreement over the acceptability or non-acceptability of a direct pesticide-induced effect on beneficial arthropods. A lack of criteria by which to judge field experiments is the biggest hurdle in this area of testing. Despite repeated calls for this to be rectified, little progress has been made.

Large-scale, long term studies, such as Boxworth, have shown that high levels of input of many different chemicals can result in a slight decrease in the levels of predation due to a mixture of direct and indirect effects (Burn 1989). Effects are particularly apparent on species resident in fields all year round and with low dispersal ability, such as Bembidion obtusum. However, some more dispersive species such as Trechus quadristriatus actually seem to increase at the expense of the affected species, though not sufficiently to replace all the lost predation capacity. How should such effects be interpreted as to what is acceptable and what is not, when the role of individual products is not completely clear ?

An empirical approach currently proposed under the EPPO/CoE system, is to decide a priori that the effects of a toxic standard chemical, yet to be identified, are unacceptable and would result in a harmful classification. The criteria would then be that the effects of the test chemical on a species of concern were significantly less than the toxic standard or not significantly different from control, with sufficient replication and relevant techniques. Indirect effects could be accounted for by the addition of a characterised selective material to the test, however, it is not clear at present how indirect effects may be regulated.

Another empirical approach could be to consider how species respond to known non-chemical perturbations, otherwise known as "the great ploughing debate". This has proved useful in microbiology in setting significant effect criteria for pesticide effects (Domsch, Jagnow and Anderson 1983). It can also be shown that cultivation is deleterious to both the abundance and diversity of soil organisms. Is it therefore acceptable to say that the effects of a pesticide are acceptable if they do not exceed these values ? Finally, I have come to the conclusion that although responses to cultivation can identify some species that are able to tolerate some disturbance in their environment, it is not necessarily a useful criterion for beneficials. Unlike the soil microflora, where generation time can often be measured in hours or days, european beneficial arthropods frequently have only one or two generations per year. Any losses due to cultivation and a number of different pesticide applications are therefore additive within a generation of beneficials, whereas soil micro-flora may only experience disturbance once in every several hundred generations and will have a much higher intrinsic rate of increase to speed recovery. Perhaps the species which "proves" this rule is Bembidion obtusum. This carabid beetle is obviously able to tolerate cultivation as it is frequent in fields that have been cultivated for hundreds of years. However, it is particularly intolerant of pesticides and is usually the most severely affected when autumn or winter treatments have been made.

Ultimately, it would appear sensible not to gather any more additional data from a variety of field experiments but to use the research money and time employed to better understand the population process governing the abundance and diversity of beneficial arthropods, so that we may identify the critical values that we should actually be measuring. A framework within which such critical values can be interpreted is proposed by Greig-Smith (1992).

The importance of methodology

There is a considerable amount of debate in the literature as to the most appropriate methods to be used in assessing the populations of beneficial arthropods. Pitfall traps are the most frequently used and the most frequently criticised method. Catches from properly set pitfall traps are a function of the population density and ground-activity of the species in the field. Necessarily, plant active predators or spiders who sit in their webs catching prey are under-represented in pitfall catches. However, a properly maintained set of pitfall traps will produce a repeatable sample which, because of its ease of handling can be well replicated, producing comparative data for some species. Critics of pitfall traps usually prefer suction samplers. These will produce a more balanced assessment of absolute density, under some conditions, but also suffer drawbacks. The cardinal error of those who prefer these systems to the the exclusion of all others are centered on the assumption that these techniques are absolute; where in reality different species and different life stages are differentially catchable. The catch is highly weather dependent, making the study of medium term affects inaccurate. The catch is not integrated over time and only represents those individuals catchable at the time of the assessment. Because of the considerable additional short-term effort involved in suction sampling compared to some other methods, the ability to replicate is frequently limited. Ideally, a mix of methods is preferable. I have found the mix of pitfall trap and evening sweep-net sampling in cereals to produce consistent and interpretable data, once the suitability of each method is taken into account and it's limitations understood. A similar mix of methods has also proved effective in Brasilian soya under very different climatic circumstances to those found in the UK.

Perhaps the most important point is to ensure that which ever partly imperfect method is used, it is used consistently. One of the biggest concerns in arthropod field trials is the use of poorly trained and poorly supervised staff, often temporary student labour. Additional errors at this stage merely result in an inability to detect differences between treatments, type II errors (false negatives).

Scale

Clearly, for an active species, a transient effect will last for longer on a large plot than on a small one. Duffield (1991) has calculated the size of plot necessary for detecting effects of a different duration (Table 2). Again, the use of plot sizes inappropriate for the effect measured could again lead to type II errors.

TABLE 2. The size of plot needed to detect different duration of effects on Carabid beetles (modified from Duffield 1991)

Duration of effect (days)	0 - 5	6 - 10	11 - 15	16 - 20
Size of plot needed (ha)	0.0017	0.12	1.4	8.4

Replication

A vast amount of data has been amassed on beneficial arthropods. One thing that we should be able to do is to study the variation in such data and to recommend the level of replication necessary to detect the level of effects we seek. This however is rarely done. One of the reasons is that, as discussed under acceptability, there is no consensus view of what level of effect we should be looking for.

The conventional view is that anything less than four replicates is potentially unreliable, anything more is unworkable. There is some truth in this, little additional statistical power is gained in experiments with more than six replicates and a majority of this is gained with the first four. One of the problems in this area of work is still the use of unreplicated experiments from which conclusions are drawn for the environment at large.

Design

When considered together, it is clear from the preceding sections that any meaningful experiment must be both on large plots (1 - 10 ha) and be replicated at least four times with a minimum of three treatments. This makes the minimum short to medium term experiment within the range of 12 - 120 ha, with data only representative of one year and one site. Anything which attempts to address larger scale effects must be an order of magnitude larger and conducted at a number of sites in different years. Such experiments are impractical to manage for a single product as the expense and practical difficulties of constraining all other variables are so large as to be practically insurmountable.

SOLUTIONS

To further pursue the answer to fundamental questions of the significance of effects on beneficial arthropods using trials of current size and design would appear to follow the law of diminishing returns. To move to a larger scale would add nothing but expense and confusion. The solution would appear to be to take stock of the existing biological data and to attempt to model what it is so difficult to measure in the field. Taking an analytical approach, Brown and Sharpe (1988) have investigated the role of different population processes in the survival or extinction of arthropod populations exposed to pesticides. However to investigate more specific points, a simulation approach is necessary. A suitable starting point for such a model is the metapopulation dynamic model of Jepson & Sherratt (1991). From this it should be possible to define what are the critical factors affecting the relationship between some beneficial species and pesticides and in the process identify what areas of these species' biology need to be better understood. I believe that we should proceed in such iterative cycles in an attempt to refine our approach to this subject and to move on our current experimental designs. Failure to do this will, I fear, result in a failure to find a solution to this ultimately soluble problem, a regrettable but all too common twentieth century mistake !

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INDIRECT EFFECTS OF PESTICIDES ON BIRDS

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ABSTRACT

Indirect effects of pesticides result from changes to the environment of a species of interest that is itself physiologically unaffected by the pesticide. A growing body of empirical data demonstrates such effects of pesticides. Insecticides primarily affect bird populations by reducing the insect prey base available to the birds. Herbicides affect various bird populations through a variety of pathways, including 1) direct reduction of the food base of granivorous species, 2) reduction in invertebrate abundance by removing the plants the invertebrates depend on for food or habitat, and 3) reduction in nesting cover. Most evidence involves reduced food availability or habitat changes but some evidence shows that interspecific relationships can be changed by pesticide use patterns. The long-term consequences of indirect ecological effects of pesticide use patterns are potentially massive but have been poorly studied and not fully integrated into associated risk assessment.

INTRODUCTION

It has long been known that some agrochemicals, particularly those based on persistent organochlorines, have major toxic effects on birds. Such compounds have been shown to impact bird populations through two pathways: first, though a reduction in survivorship among full-grown birds, and second, through a reduction in the nesting success experienced by breeding adults, particularly where mediated by a chemically-induced interference with egg shell production; eggs laid were then especially thin-shelled and prone to physical damage in the nest. These effects have been extensively documented among predatory birds, for which successive biological magnification of the chemical along the links of their food chains results in high dose rates to the predator. Similar effects have, however, also been recorded in non-predatory birds extensively exposed to organochlorines. Thus in Britain Stock Doves (Columba oenas) - a specialist granivore of arable land - were regularly exposed to organochlorine seed-dressings during the 1950s and their numbers decreased almost ten-fold during that decade, recovering after the removal of these compounds from British agriculture (O'Connor & Mead, 1984).

Such effects are the outcome of direct exposure of individual birds to pesticides. In contrast indirect effects - defined as effects on individuals not due to contact with the pesticide or its metabolites but due to pesticide-related changes in one or more components of their environment - have recently been realized to have as significant effects on bird populations (Potts, 1980; Sheehan et al., 1987; Greig-Smith, 1992). Such effects are particularly insidious in that they can lead to substantial reductions in populations of birds in the absence of any toxicity to the species. Indirect effects may also be very difficult to implicate as the cause of observed declines since measurable residue loads are no longer correlated with the probable impact of the compound (Mineau et al., 1987). Moreover, indirect effects may interact with direct ('toxic') effects. As a result, detection of adverse effects becomes contingent on population monitoring, never the easiest of tasks.

In this paper I discuss the evidence for indirect effects on bird populations due to pesticide-induced changes in food base, in habitat, and in interactions with other species, and then consider the problems in identifying and regulating such effects.

PESTICIDE-INDUCED CHANGES IN AVIAN FOOD BASES

A well-studied case history

The grey partridge (Perdix perdix) provides one of the clearest demonstrations of how a bird population may decrease as a result of the use pattern of pesticides that are themselves not toxic to birds. This species typically nests along the margins of arable fields and the precocial chicks follow their parents through the crop in search of arthropods. Southwood & Cross (1969) showed that recruitment to the population, measured as the juvenile to adult ratio, was highly correlated with the abundance of insects present. Where herbicides had been applied, brood movements in search of food were 3-4 times greater than in untreated fields. Potts (1980) summarized a long series of autecological studies that showed that arthropod abundance was a crucial factor for chick survival and a key element in maintaining recruitment at levels high enough for population balance. However, pesticide use has brought about steep declines in the abundances of three groups of insects in cereal fields - species that feed upon field weeds, polyphagous species that feed on a variety of other insects, and species that feed on fungi - and many of these were favoured foods of partridge chicks. For example, among similar fields each extra plant bug (Heteroptera) per m^2 of cereal crops increased chick survival by 1.5%; each extra leaf beetle (Chrysomelidae) was worth 3%; and each extra sawfly larva (Hymenoptera: Symphyta) was worth 4%. Herbicide use has been responsible for a long-term 50% reduction in the numbers of these groups whilst the direct effects of insecticides were smaller, though as high as 20% in particular crops such as winter wheat. Subsequent experiments (Rands, 1985), in which herbicide and fungicide spray patterns were manipulated along the field margins to promote a reservoir of arthropods, showed conclusively that the reduction in food base was indeed implicated in the observed declines in partridge numbers. Brood survival was markedly greater on the experimental farms where spraying was reduced along the field margins but was unaffected on the control fields.

Indirect effects of herbicide use

Herbicides are used at three stages of cultivations, namely pre- and post-emergence, and during crop cleaning. Pre-emergent herbicides may be particularly significant for species such as the grey partridge since their use inhibits weed development at the time of crop establishment, often assisted by rapid tillering stimulated by heavy nitrogen doses delivered to rapid-growing varieties of cereals. Most weeds never get established, and those that do are eliminated by the application of post-emergent herbicides during the early stages of crop growth. With so few weeds maturing, habitat for arthropod species dependent on these weeds is reduced, impacting insectivorous birds. Herbicidal cleaning of crops comes later in the season, but attacks those weeds that spring up in response to light penetration as cereals approach maturity and lose their lower leaves. These plants thus never set seed, with consequent reductions in over-winter food supplies for granivorous birds. Combined with the effects of early stubble-cleaning and greater use of autumn-sown crops, this results in cereal fields now offering many fewer weeds to winter-feeding birds (finches and buntings, in particular) than in the past, when individual weed species yielded anything from 20,000 to 300,000 g seed/ha (O'Connor & Shrubb, 1986). Root crops are similarly now much poorer as winter feeding areas for these species since pre-emergent herbicide use at their sowing now eliminate much of the weed biomass that used spring up between the widely-spaced rows of these crops. Yellowhammers (Emberiza citrinella), reed buntings (E. schoeniclus), chaffinches

(Fringilla coelebs), house sparrows (Passer domesticus) and tree sparrows (P. montanus) are among the species that occur in smaller numbers where arable weed seeds are less abundant (ibid.).

In Potts' study the reduction in the food base for partridge chicks was itself an indirect effect, in that the herbicide use reduced the abundance of weeds that formed the habitat of the chick prey species. A direct effect of herbicide use on arable weeds has been shown by Green (1978), for skylarks (Alauda arvensis) in eastern England. This species has a rather varied diet for most of the year but in late winter uses one of two major feeding strategies depending on food availability. The preferred strategy is to forage on ploughed land for the seeds of arable weeds which have relatively high energy content. However, where herbicides are used for weed control on sugarbeet crops such seeds are scarce and the skylarks then switch to grazing the lower energy beet seedlings at levels that make the species a significant pest of beet. O'Connor & Shrubb (1986) similarly attributed a sustained decline in regional populations of the linnet (Carduelis cannabina) in Britain to the introduction of herbicides to reduce arable weeds. Since the linnet specializes on the seeds of arable weeds, it is particularly vulnerable to reductions in the abundance of these weeds. The resulting decline in linnet numbers has continued, taking the linnet from the status of a rather common bird on agricultural land to an extremely rare one. Bunyan & Stanley (1983) suggest that other common farmland birds that utilize seeds in this manner e.g. the woodpigeon (Columba palumbus), rook (Corvus frugilegus), and some granivorous passerines - might also be affected in this way. O'Connor & Pearman (unpublished data) analyzed long-term (1950-85) national data on trends in nesting success of some 18 species common on farmland in Britain. They found that most species improved in nesting success with the introduction of restrictions on the use of persistent agrochemicals, a pattern also apparent in North America according to recent analysis of data from the Cornell Laboratory of Ornithology nest record card scheme (G. S. Butcher personal communication). However, in Britain many species showed evidence of decreasing success over the last ten years of O'Connor & Pearman's study, a pattern they attributed to the ecological changes due to modern agricultural management.

Indirect effects of insecticide use

Insecticide use has also been implicated in reductions in the numbers of insectivorous birds in a variety of habitats. In Norway scrub control by herbicides brought about a 30% decrease in breeding bird density on the site, primarily because of the reduction in food (Slagsvold, 1977). The application of the carbamate insecticide Sevin (carbaryl) to the control of gypsy moth (Porthetria dispar) in New Jersey forests was accompanied by reductions of 45-55% in the abundance of forest birds (Moulding, 1976). Some species disappeared completely and numbers and diversity decreased during the eight weeks after spraying and numbers were still depressed the following summer. Canopy insect abundance was markedly reduced but both canopy feeding and ground feeding birds were affected. Moulding also cites several other studies that recorded decreases of 10-16% in bird abundance following applications of organophosphorus or carbamate insecticides. However, in another study the use of organophosphates for gypsy moth control yielded so many dead insects that an overt increase in their consumption by birds was apparent (Stehn et al., 1976) and carbamate use against spruce budworm also resulted in birds feeding on the dead insects.

Indirect effects on wetland food webs

Several authors have expressed concern about the possible effects of pesticide contamination of wetlands (Sheehan et al., 1987; Mineau et al., 1987). The latter authors identify ducks in the prairie potholes of North America as particularly vulnerable to the indirect effects of pesticides. Taxonomically, waterfowl are especially vulnerable to shortage of aquatic invertebrates for food, with the young of many species (especially among the diving ducks) having especially long periods of dependency on such foods. The prairie pothole region produces about 22 million ducks annually, about a quarter of the entire North American production, but is also an area of intensive agriculture. The potholes or sloughs are analogous to islands in a sea of cropland, with many of them being less than 1 ha in size and therefore highly integrated with their environs. As a result, large parts of the waterfowl breeding habitat in the region are directly oversprayed during insecticide applications, especially during aerial spraying. Mineau et al. estimated that about 2% of the Canadian population of diving ducks nesting in the prairie potholes would be within the spray zone during a typical canola pest outbreak. The potential population consequences of this have been demonstrated by Sheehan et al. (1987) who developed a computer simulation model comparing persistence and concentration of pesticides in prairie ponds with levels of toxicity to the aquatic invertebrates present. By incorporating duckling growth they concluded that an overspray with a high hazard compound such as permethrin could reduce macroinvertebrate levels by 90% or more, abundances inadequate to support the growth of mallard (Anas platyrhynchos) or lesser scaup (Aythya affinis) broods of typical size. Such results leave regulators in a dilemma, in that the compounds with lowest toxicity to vertebrates e.g. the synthetic pyrethroids, offer the greatest hazard to the food supply of breeding waterfowl. Amongst those chemicals found to be especially hazardous in this way were azinphos methyl, chlorpyrifos, malathion, and methoxychlor.

Some empirical data in support of these ideas are available. A large part of the distribution of the American black duck (Anas rubripes) coincides with the distribution of the eastern spruce-fir forest. Many millions of acres of this forest are sprayed with insecticides during treatment of spruce budworm (Choristoneura fumiferana) outbreaks, typically (since about 1970) using short-lived chemicals such as carbamates that are not acutely toxic to vertebrates but that may be toxic to aquatic invertebrates in lakes accidentally over-sprayed. Experimental addition of carbamate insecticides to a lake in Maine led to reductions (relative to a control lake) in the abundance of macroinvertebrates and mallard and black duck ducklings on the treated pond then spent more time searching for food than did birds on the untreated pond (Hunter et al., 1984). Large scale run-off or accidental spraying of the lakes might therefore be expected to have population-level effects on such waterfowl, paralleling the processes documented for partridge populations by Potts (1980). Concern about such large scale effects has led to recent experimental investigation of these issues (C. Grue personal communication). In one experiment ethyl parathion was applied aerially and in normal doses to a sunflower crop. Despite the pilot attempting to avoid over-spray of the wetlands, local air movements led to contamination of the water in sufficient amounts to kill off the invertebrates present. As a result the number of mallard ducklings present fell by 96% within 4d of the original application. Thus both experimental and observational data indicate that prairie wetland birds are very vulnerable to indirect effects of pesticides.

Mineau et al. (1987) remark the lack of empirical data as to the likely effects of herbicides on waterfowl. Herbicides are of even greater concern than insecticides for several reasons. First, the use of herbicides is usually far greater than insecticides, Second, the herbicides target plants, so that overspraying of prairie sloughs is likely to reduce the density of the macrophytes on which herbivorous invertebrates in the sloughs depend for food, thereby reducing invertebrate densities. Finally, certain compounds, notably 2,4-D, atrazine, simazine, and trifluralin, can be significantly toxic to key macroinvertebrate groups in the duckling diet.

Summarizing, a variety of pesticides have been shown to reduce the invertebrate prey base of insectivorous birds by ecologically significant amounts, either through toxicity to invertebrates or because the chemical destroys plants that provide invertebrate food or habitat.

HABITAT CHANGES INDUCED BY PESTICIDES

Herbicide use has been implicated in changes in habitat structure that reduced the carrying capacity of a site for birds. Dwernychuck & Boag (1973) reported the effects on ducks of 2,4-D treatment to improve grassland in Alberta for agriculture. Following application, nesting ducks initially crowded together into the remaining patches of broad-leaved vegetation but nest densities declined by 75% over the long-term. O'Connor & Shrubb (1986) noted that the disappearance of reed buntings from cereal fields in Hertfordshire, England, followed the herbicidal removal of weeds that formerly provided nesting sites and suggested that a larger regional decline in the numbers of this species in England was closely enough correlated in space and time with the use of cereal herbicides to consider the two causally linked.

In the cases just cited the habitat changes constituted instances of habitat modification rather than habitat destruction. However, several cases of larger-scale habitat destruction by use of herbicides have been documented in North America, particularly within sagebrush habitats. Thus in central Montana Brewer's sparrows (Spizella breweri) decreased sharply in sagebrush treated with 2,4-D (Best, 1972) and in a Wyoming study had largely disappeared two years after the treatment (Schroeder & Sturges, 1975). The significance of these results is more than merely as case histories: sagebrush covers about 87 million acres in North America and is extensively treated with herbicides for conversion to grazing. Changes on this scale have almost biogeographic consequences for a species as closely coupled to the habitat as the Brewer's sparrow. Other examples of indirect effects of herbicides come from forestry studies, with species totals and individuals both decreasing in a Californian pine plantation treated for brush removal (Savidge, 1978) and with red alder removal from Oregon clearcuts accompanied by decreased densities of nesting birds (Morrison & Meslow, 1982). Again, the extensive acreage of such forestry practices has major conservation implications for bird species affected.

There have been few attempts to estimate the population consequences of indirect effects of such large-scale use patterns. In one such attempt Mineau et al. (1987) incorporated the results of Dwernychuck & Boag (1987) into a computer model of normal herbicide use in the Canadian prairies. They calculated that the resulting loss of nesting cover would bring about a decrease in total duck production of 7-18%, rising to perhaps 30% if the reduced cover additionally allowed increased predation.

Summarizing, herbicides provide a very effective means of manipulating the vegetative component of bird habitats. Sufficient evidence has now accumulated to show that the avian carrying capacity of these habitats can be significantly reduced as a result and that these effects have the potential to be nationally or regionally significant.

INTERACTIONS WITH OTHER SPECIES

Rather few examples of pesticide-mediated interactions between species have been recorded, in part no doubt because of the difficulty of documenting the simultaneous occurrence of two indirect processes. Bracher & Bider (1982) report a case in which many dead insects accumulated on the ground following aminocarb applications to control spruce budworm. As a result many more birds than usual started feeding on the ground and this in turn attracted mustelids (Mustela spp.) in to prey on the birds. Bird mortality thus increased as a consequence of the normal insecticidal properties of the chemical.

ASSESSING THE INDIRECT EFFECTS OF USE PATTERNS

Two distinct issues arise when considering the indirect effects of pesticides. The first concerns the extent to which regulatory decisions should incorporate indirect effects of pesticides, the other concerns the environmental consequences of the use patterns that develop as pesticides do the work they were designed to do.

Regulatory reviews of individual chemicals are expected to take account of unintended side-effects of each compound and historically have focussed on adverse direct effects on non-target organisms. This manifests itself in the "hazard = toxicity x exposure" model typically used in North American risk assessments (Urban and Cook, 1986). What is emerging from the research reviewed here is a growing need to recognize that adverse effects may also manifest themselves through indirect pathways and that their cumulative effect on the environment increasingly needs consideration. There are actually two separate issues involved here. The first is that chemicals may have adverse effects that arise along pathways that the chemical was not intended to follow, as when a herbicide incidentally possesses insecticidal properties. The second is that the elimination of, or reduction in, the size of pest species populations by use of pesticides may have consequences for the environment, even though the pesticides may be absolutely safe for all except the target organism.

Unintended toxic side-effects of pesticides are possibly adequately taken into consideration within current regulatory practices in the United States and in Europe, at least in comparative evaluations (Greig-Smith, 1992). Given two equally effective herbicides, each without toxic effects on birds, but one of which has an insecticidal side-effect, it is clear that the adverse effects of the latter can potentially be larger. This point might then be validly factored into the environmental cost-benefits of that chemical.

A philosophically different issue arises, however, when one considers the environmental consequences of using a safe insecticide to kill insects on which one or more bird species depend. From a species conservation standpoint it matters little whether a bird population goes to extinction because the adults were poisoned by a toxic chemical or whether they starved to death because a non-toxic insecticide eliminated their insect food base. This dilemma is one well-considered by regulatory authorities neither in the United States nor in Britain, though it is beginning to emerge as an issue in developing broader risk assessment and management strategies (Greig-Smith, 1992). In effect, this issue turns on the question of the extent to which the agricultural community can be allowed to deploy, in the interests of agricultural production, practices that impinge on society's larger interests, here the maintenance of biodiversity.

In evaluating this question, there is much to be said for recognizing that the scale and duration of the effects of agricultural practices are distinct aspects of the indirect effects of interest here (Greig-Smith, 1992). Indirect effects may be quite extensive in spatial scale, as the end-result of treating a widely grown crop, for example, but if their effects are transient they pose little concern for conservation. Where the effects are persistent, however, the populations affected are permanently held to low levels and may then either be cumulatively driven towards extinction or may be simply more vulnerable to stochastic extinction at low numbers. Given the enormous scale on which some crops are grown either nationally or regionally, any associated permanent reduction in ecological resources critical for individual species is undesirable.

Cost-benefit analysis of proposed or current chemical use pattern, currently a major tool in the US Environmental Protection Agency's regulatory approach to pesticides, can be extended to accommodate these ideas, though there are practical problems in determining the population consequences of the indirect effects involved. On the one hand, case-histories such as those considered here provide evidence as to processes but cannot demonstrate population changes. On the other hand, monitoring of population status through such schemes as the US Fish and Wildlife Service's Breeding Bird Survey or the British Trust for Ornithology's Common Birds Census documents changes but not causes. Monitoring detects the results of some mixture of the direct and indirect effects of pesticide use, often further confounded with land management changes that do not involve pesticide use. Separation of these effects one from another poses major analytical problems that may in fact be insurmountable. O'Connor & Shrubb (1986) emphasize that many farming practices take place within distinct agricultural regimes or suites of mutually supporting practices that cannot persist independently of each other. For example, direct drilling of cereals is impractical without the use of herbicides to control weeds. Ultimately the consequences of indirect effects of pesticides on bird populations may prove to be an environmental problem that cannot be addressed in their own right. They may instead need to be considered as merely one component of the larger problem of the environmental consequences of human ability to manipulate, and in particular to bring about very rapid changes in, land use patterns on landscape and regional scales.

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A LINK COLLABORATIVE RESEARCH PROGRAMME ON TECHNOLOGIES FOR SUSTAINABLE FARMING SYSTEMS

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ABSTRACT

A research programme on sustainable agriculture, which is funded jointly by industry and government, is described against the background of the LINK Scheme which currently involves some 400 companies and 200 academic research groups. The scope and objectives of the programme are outlined and, by way of example, a project on Integrated Farming Systems is described in some detail. This project sets out to integrate the latest results coming from research into an arable production system which will optimise the use of inputs compatable with production needs, profitability and environmental concerns. The project involves comparing the integrated system of production and conventional practice for profitability, energy balance and environmental effects.

THE LINK SCHEME

LINK is a government scheme which supports collaborative research between industry and the research base (academia, research institutes and organisations). There are now 30 programmes with a value in excess of £380M, involving approximately 400 companies and 200 academic research groups. It is the first truly government-wide initiative of its kind, and so far has active participation from eight government departments and four research councils.

Its key objective is to help the UK exploit developments in science and technology, bridging the gap between industry and the research community. This will create a channel through which academic research can be influenced by the needs of industry, thus increasing the likelihood that results will be utilised. LINK provides a framework for research, and a portfolio of well focussed programmes within which partners from a variety of backgrounds can come together in collaborative projects.

Government support at 50% is offered for suitable projects, with the remainder coming from industry, and participation of small and medium-sized enterprises is the actively encouraged.

The LINK initiative is overseen by a steering group comprising representatives from industry, academia and sponsoring agencies. LINK programmes support long-term enabling or generic research rather than curiosity-driven work or specific product development. The initiative is intended to help whole sectors of industry or communities of interest, rather than individual companies or groups. The LINK Steering Group is particularly keen to encourage a two-way flow of ideas and information, with industry's needs feeding into programmes of basic research. LINK is effective in drawing industry and the research base more closely together.

Most LINK programmes are run by a Programme Management Committee (PMC) whose membership is drawn from industry, academia (including research institutes and organisations) and Government.

Most programmes also have the support of a technical co-ordinator or programme manager, who plays a key role assisting potential applicants in 'project building'.

The LINK Steering Group approves new programmes in key areas of science, technology and engineering. Individual PMC's are then responsible for the approval of projects within these programmes.

LINK PROGRAMME: TECHNOLOGIES FOR SUSTAINABLE FARMING SYSTEMS

Technologies for Sustainable Farming Systems is a new LINK programme which was started in 1991 to run for three years. The present value of the Programme is £4.4M, of which half has been committed by the sponsoring Government departments (MAFF, SOAFD, DTI) and the AFRC.

Rationale of Programme

Farming is facing a difficult future with increasing constraints on profits as Governments seek to decrease the costs of agricultural support. At the same time farmers are being asked increasingly to protect the countryside and to minimise the adverse effects of farming on the environment. The adoption of less intensive production systems can help to meet these concerns but there is a very real risk that such production will be less profitable. There is, therefore, a need to foster research into technical developments which will help develop systems of farming better attuned to future needs but which will still be sufficiently profitable to be sustainable.

The term 'sustainable farming' can mean different things depending on the circumstances, and is therefore extremely difficult to define in a general sense. 'Sustainable' does, however, encompass three main elements, namely economic viability, conservation of the means of production and having acceptable effects on the environment. The aim of the programme is, therefore, to stimulate research in new technologies which, when combined with knowledge of agricultural ecosystems, would create viable production methods which will meet both environmental and consumer requirements.

Nature of Industrial Support

The nature of this programme differs from many of the other LINK programmes in that support comes predominantly from farmers and growers rather than from companies supplying the agricultural industry. The organisations representing the farmers are the various commodity levy bodies who have authority to administer research programmes from the levies paid by producers and processors.

In order to justify their investment to levy-payers, the levy bodies need speedy economic gain from their research programmes. Therefore, many of the research projects supported through levies are of a directly applied nature. However, farmers and growers are aware also of the need to support research work in its earlier stages, and of the need to take account of the potentially harmful environmental effects of their production systems. It is the research into technical innovation, and the integration of this into new production systems to help meet these needs, which is being funded by this LINK programme.

Scope and Objectives of the Programme

The Programme seeks to utilise research in a range of sciences to investigate technical innovations for their potential as new practices in agriculture. The following priority areas have been identified:

techniques that will lead to lower costs of production while maintaining profitability;

making production methods responsive to consumer preferences and sensitive to environmental needs;

control of crop pests by manipulating ecosystems and novel methods of pest control;

optimising the use of agrochemicals;

the latest diagnostic techniques for disease detection;

manipulating leaf canopies for maximum photosynthetic metabolism;

identifying and propogating desirable genetic characters;

spatial analysis for quiding machine operations;

novel conservation methods for animal feed stocks;

innovations in animal management systems;

Exploitation

A principal aim of LINK Programmes is to obtain the maximum commercial use of research results. Intellectual Property Rights have to be agreed between the collaborating partners prior to the commencement of a project.

SUSTAINABLE FARMING SYSTEMS PROJECTS

Nine projects have, so far, been approved and received funding. They are all due to start during the 1992/93 financial year.

LINK: TECHNOLOGIES FOR SUSTAINABLE FARMING SYSTEMS

PROJECTS STARTING IN 1992/93

Spatially selective treatments in agriculture

Parasites of seed weevil and pod midge

Integrated farming systems

Improving the welfare and meat quality of pigs

Integrated nitrogen nutrition for wheat

Decision models for the use of fungicides on wheat

Molecular detection/diagnosis of blackcurrant reversion virus

Mode of action of fungicides

Whole crop cereals

The largest of these projects is the multi-site, arable Integrated Farming Systems project.

Integrated Farming Systems

The Integrated Farming Systems project seeks, in part, to compare the profitability and environmental effects of integrated and conventional farming practices. The project is funded by the Ministry of Agriculture, Fisheries and Food and the Scottish Office, Agriculture and Fisheries Department on the one hand, together with the industrial partners - the Home-Grown Cereals Authority, Imperial Chemical Industries and the British Agrochemical Association. It is hoped that other industrial partners will join.

Background

During the past decade output values for agricultural products have decreased progressively in real terms, while at the same time input costs have increased. There has been a consequent squeeze on margins. This generalisation is particularly pertinent in the arable crop sectors. There is downward pressure on CAP support prices for budgetary (cost of subsidies) and international (GATT/export subsidies) reasons. Such pressures are expected to continue and possibly intensify. The recent reform of CAP takes much greater account of the environmental impact of farming on the countryside.

The adoption of organic farming is, and will continue to be, an extreme response to such pressures. The system is made viable only if the premia obtained for organic products offset the reduced yields. Such premium payments arise only if consumer demand exceeds supply. It seems that, although organic farming will continue to grow during the next decade, it is unlikely to supply more than 10% at most of the UK farm output.

Response to the prevailing pressures by the majority of farmers will be dependent upon many factors, including the relationship between fixed and variable costs on individual farms. On some a continuation of high-input, intensive farming will be essential if they are to remain economically viable. On others a reduction of inputs to optimise output will be the only option. The need, overall, will be to ensure that the systems adopted will produce adequate food supplies for the nation, by methods which are acceptable to the consumer and environmentally, whilst ensuring profitability and sustaining rural communities.

High-input farming practices, which have evolved over the last 25 years, have resulted in major changes to the structure and the degree of specialisation of farms in the UK. Specialist arable farms in the eastern counties produce the majority of arable crops, and use most of the pesticides and fertilisers applied in the country. For such farms it would be particularly difficult to revert to, say, mixed farming, because of the capital investment and additional labour required. For these reasons, a much more likely development is the reduction of inputs to the specialised farming systems which exist now.

However, simply cutting back on agrochemical inputs, without modifying husbandry practices, has potentially serious consequences. Crops receiving high levels of nitrogen, but denied full protection by fungicides, are likely to be uneconomic unless varieties and husbandry techniques appropriate to low-input situations are developed. Systems which integrate cropping sequences, husbandry techniques (such as delayed drilling, mechanical weeding, minimum cultivations and use of cover crops), disease resistant varieties and limited agrochemical use are potentially commercially viable and environmentally more acceptable. Such integrated farming is being researched in several other EC countries, but differences in climate, farm structure and cropping sequences make it unlikely that results from continental work could be applied directly to UK conditions. Consequently, it is important that work on integrated farming systems is done in the UK, which is why this project has been supported under LINK.

Data from previous research have yielded qualitatively useful information to aid the design of an integrated arable farming system, but they will not give quantitatively reliable information on which to base decisions. Experimental work is necessary, therefore, to develop an arable farming system which integrates the best scientific knowledge to achieve acceptable levels of output and profitablity with acceptable levels of agrochemical input.

<u>Objectives</u>

1. To integrate the latest results coming from research into an arable production system which will optimise the use of inputs compatible with production needs, profitability and environmental concerns.
2. To make valid comparisons between the integrated system of production and conventional practice for profitability, energy balance and environmental effects.
3. To investigate scientifically the interactions between component parts of the systems.

<u>Definitions</u>

Conventional Practice

Crop husbandry which maximises profitability using external inputs applied within permitted limits to overcome constraints on production.

Integrated Farming Practice

A crop husbandry system which maximises profitability with a different balance of inputs, and aims to achieve environmental benefits.

Sites

The experiment is located at six sites, five in England and one in Scotland:

1. Institute of Arable Crops Research/Royal Agricultural Society of England - Sacrewell, Huntingdonshire
2. ADAS - Boxworth, Cambridgeshire
3. ADAS - High Mowthorpe, North Yorkshire
4. ADAS - Rosemaund, Herefordshire
5. Game Conservancy Trust/Southampton University - Manydown Estates, Hampshire
6. Scottish Agricultural College- Pathhead, Midlothian

The sites selected constitute a good sample of climatic zones, soil types and agronomic practices in the main farming belt of the UK.

Rotations

The basis of the experiment is a five-course rotation with crops chosen to be appropriate for the locality and soil-type of the site. Each course of rotation is represented in each of the five years, and there is a baseline year at the start of the project. Set-aside will be included in both the conventional and integrated rotations, to represent typical cropping sequences resulting from the CAP reforms. The exact details of the form and position of set-aside are still being discussed in the light of the rules of the scheme, as they become known.

Design

Comparisons are by half or quarter fields (paired plots), one half managed on an 'integrated system, and the other according to conventional practice. The experiment is partially replicated within sites.

Crop Husbandry

The details of husbandry practice are being decided by a small team composed of site leaders with Mr A W Pexton (NFU) as adviser. All husbandry will at least be to the Code of Good Agricultural Practice.

Assessments

A wide range of measurements and samples are being taken to enable the effects of the two main approaches to be assessed. These include:

Weed and weed-seedbank surveys

Routine monitoring of pests and diseases

Environmental monitoring in the form of pitfall trapping and D-Vac sampling of selected species, autumn sampling for pH, P, K, Mg and O.M.%, and autumn and spring assessments of soil mineral nitrogen

Crop growth as shown by weekly crop inspections during the main growing season, autumn and spring plant population assessments, and yields from defined areas.

Profitability as shown by the gross margins for each crop in each system

In addition, other assessments will be done if more funding becomes available. These would include harvest indices for each crop, analyses of grain and straw for nutrient offtake, earthworm and more detailed invertebrate monitoring, detailed floral studies in field margin and crops, and evaluation of interfield grass banks.

One of the intentions of the project is that it should form a 'work-bench' onto which additional studies can be bolted. Suggestions for additional work are, therefore, very welcome - provided they come forward with the backing of industry.

<u>Benefits</u>

These will arise from the successful development of techniques and farming systems which maintain profitability for producers by environmentally accepable means, which also meet consumer requirements. The expected outcome will be:

- reduced energy inputs
- enhanced biological diversity
- optimised use of pesticides and nutrients
- integrated alternative control measures for insect pests, diseases and weeds
- enhanced rural environments
- increased protection of water supplies