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Working Group:
Use of Pheromones
and Other Semiochemicals
in Integrated Control

MATING DISRUPTION:
BEHAVIOUR OF MOTHS AND MOLECULES

Proceedings of a conference
held 8-12 September 1986 at the
Landes-Lehr- und Forschungsanstalt für
Landwirtschaft, Wein- und Gartenbau,
D-6740 Neustadt an der Weinstraße

Editor: Heinrich Arn,
Convenor of the Working Group

Introduction

Insect pheromones were considered as potential pest control agents long before they were chemically identified and synthesized. In 1940, the German entomologist Bruno Götz concluded from his field experiments that is was possible to control the two grape tortricids, *Eupoecilia ambiguella* and *Lobesia botrana*, with the sex attractant produced by the female. Now the synthetic sex pheromone has been registered in the Federal Republic of Germany and in Switzerland to control the first of the two species, not by mass trapping, as originally proposed, but by mating disruption as established for the pink bollworm and a number of other insects.

For many pheromone researchers in Europe this seems to be the breakthrough we have been hoping for and perhaps the signal for developing other applications we have proposed and investigated. On the other hand, disruption has failed in some cases for unknown reasons. Even where it is successful we don't fully understand the mechanisms. However, the grower will want to know under what conditions the method will or will not work. This means that we still need a better knowledge of the mechanisms of disruption and, more practically, what the dispensers should contain and where and when they ought to be placed for best results.

The Working Group on the Use of Pheromones and Other Semiochemicals held a conference in September 1986 under the title "Mating Disruption: Behaviour of Moths and Molecules". It took place at the Agricultural Research Station of Neustadt an der Weinstrasse, the site of extensive grape moth disruption trials. The abstracts and miniposters in this booklet were prepared before the conference and circulated to the participants as a basis for the discussions. For publication as a bulletin, some of the papers were updated by the authors.

Neustadt is located *ante portas* of a huge centre of chemical industry. BASF Aktiengesellschaft has invested a major effort in the development of pheromones. We are grateful to scientists and administrators of this company, not only for the strong financial support, but also for their active participation in the demonstrations and discussions during this conference. We also thank people in Neustadt for their excellent organization and overwhelming hospitality.

Wädenswil, in the spring 1987

Heinrich Arn

PERSPECTIVES ET PROBLEMES DE LA LUTTE PAR CONFUSION

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Il y a une dizaine d'années que l'expérimentation de la technique de lutte par confusion sexuelle contre les Lépidoptères nuisibles aux cultures et denrées stockées a débuté en Europe de l'Ouest. Depuis, 13 espèces au moins ont fait l'objet d'essais d'importance variable : de l'essai ponctuel sur moins de 1 hectare à l'essai pluriannuel sur quelques dizaines ou centaines d'hectares. Au total, une dizaine de types de formulation différents ont été utilisés dans une centaine d'hectares.

Cette expérience acquise, presqu'essentiellement en verger et en vignoble, a permis de définir progressivement une méthodologie générale pour les essais. Elle concerne leur mise en place et l'appréciation des résultats, c'est-à-dire des doses de phéromone émises et de l'efficacité pour la protection de la culture.

Par ailleurs, à partir des essais réussis, on peut dégager quelques recommandations générales pour la conduite de la lutte par confusion et mieux en cerner les limites :

- aire traitée suffisamment vaste et isolée des sources de contamination extérieure ; le cas échéant, création d'une zone tampon.
- population d'adultes assez faible impliquant la connaissance de la situation au départ et sa surveillance durant la période de lutte ; si nécessaire diminution préalable de la population par la lutte chimique.
- composé phéromonal présentnt les caractéristiques requises (composition, ratio des constituants, pureté...).
- dose de phéromone émise constamment suffisante, ce qui implique des contraintes au niveau de la formulation, du nombre d'applications et du dispositif de diffusion. Ce dernier point est bien mis en évidence par le renforcement des diffuseurs sur les bordures.

Pour 6 espèces (Cydia pomonella L., Cydia molesta Busck., Anarsia lineatella Z., Synanthedon myopaeformis Borkh., Adoxophyes orana F.v.R., Eupoecilia ambiguella Hb.) de bons résultats ont été obtenus dans certaines conditions. Les doses de phéromone efficaces qu'il faut diffuser varient de 10 à 60 mg/ha/h selon les espèces. Compte-tenu des caractéristiques des formulations et des périodes à couvrir cela représente 40 à plus de 200 g/ha pour une saison. L'homologation de la méthode a été accordée pour C. pomonella en Suisse et E. ambiguella en République Fédérale d'Allemagne.

Ces perspectives encourageantes ne doivent pas nous faire oublier les échecs et les insuffisances. Si dans bien des cas les causes n'ont pas pu être établies avec certitude, l'analyse de l'ensemble des essais suggère des améliorations possibles et souligne certains problèmes posés pour une application de la technique de lutte par confusion :

- technologie des fabrications, notamment la mise au point de meilleures formulations et essais de modification des constituants des attractifs utilisés.
- toxicologie des phéromones.
- adoption de procédures spéciales d'homologation.
- définition de règles simples de réalisation des applications. Les cultures jeunes, les parcelles non homogènes, celles de dimensions réduites, les vergers avec des arbres de haute taille nécessitent des études particulières.
- intégration de la méthode dans un programme global et cohérent de protection phytosanitaire de la culture (protection intégrée).
- adaptation des systèmes de commercialisation et de vulgarisation. Le coût de la lutte doit être compétitif, ce qui recouver de nombreux aspects.

Par ailleurs, le développement des recherches sur le comportement des insectes est indispensable pour : comprendre comment intervient la rupture des communications à distance, déceler les causes d'échec, développer des essais avec des composés non phéromonaux, essayer d'agir sur les séquences du comportement à courte distance.

Several years of experience with the mating disruption technique for control of the European grape moth Eupoecilia ambiguella Hbn.

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Abstract

Since 1980 field trials on mating disruption of E. ambiguella have been carried out by the phytomedicine department of the LLFA Neustadt in cooperation with the BASF company.

In the first year of experimentation hollow fibres from Albany International were used, beginning from 1981 the Hercon system (three-layered pheromone dispensers) was applied.
In the beginning, the experiments were carried out on several plots, each of about 5 ha size, since 1984 on a coherent area of about 120 ha. - This expansion of the field trials rendered possible to examine the efficacy of mating inhibition on topographicly different areas and especially at different population levels.

The pheromone quantities used in the years 1982 to 1985 varied from 10 to 150 g Z-9-DDA (2,6 % E) per hectare, the number of pheromone sources from 50 to 1000 per hectare (handapplication) and 10.000 per hectare (application by helicopter). The pheromone effectiveness was checked as follows:

1. Control of disorientation of male moths using pheromone traps;
2. Dissection of female moths (caught in bait traps) to look for the presence of spermatophores;
3. Checking for larval attack;
4. Special experiments.

In each case disorientation amounted to 98 - 100 %. Yet, these good results could not always be confirmed by infestation control, which revealed different pheromone effectiveness dependent on the site of the treated plots: whereas in areas with low or moderate population levels good results were obtained with a pheromone quantity of about 25 g Z-9-DDA and a number of sources of about 180/ha,

this combination did not succeed in plots with higher population pressure (a survey on population levels was possible by the use of bait traps). By increasing the pheromone amount and/or the number of pheromone sources per hectare, larval attack could be reduced in these areas below the damage threshold (with the exception of two plots only). Moreover, the percentage of unmated females in bait traps amounted to 80 % (versus 15 % in the control area). These results were obtained with handapplicated dispensers in the 2^{nd} generation in 1985. The application of miniflakes by helicopter in the 2^{nd} generation 1984 proved a failure. According to the present results we suggest an amount of 50 g Z-9-DDA and 500 sources/ha for mating inhibition of E. ambiguella.
In the Federal Republic of Germany the mating disruption technique is registrated by the Biologische Bundesanstalt (the authority for registration)since March 1986 for use against E. ambiguella in the 2^{nd} generation. - The investigations on the optimum pheromone quantity and number of pheromone sources necessary for a succesful treatment of the 1^{st} generation are not yet accomplished.

In laboratory tests mating of E. ambiguella was prevented completely by the use of synthetic pheromone substances and the role of population density for the success of the confusion technique was shown. These tests and special experiments with tents (occupied by different numbers of moths) confirmed the observations made in the field trials.

Mating disruption in field populations of the grape berry moth *Eupoecilia ambiguella* (Hb.)(Lep. Tortricidae, Cochilini) with Z-9-dodecenyl acetate

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Mating disruption trials were made in two vineyards, each of four hectares, in 1983. A total of 150 pheromone dispensers per hectare (25 g pheromone) were attached to wires, grape-sticks or arched canes at the beginning of May to coincide with the first generation. At the beginning of July, to coincide with the second generation, dispensers were distributed at the same rate by helicopter. The use of helicopters facilates the rapid distribution of dispensers over large areas, particularly where vineyards are on steep slopes. The activity of male moths was monitored by pheromone traps and larval attack was assessed, both within and outside the test fields. In both generations only occasional single moths were trapped and the larval attack was below the economic threshold level (first generation: 10% of inflorescenses attacked, second generation: 5% of grape bunches attacked). In the marginal area of one trial plot a moderate attack was observed, probably due to the immigration of mated females from neighbouring fields.

On the basis of this promising result the confusion method was tested on an area of about 75 hectares in 1984. For the first generation dispensers were distributed by hand and by helicopter. For the second generation dispensers were distributed by helicopter only but applicatin rates of both 25 and 50 g per hectare were tested. Manual application of 25 g pheromone dispensers proved effective for up to four weeks, 90% od field caught females examined beeing unmated. However because of cold weather the flight of the moths was retarded, and larval attack on inflorescenses was late and heavy. Helicopter distribution of pheromones gave insignificant control with the first generation. However, in the second generation only 2,4% of the grape bunches were attacked in the plots treated with 25g pheromone and 1% in those with 50%, respectivly, attack in control plots was very low at 7,4%.

In 1985 further trials were carried out with doubled rates of pheromone (50 g/ha). Two plots, one of 9 and one of 30 ha were used and dispensers (150/ha) were distributed by hand. In the smaller plot the test ended on the 17th of May, when out of a total of 55 field caught females, 29 were found to be fecundated. The second test was terminated on the 28th of May when 8 out of 25 inflorescenses bore a total of 19 fertile eggs all of which were fertile. By contrast all the dispensers used at the beginning of July were this time distributed manually. No males were taken in pheremone traps within the trial areas. Larval attack rates were low at 2,8 and 5,6% contrasting with the controls at 24% and 31%.

Field trials with the first 1986 generation were carried out on the 13th of May, all dispensers beeing manually distributed in a total of 30 hectares. The rate of application (50g/ha) remained the same as in the previous year but the pattern of distribution was changed, a total of 500 dispensers beeing deployed. Larval attack was assessed on the 26th of June, the overall avarage amounting to 11,25%. However in individual fields attack rates as high as 24 and 32 % were recorded. A first full scale application by growers of Kröv/Mosel was planned over a total of 200 hectares for the second 1986 generation. However, the moths emerged early in large numbers and it proved impossible to distribute the pheromones in time.

In spite of an increased application rate of pheromone and dispenser number, mating disruption tests against the first generation failed to demonsrtrate significant control. Tests against the second generation gave more satisfactory results and in consequence this method is now officially registered in the Federal Republic of Germany. Therefore mating disruption can be recommended for the control of the second generation of *Eupoecilia ambiguella*.

BASF Trials programme on the mating disruption technique with sexual attractants: Results obtained with the Grape Berry Moth (Eupoecilia ambiguella)

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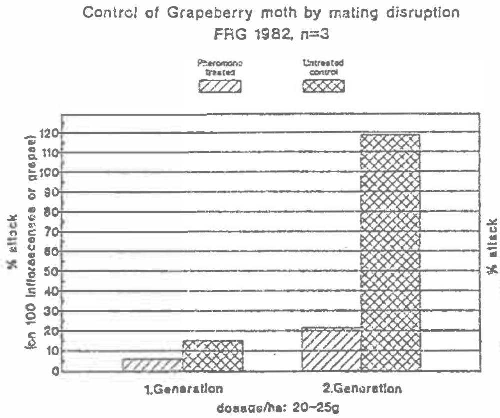
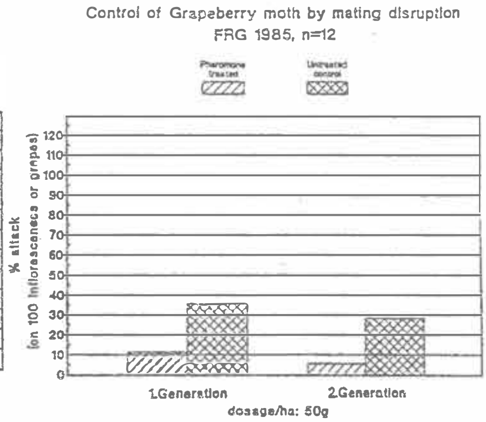
For a number of years BASF has been carrying out trials on mating disruption in insects using sexual pheromones, under conditions as close as possible to those encountered in practice. The insects used in the studies are both species of grape berry moth (Eupoecilia ambiguella and Lobesia botrana), the codling moth (Cydia pomonella), summer fruit tortrix (Adoxophyes orana) and apple clearwing moth (Synanthedon myopaeformis) on apples and the oriental fruit moth (Grapholitha molesta) and peach twig borer (Anarsia lineatella) on peaches.

The experience gained in these trials as regards dosage, number of applications and site differences resulted in the production of commercial recommendations for the method for the control of the second generation of Eupoecilia ambiguella.

The method is now registered for use in the Federal Republic of Germany on the second generation and the first use on a commercial scale took place this year.

A selection of trials results demonstrate some difficulties that can arise with E. ambiguella.Different conditions during the flight periods of the 1st and 2nd generations lead to variable results: whereas the vines form a closed leaf canopy at the time of flight of the second generation, which retains the pheromone atmosphere within the crop, at the flight time of the 1st generation the stand is open and the pheromones can be dispersed on the wind, so that the necessary concentration is difficult to maintain. This can clearly be seen in the results of 1982 and 1985, when, concerning degree of efficacy, poorer results were obtained with the 1st generation (In the central and northern wine-growing areas of the Federal Republic of Germany the threshold of damage caused by the 1st generation is in the region of 10-12 %, that for the 2nd generation 5 %). Control of the 2nd generation was better than that of the 1st generation. The 1982 results, and others, show, however, that the pheromone concentration in the vineyard was not high enough, and so the rate used needed to be increased from 25 g to 50 g/ ha. More investigations are necessary to determine how better results can be obtained on average with the 1st generation.





SOME CONSIDERATIONS ON MATING DISRUPTION OF CODLING MOTH *CYDIA POMONELLA* AND SOMMERFRUIT TORTRIX MOTH *ADOXOPHYES ORANA* IN APPLE ORCHARDS

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CODLING MOTH

The available knowledge on mating disruption technique of codling moth is now sufficient to allow its introduction under supervision in the practice. In Switzerland a provisional registration has been granted for 1986 already, even if all problems are till not resolved. Presently the multiplication of practical experiments seems to be the most appropriate way to supply for the needed improvements and to define the limits of application of this control method.

FORMULATION OF THE ATTRACTANT

Both formulations tested in Switzerland (HERCON flakes and rubber tubing) present a half diffusion time between 40-60 days and are susceptible to protect efficiently the attractant from degradation. With 40-70 g of codlemone per ha, distributed in 2-3 applications during the season, the average diffusion amount do not generally fall under 10 mg/ha.h. However further trials are needed to study if the efficiency could be improved by addition of minor components.

SPACING OF DISPENSERS

Inside the orchards a density of 40-50 dispensers per ha is enough to insure a good efficiency, at least in plot larger than 3 ha. However a dense belt of smaller dispensers placed at 4-5 m is required on the borders. Further trials are needed to define the optimal height of placement in the orchards were the trees are tallest than 3-4 m high and when the plantation is not homogeneous.

SIZE OF ORCHARDS

As the failure always appears in the borders, mating disruption technique is now not recommanded in orchards smaller than 1-3 ha. Future experimentation should show if an increase of attractant amount per ha or of sources density could improve the efficiency.

MOVEMENT OF ADULTS

Codling moth is able of moving over relatively big distances. An isolation of at least 100 m from outside sources of codling moth seem to be necessary.

POPULATION DENSITIES

As efficiency depends on population density, mating disruption technique should only be introduced in low or mean populations with the aim to maintain them at long term under the tolerance level. When the populations are too high, it is preferable to lower them previously with chemical treatments.

INTRODUCTION OF MATING DISRUPTION TECHNIQUE IN THE PRACTICE

The time needed for the 2-3 placements of dispensers per season seem to be supportable for the growers. However a particular supervision is required during the first few years until the growers are able to overcome this new control method.

PRACTICAL RESULTS

From 1976 to 1986 mating disruption technique was tested over more than 250 ha of apple and pear orchards in western part of Switzerland. During this period some experimental factors have changed such as the amount of attractant used per ha, the number of applications per season, the size and the isolation of the test orchards. The results are summerized in figures 1 and 2. With rubber tubing dispensers, 70,5% of the 157,6 ha of trials did not receive any curative treatment in summer, 18,1% of that surface was treated once while summerfruit tortrix moth exceeded tolerance level and 11,4% need a curative treatment after failure in mating disruption against codling moth. We obtained about the same results from 1982 to 1986 with HERCON flakes tested over 100.6 ha (fig. 2). With both kind of dispensers we did no more apply any curative treatment against summerfruit tortrix moth from 1983 on, because from that time we solved that problem by using an IGR in spring. During the successive years the proportion of failure in mating disruption against codling moth decreased as we increased the amount of attractant per ha, the number of applications per season and as we renounced to that technique in orchards smaller than 1-3 ha and in those with insufficient isolation.

SUMMERFRUIT TORTRIX MOTH

Mating disruption technique of summerfruit tortrix moth is yet not so far developped as with codling moth. The lack of formulations able to dispense fast enough the two main components of that specie and the generally higher population densities are responsible of that situation. The use of minor components easier to dispense, could perhaps contribute to overcome the problems.

PRACTICAL RESULTS

From 1979 to 1986 mating disruption technique was tested against A. orana over 88 ha apple orchards in western part of Switzerland (fig. 3). During the first years a curative treatment was necessary on 60% to 90% of the trial surfaces. Afterwards this proportion decreased, related to the increasing amount of attractant used per ha.

RUBBER TUBING

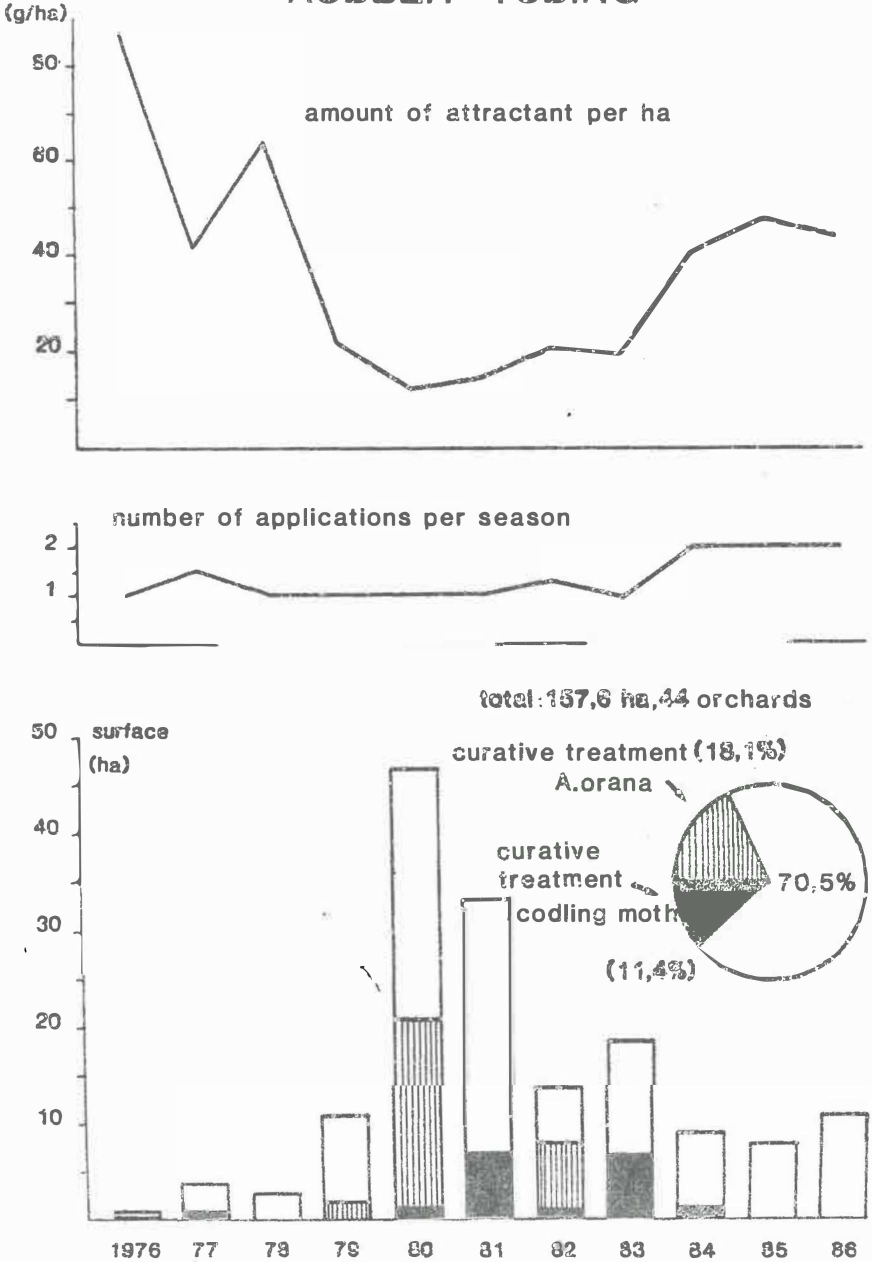

Figure 1

HERCON FLAKES

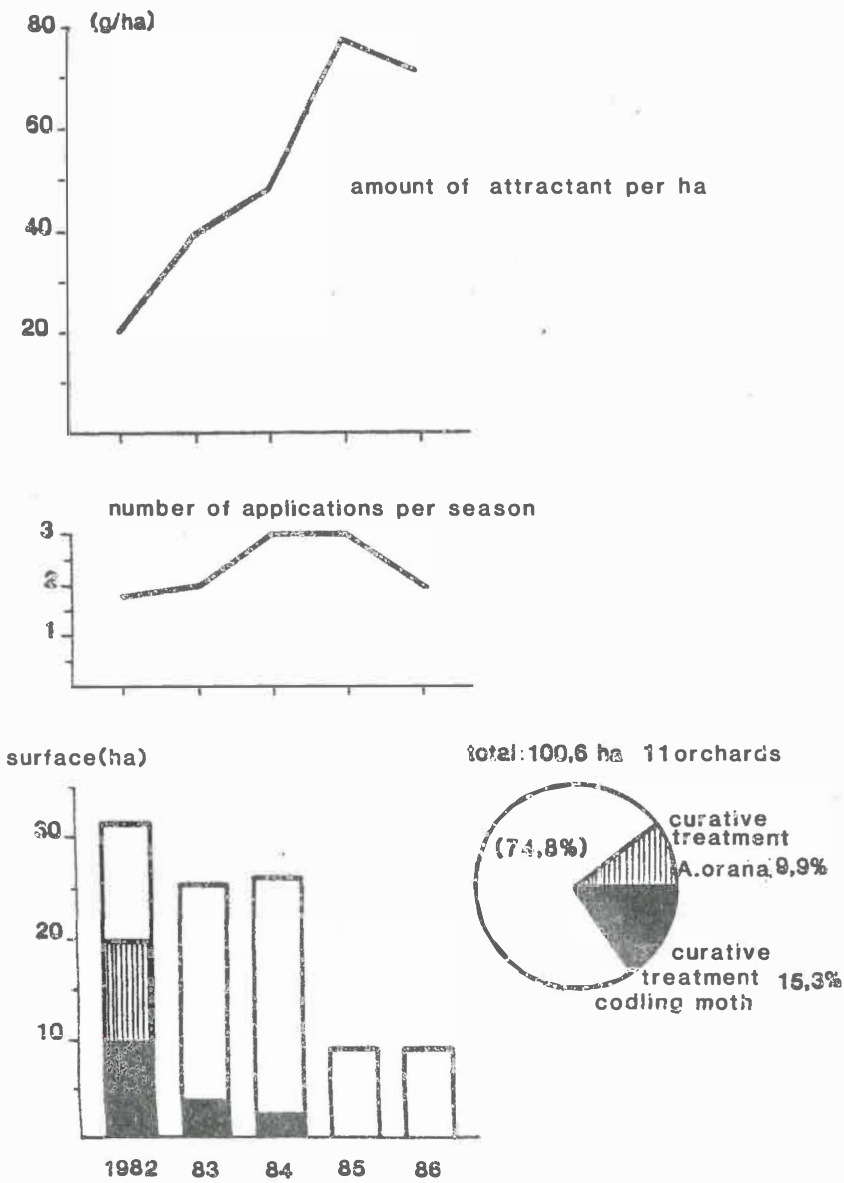

Figure 2

MATING DISRUPTION TECHNIQUE against A.ORANA

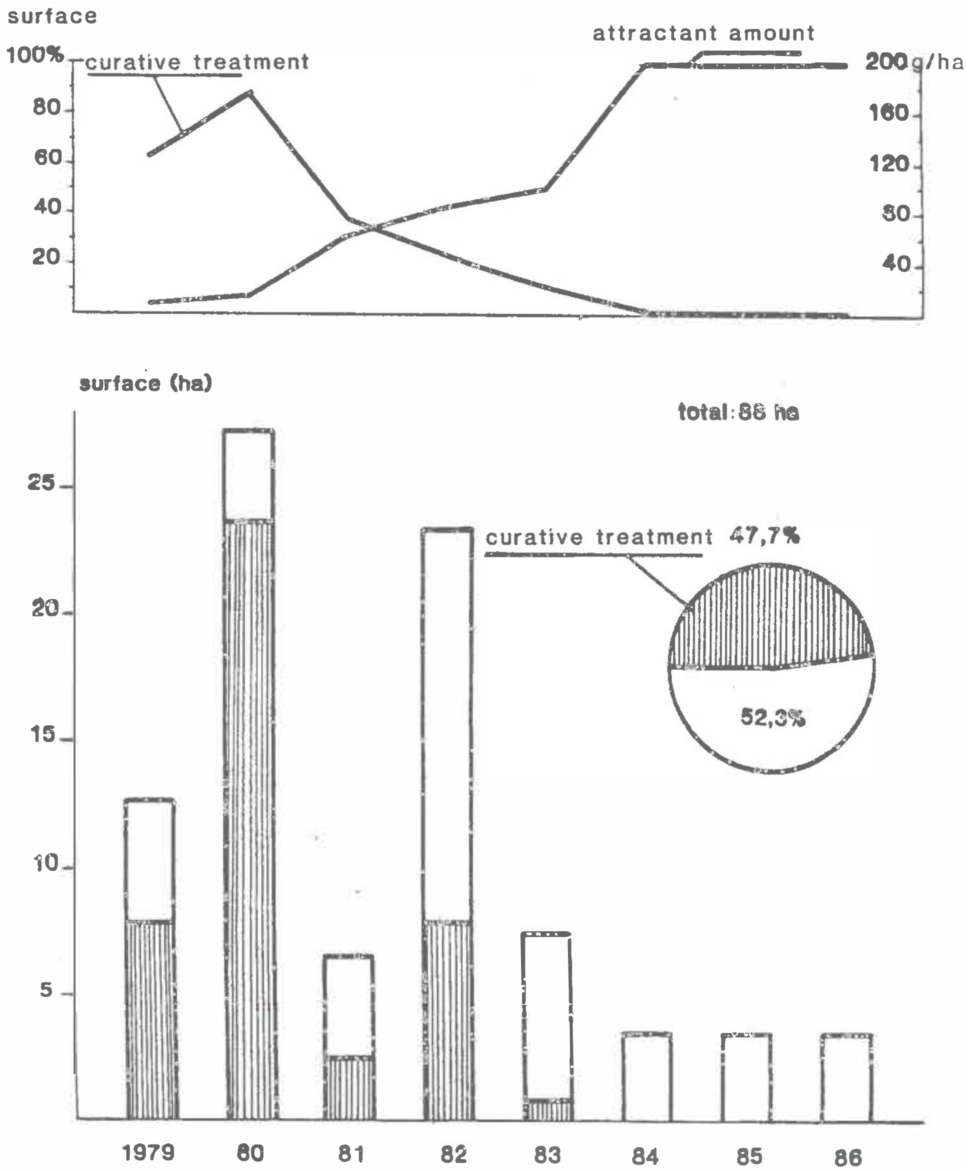

Figure 3

TRAP CATCHES AS INDICATORS OF DISRUPTION EFFICIENCY AND UNIFORMITY OF PHEROMONE DISPERSAL IN CYDIA POMONELLA TRIALS

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Experiences made during 18 disruption tests with Cydia pomonella over 8 years show the following:

Even in successful trials, significant catches were made with pheromone traps placed in the canopy or in border rows. Problems occurred in orchards with a starting population above 2000 full-grown larvae per hectare. In these cases, strong catches were made with traps at eye level, predominantly in the center of the orchard. Similar results were obtained with tethered females.

In some tests, catches were made during the first week, probably because the leaf surfaces took time to charge up with pheromone. Leaves taken from disruption orchards or pre-exposed to pheromone were found to be attractive to codling moths in the field.

The divergent results obtained in one location with orchards separated by only 300 m (Uttwil 1 & 2 in 1984) raise the question whether topographical details can determine the success or failure of disruption.

Location and orchard size (ha)		Year	Larvae per ha in previous year	Ave. catch per pheromone trap in treated orchard					Fruit attack (%)	
				low		high				
				center	border	center	border	untreated	treated	untreated
Molinära	0.9	1979	300	1.5				189	0.3	7.3
Molinära	0.9	1980	450	0.0				253	0.5	17.7
Molinära	0.9	1981	1050	0.0				275	1.0	53.0
Andwil	3.5	1982	300	0.0				70	0.2	3.9
Andwil	3.5	1983	250	0.5	0.9	3.0	22.8	62	2.0	10.3
Andwil	3.5	1984	2700	0.0	4.1	10.0	35.5	118	1.1	6.8
Uttwil 1	4.5	1982	250	0.0				122	0.3	3.9
Uttwil 1	4.5	1983	300	0.0	0.0	3.5	6.2	52	0.7	10.3
Uttwil 1	4.5	1984	800	0.3	1.3	8.3	16.4	144	0.4	6.8
Uttwil 1	4.5	1985	450	0.3	1.0	15.6	12.5	145	1.1	
Uttwil 1	4.5	1986	1200	0.7	2.5	15.3	24.5	56		
Uttwil 2	2.0	1984	250	1.0	2.5	20.7	6.8	144	2.3	6.8
Uttwil 2	2.0	1985	5800	10.5	9.5	98.0	45.0	145	1.4*	
Stegen	3.7	1984	2000	1.3	29.8	26.0		226	1.7	20.0
Stegen	3.7	1985	2400	57.5	32.3			149	4.2	27.7
Stegen	3.7	1986	4500	25.0	33.0			52		
Dietikon	0.9	1985	8000	67.0	21.3				6.3	
Dietikon	0.9	1986	5000	26.0	17.0					

* some rows treated with insecticide

CONTROL OF *Cydia molesta* BUSCK. AND *Anarsia lineatella* Z. IN PEACH ORCHARD BY THE MATING DISRUPTION TECHNIQUE (1982-1986)

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The characteristics of the mating disruption trials for controlling the Oriental fruit moth (OFM) and the Peach twig borer (PTB) in peach orchards of Rhône valley are reported below (see table).

Initially the required dose of pheromone diffused was determined for OFM by the tethered females method and for PTB by analogy. It is a global rate including the diffusion of dispensers located on the borders, while 12-17 mg/ha/h only were diffused inside the orchard. These date were indirectly checked by the observation of injuries subsequent to lower dosages.

The amount of pheromone used for 1 application (42 g/ha) with the Hercon formulations was fixed on the basis of analyzed diffusion rates and especially the lowest dosage diffused in spring.

According to the size and the shape of the orchard the number of dispensers ranged from 110 to 260 ha. Inside the orchard it is placed 1 dispensers /150-250 m² (1 row/2 and on the row 1 tree/3) and on the borders 1 dispenser per tree (spacing 4-5 m). In a practical view the time required to set 1 dispenser/ 2 trees and 1 row out of 2 is not increased.

For OFM, with 42 g/ha the time of Hercon formulation diffusion is 5-6 weeks in spring (april-may early of june) and 4 weeks only for PTB. In summer the diffusion of the 2 pheromones is too rapid and sometimes does not last over 2-3 weeks.

When the amount of pheromones diffused were adequate the results were good : 0-2 % of harvested peaches injured, even on late season varieties. A few days shortage of amounts caused in few orchards 4-23 % of damages in 1984 and 1986.

An increase of the dispenser density and sometimes of the pheromone dosage were necessary to different orchard situations : young, small in size, of irregular shape, unprotected from the wind. This did not always provide effective results.

Encouraging trials were carried on to reduce the rate of pheromone used, the cost and to obtain a reliable control method. They concern : formulation, 1st application delayed to mid-april for OFM, beginning of protection on the 2nd OFM flight, control of PTB restricted to the time before the harvest.

CHARACTERISTICS OF MATING DISRUPTION TRIALS 1982-1986

	Cydia molesta	Anarsia lineatella
Pheromone	Z8 DDA/E8 DDA (92/8)	E5 C10 OH/E5 C10 oAc (87.1/12,9)
Formulation	Hercon flackes dispensers	
Aera of trials 1982 1983 1984 1985 1986	2 ha Avignon 7 ha 16,5 ha } Avignon + St. Marcel 19 ha 19 ha	Trials combined 14 ha 15 ha } Avignon + St. Marcel 15 ha
Required dose do diffuse	20 mg/ha/h...(12-17 inside the orchard)	
Amount used Total Borders	42 g/hax2-5=84-210 .... 15 to 40 % of total.......	42x1-4=42-168
Diffusion time (weeks)	April-may 5-6 June 3-4 July 2,5-4	4 3 2
Devise of dispensers Density inside orchard Density on the borders	.... 110 to 260 dispensers/ha........ .... 1 dispenser / 150 - 250 m²...... 1 smaller dispenser / 1 tree + hedges (if necessary)	
Required time per application	.... 45 to 60 minutes / ha........	

Mating Disruption and Control of the Oriental Fruit Moth, *Grapholitha molesta* (Busck) in California.

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Field trials on the mating disruption and control of *Grapholitha molesta* were conducted in California peach and nectarine orchards during 1985 and 1986. These trials were done in cooperation with BioControl Ltd. of Warwick, Queensland, Australia, and Cooperative Extension farm advisors from seven San Joaquin Valley counties.

Pheromone dispensers in all trials were manufactured by the Shin-Etsu Chemical Co., Ltd., Tokyo, Japan. These dispensers consist of a semi-permeable hollow polyethylene tube 1 mm in diameter, 20 cm. long, and sealed on both ends. Imbedded into one side of the tube is a thin aluminum wire to facilitate tying the dispensers onto tree limbs or twigs. Dispensers, each containing 75 mg. of pheromone (93% Z-8-DDA, 6% E-8-DDA, 1% Z-8-DDOL) were applied by hand (400/hour) at a rate of 1000/ha., placed at heights of 2-3 m. Dispensers were put into orchards in late February, prior to first emergence of overwintered moths, and again in late May. Moth populations were monitored with Zoecon I-C pheromone traps, terpinyl acetate bait traps, and a minimum of 2000 infested fruit at harvest from each treated and check block. Female moths collected in bait traps were dissected to determine mating success in check vs. treatment blocks. Plot sizes ranged from 0.8 ha. to 4.0 ha.; harvest dates ranged from 14 May to 9 September. All conventional (or check) blocks received at least two insecticide treatments for OFM each year, except as noted in the tables.

Application of pheromone dispensers resulted in almost complete (99.9%) disruption of male OFM response to pheromone traps in 5 tests in 1985, and 99.8% disruption in 8 tests in 1986. Collections of moths in bait traps were also reduced in the pheromone treated blocks in both years, except in the Livingston, Modesto, and Escalon plots in 1986. The reason(s) for this reversal of the general trend in bait trap collections is not known. Mating success of female OFM was also consistently lower in the pheromone treatments, although not as low as anticipated or desired in all cases. Two factors may have contributed to this result; 1). small plot sizes in some instances, and 2). greater attraction of mated females over unmated females to bait traps.

The effect of pheromone treatments on OFM fruit infestations at harvest were quite encouraging. In 11 of 13 trials reported here, percent OFM damaged fruit in the pheromone treatments was equal to or lower than in the insecticide or untreated checks. However, fruit damage from other lepidopterous pests was in most cases much higher in the pheromone treated plots, as a result of not using in-season sprays for OFM control. These other pests were primarily *Anarsia lineatella*, *Platynota stultana*, and *Cydia pomonella*.

Table 1. Efficacy of pheromone treatments for mating disruption and control of Oriental Fruit moth in California, 1985 and 1986.

1985		No. OFM Collected- Trap Type[1/]		% Mated	% Infested Fruit	
Location	Treatment	Pheromone	Bait	Females	OFM	Other Spp.
Rio Oso	Pheromone	1	70	47	0.05	1.15
	Check	1176	133	100	0.32	0.17
Yuba City	Pheromone	0	348	40	0.00	2.65
	Check	2124	897	97	0.00	0.00
Sanger	Pheromone	0	9	77	0.10	0.30
	Check	1104	34	96	0.15	0.25
Parlier	Pheromone	0	45	84	0.10	2.40
	Check	2500	347	97	4.00[2/]	0.85
Arvin	Pheromone	2	-	-	0.05	2.75
	Check	1184	-	-	0.40	3.35

1986		No. OFM Collected- Trap Type[1/]		% Mated	% Infested Fruit	
Location	Treatment	Pheromone	Bait	Females	OFM	Other Spp.
Reedley	Pheromone	1	54	74	0.81	0.0
	Check	277	97	96	1.73	0.0
Kingsburg	Pheromone	0	74	83	0.15	1.54
	Check	2387	220	97	1.90[2/]	5.00
Parlier 1	Pheromone	0	310	92	0.90	1.90
2	Pheromone	21	4629	91	14.18	7.78
	Check	9067	6439	97	41.53[2/]	25.23
Exeter	Pheromone	2	631	84	1.08	2.05
	Check	2938	1540	97	1.15	1.08
Livingston	Pheromone	4	735	81	0.23	1.50
	Check	408	392	91	0.0	0.19
Modesto	Pheromone	10	719	77	0.0	0.14
	Check	2368	637	86	0.0	0.20
Escalon	Pheromone	16	3291	89	0.43	1.88
	Check	3218	1151	96	0.0	0.16

1/ Total Number of moths collected during season.

2/ No insecticide treatments for OFM during season.

CONTROL OF GRAPHOLITHA FUNEBRANA L., GRAPHOLITHA MOLESTA BUSCK. AND CYDIA POMONELLA L. BY THE MALE DISRUPTION METHOD

Maria Iacob and N. Iacob

Summary

The effectiveness of this method was demonstrated by the trials against Grapholitha funebrana L. using two rates of pheromone: 180 and 270 mg/hectare/day, diffused from polyethylene microcapillary tubes with 50 mg pheromone, replaced once during the vegetation period. The differences in effectiveness between the two rates were insignificant both as regards the fruit infestation, i.e. 2.12% and 1.75%, respectively, as compared to 32% in the check, and the number of males caught (18 and 6 catches, respectively, and 1234 in the check).

An efficient control of the oriental fruit moth (Grapholitha molesta Busck.) in a peach orchard was achieved by the diffusion of a quantity of 200 mg pheromone/hectare/day, using the same polyethylene tubes. The effectiveness estimated in relation to the attack on fruits and shooots was 94%; the number of the males caught in the pheromone traps placed in the treated plot represented but o.89 of the catches in the check.

In the control of Cydia pomonella L. in apple orchards, experiments was carried out with sex pheromone formulated as microcapsules by Montedison Company. The pheromone was applied in water (low volume: 200 l/hectare) at the rate of 20 g/hectare (400 g formulated produce) in two applications. The second application was made 40 days from the first one. The evaluation of the data on the efficiency of the disruption estimated in terms of the number of the catches in the traps during the observation period (May - September) was 37 and 34, respectively, in the treated plot with pheromone and in the treated plot with Cidial 50L as compared to 159 in the check plot. The high efficiency of the control by the criteria of attack level of the fruits (95.53) is comparable to that achieved with the cmemical control of the pest.

The evaluation of the data on the efficiency of the male disruption method proves that the use of this method in a decisive way in the integrated control of the above-mentioned pest is materially feasible and that these treatments are accompanied by favorable effects in conditions of low infestation.

Investigations on the biology of apple clearwing moth Synanthedon myopaeformis (BORKH.) as basis for its control using the confusion technique.

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The larvae of the apple clearwing moth Synanthedon myopaeformis are difficult to control with chemical insecticides because of their way of living hidden between the bark and the wood of apple trees.

An alternative method of controlling the larvae is to apply pheromones within the framework of the confusion technique.

Experiments to control the apple clearwing moth using the confusion technique were carried out in an apple orchard of approximately 7 ha over a period of 4 years.

The degree of confusion shown by pheromone trap catches was 100 per cent.

After 3 years of experiments damage reduction by confusion method reached 60 per cent in average.

Within the field trials the 3 varieties Golden Delicious, Jonagold and Cox Orange Pippin were observed and the reduction in damage was found to be highest among the Cox Orange Pippin reaching 72,8 per cent.

Counting the empty pupal skins on these trees brought about comparable results.

Lure pots within the confusion area caught 46,3 per cent less moth and the number of mated females was reduced by 71,6 per cent compared with untreated.

In studies carried out on the behaviour of orientation, coloured pheromone traps were used. The number of moths caught in different coloured trapy varied significantly.

In another experiment pheromone traps were set up in the orchard at varying hights. It could be seen that there were significant differences on the number of moth caught.

The behaviour of courtship and mating were analysed in detail.

AN OVERVIEW OF MATING DISRUPTION IN THE ARTICHOKE PLUME MOTH

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The artichoke plume moth (APM), Platyptilia carduidactyla (Riley) (Lepidoptera: Pterophoridae) is the primary insect pest of the globe artichoke, Cynara scolymus L., in California. The APM came from Europe to the United States where it added the cultivated artichoke to its normal foodplants, thistles. The APM populations became a pest problem in 1920's[1,2]. The females lay their eggs under the leaves or by the flower buds. Larvae bore very quickly and burrow deeply into the floral heads: one larva is sufficient to cause serious damage in a globe. There can be three overlapping generations, so all stages occur in each month, with populations higher in the autumn (fall) and maybe in spring too. Insecticides are used to kill female moths in the first few days after emergence when they mate and lay eggs; after that, the larvae are in the globes and are inaccessible to insecticide. Artichoke growers apply a large number of insecticide sprays throughout the year, with the result that some degree of pesticide resistance has developed in the APM and normal biological controls have been disrupted and probably not used at all. Recent harvests have 25-50% of the bud crop infested with the APM. The primary insecticide was methyl parthion, and usually 10 applications are made per season in most years, but there were 20-26 applications in 1976 because the APM population was very large[2]. Several new insecticides are now in use.

It is important to bear the following points in mind: (1) Pesticide resistance is now a real problem. (2) The globe artichokes crop occupies 10,000 acres (4050 ha) in the United States, all in one area of California[2]. (3) The crop is a luxury food and there is a lot of money available to deal with the pest in this crop. (At a guess: in 1981, $300 used for insecticide/acre/season, and this makes $3M for the whole crop. Even in 1975-6 the crop suffered about $13M damage [2].) For these reasons this crop-insect system seems to be ideal for the use of mating disruption.

Virgin females emit a sex pheromone that attracts male moths and a sequence of behaviours coordinate the reproductive activities of the male and female. Males respond to a calling female by a stereotyped courtship and copulation[3]. The pheromone was identified by washing in heptane the excised ovipositors of 3-day old females. One single chemical, (Z)-11-hexadecanal[5], stimulates all the recorded behaviour up to and including copulatory attempts with a model female moth. Although other workers have suggested that there must be a blend of sex pheromones, we have isolated only one chemical.

In all field tests, 100ug of synthetic pheromone attracted significantly more male moths than did traps containing four 3-day old virgin female moths[2,3]. In some, a preliminary test of male confusion, Pherocon 1C traps (with 2.5 mg pheromone in the bait) were used and the traps were surrounded by 16 of the same baits in a 4 x 4 block with 9ft. between baits. There were controls with the centre trap but without the evaporative sources round it. In the first run there was 100% reduction with no males in the centre trap, and in a larger experiments there was 96.9% and 93.8% reduction. With the same set-up, but when the four corner evaporative sources only were used, there was no significant reduction.

The APM sex pheromone, (Z)-11-hexadecanal, was formulated by Albany International in black celcon R hollow fibres and aerially applied at the rate of 54 gm/acre[1]. This was used in some fields with controls (conventional practices) and was effective in controlling the population levels of APM, as evidenced by a reduction in trap catch, mating table activity and infestation levels versus conventional practical check plots. The pheromone was applied by air about every 18 days, from January to August. The insecticide applications, as is conventional practice, were started in March, and repeated at 22 day intervals. After each aerial pheromone application the males trapped from test and control fields were counted. The results were very encouraging (infestation rate of pheromone-treated plants was 4.5% versus 12% in conventionally-treated plants; but infestation in pheromone-treated buds was 2.1% versus 5.3% with conventional practices[1]. However, later in the fall one pheromone-treated field was more damaged (infested buds were 21.5% in pheromonal-treated versus 8.0% in conventional-practice)[1].

APM sex pheromone mating disruption works well under certain conditions, but there trials were conducted in a limited number of fields and for only one year. The single field 'swamped' with aerial pheromone might act as a beacon so that male APMs fly in to it from adjacent fields where they then cause problems. The entire crop would need to be treated aerially with the pheromone. An effective person in needed to galvanise and integrate interested parties such as the Artichoke Research Association, all growers and Albany International (or another firm) in starting the control of APM by using mating disruption and using insecticides for back up control when necessary. It is now a matter for business politics and prayers; hopefully this mating disruption technique will be used, maybe it already has been, but has yet to be published.

Mating disruption aside there is an additional interesting point to note: males of APM and its sibling species, P. williamsii Grinnell (WPM) respond to the same synthetic sex attractant[4]. Both species occur in the same area, with different ~~thistl~~ies as their food plants. Pheromone release by the females is temporally separate: APM emits pheromone during the first half of the night and WPM calls during the second half of the night. When the temporal differences between the two species is experimentally eliminated, the result can be cross-attraction, interspecific courtship, even copulations and transfer to spermatophores[4]. Sex pheromones are clearly implicated in speciation events and these two species may have recently separated.

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MATING DISRUPTION OF THE COTTON LEAFWORM, SPODOPTERA LITTORALIS, MONITORED BY DIRECT NIGHT OBSERVATIONS

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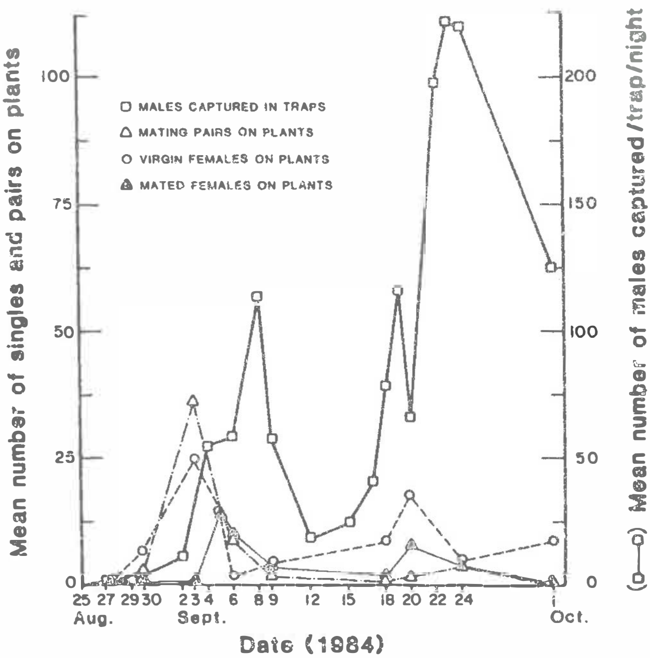
Night observations were conducted in pheromone-treated and untreated plots in which males, females, mating pairs on plants and males caught in traps were collected. Results indicated that emergence of a new population was rapid (8-9 days) and that number of virgin females and of mating pairs reached a peak 5-6 days prior to that of males captured in pheromone traps. Males responded to pheromone traps most actively when the actual virgin female population has already declined considerably (Figure 1).



Dispensers, absorbed with (Z,E)-9,11-tetradecadienyl acetate and located 25 m apart effectively reduced male captures in traps. However, the number of native mating pairs observed in the treated field during the nights was not reduced (Table 1). Few releasers at wide spacing, even with high amounts of the major pheromonal component were ineffective in causing mating disruption of Spodoptera littoralis (1).

Table 1. Number of Spodoptera littoralis single insects and mating pairs collected on cotton plants and number of males captured in traps in pheromone-treated and control plots.

Date (1984)	Days after treatment	Plot type	Singles Males	Females virg.	Females mated	Mating pairs	Males/trap night
3 Sept	-1	Control	27	25	0	36a	11.3 a
		Treatment	19	10	2	28a	10.7 a
5 Sept	1	Control	38	15	15	15a	57.0 a
		Treatment	-	-	-	12a	0 b
6 Sept	2	Control	7	2	10	8a	58.0 a
		Treatment	9	3	5	5a	0 b
9 Sept	5	Control	5	1	0	2a	57.8 a
		Treatment	1	5	4	1a	0 b
18 Sept	14	Control .	15	8	2	1a	79.6 a
		Treatment	6	9	2	1a	0.2 b

On the other hand, a polymeric aerosol formulation containing (Z,E)-9,11-tetradecadienyl acetate (500 release points per ha; total of 75 g a.i./ha; release rate of approximately 3 g/ha/day), effectively reduced male captures in traps and numbers of females copulating in the treated field (Table 2). It seems that many releasers at close spacing are needed for effective mating disruption of Spodoptera littoralis (2).

Table 2. Number of Spodoptera littoralis mating pairs collected on cotton plants and number of males captured in traps in pheromone-treated and control plots.

Date (1985)	Days after treatment	Plot type	No. of mating pairs	♂♂ per trap per night
23 Sept	-1	Control	6a	5a
		Treatment	7a	4a
24 Sept	1	Control	24a	9a
		Treatment	2b	0b
27 Sept	4	Control	15a	6a
		Treatment	3b	0b
3 Oct	10	Control	1a	56b
		Treatment	0b	3b

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RESEARCH ON MATING BEHAVIOR AND ITS IMPORTANCE FOR DEVELOPING TECHNIQUES OF MATING DISRUPTION

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The two principal pathways by which synthetic sex pheromones can disrupt mating area a) by the creation of false trails to lure males away from females, and b) the creation of a 'fog' of pheromone which masks the natural plumes. Resolving which technique is more effective is important since it affects the type of formulation required. Wind tunnel experiments suggest that the false trail technique requires less overall pheromone than the masking technique to achieve the same level of disruption. Success of the false trail technique depends on luring the males away from the females and keeping them occupied so that they do not renew their search for a female moth. In order to outcompete the females it is essential that the natural pheromone blend is used. Selection of the appropriate pheromone concentration is important. Sources of low concentration activate few males, but most of these reach the source (Fig. 1). High concentrations activate most males, but few of these reach the source, presumably due to habituation. For males to be effectively removed from the population by habituation, concentrations must be very high, and a more effective technique might be to 'lure and kill' the males.

Chemicals are availalbe, which 'inhibit' the response of male spruce budworm (Fig. 2), but permeation of the atmosphere with these chemicals does not prevent males from locating the females.

The role of female behavior in the disruption of mating is not usually taken into account but it may be important. Female spruce budworm can detect their own pheromone and are more active in pheromone-permeated air (Fig. 3 & 4). However, of the virgin moths, only the older are affected (Fig. 3), and young females call and mate as readily in pheromone-laden air as in pheromone-free air (Table 1). Mated females are far more active in pheromone-laden air than in pheromone-free air (Fig. 4), and it is possible that this leads to more dispersal, although no increase has been seen in areas of artificially high pheromone-concentration.

Table 1. Reactions of calling female SBW when contacted by male SBW. Percentages of each category copulating shown in parentheses.

Pheromone concentration (pg/m^3)	% Remaining quiet	% Moving away
0	53 (97)	47 (23)
10	63 (89)	37 (38)
100	72 (83)	28 (33)
100	56 (84)	44 (20)

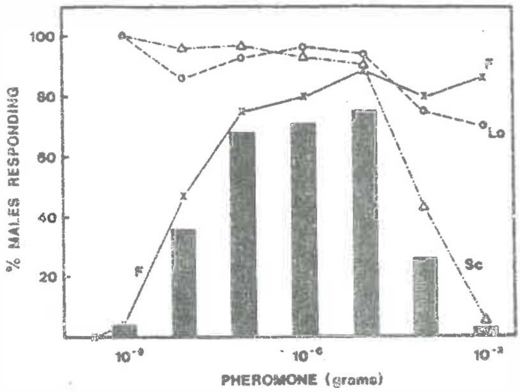

Fig. 1. Response of male spruce budworm (SBW) to different concentrations of pheromone. Histogram = % of total reaching source. F = % total flying; Lo = % F locking on; Sc = % Lo reaching source.

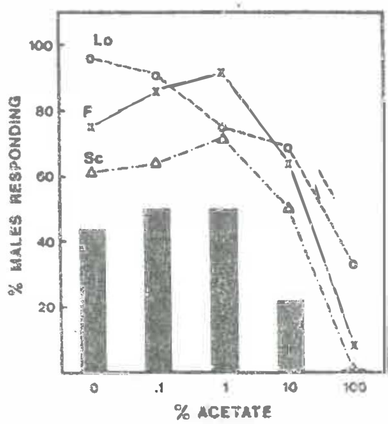

Fig. 2. Response of male SBW to pheromone plus acetate.

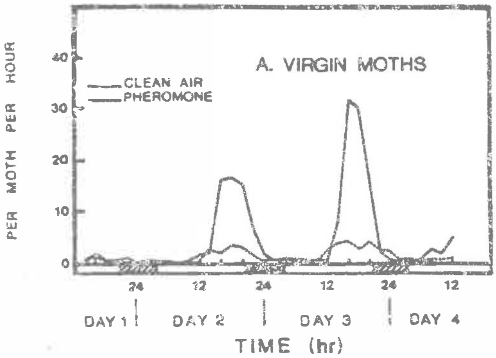

Fig. 3. Flight activity of virgin female SBW in pheromone-permeated and clean air.

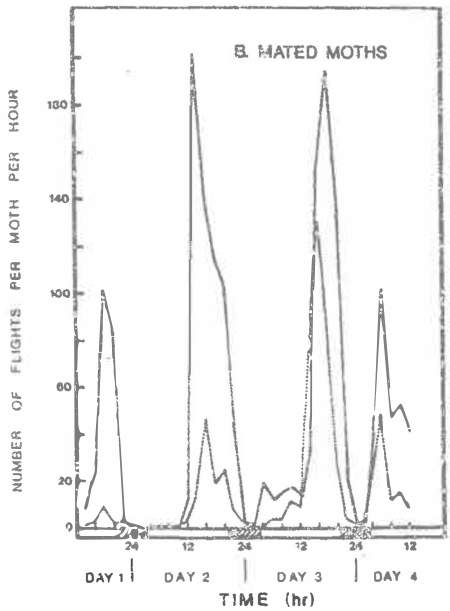

Fig. 4. Flight activity of mated SBW moths in pheromone-permeated and clean air.

Mechanisms of Confusion

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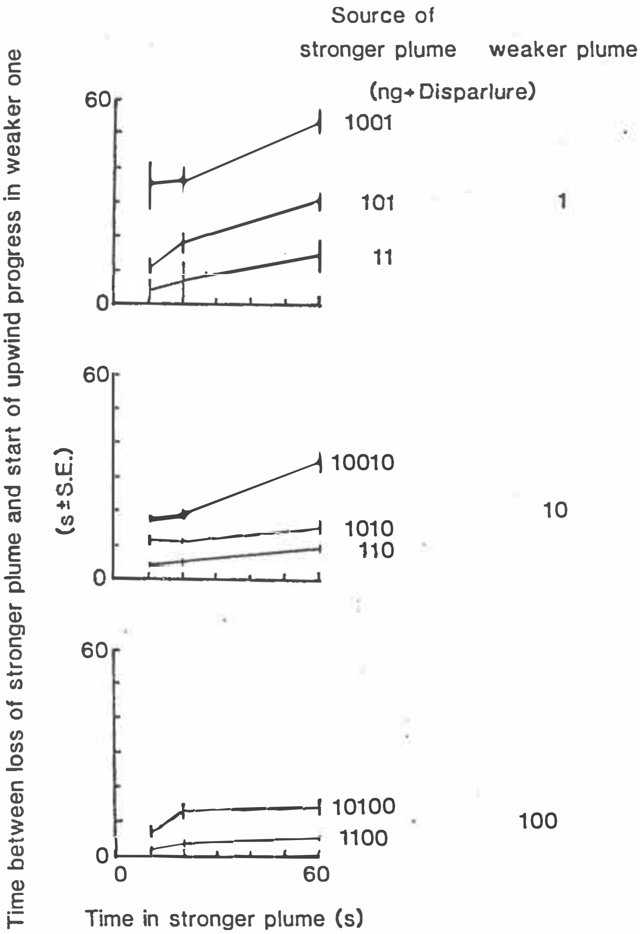
There are several mechanisms postulated by which the "confusion" technique could work. One possible mechanism, first suggested by C. van der Kraan at the O.I.L.B. meeting at Nyon, was examined in experiments in the laboratory and in the field using gypsy moths. The idea was that moths would orient to the source of odour plumes containing higher than the natural concentration of pheromone, they would then become adapted or habituated for a certain length of time, and would not respond to the natural plumes from calling females.

1, Gypsy moth males are habituated or become adapted by high concentrations of pheromone in a plume so that they do not respond to a plume of lower concentration. The duration of this unresponsiveness depends on the time they have been in the higher concentration plume and the concentration difference between the higher concentration plume and the plume they are subsequently tested with (Fig. 1).

2, Electroantennagram recordings suggest that the lack of response is due at least partly to habituation rather than sensory adaptation.

3, Field experiments using plumes marked with soap bubbles show that the lack of responsiveness to a weaker plume after they have been in a stronger one stops males from arriving at the weaker source. This finding has implications to the use of trap catches in assaying pheromone mixtures.

Figure 1.


Source of
stronger plume
weaker plume
(ng + Disparlure)
1001
101
11
1
10010
1010
110
10
10100
1100
100
60
0
Time between loss of stronger plume and start of upwind progress in weaker one
(s ± S.E.)
Time in stronger plume (s)

ZIGZAG FLIGHT AS A CONSEQUENCE OF ANEMOTACTICAL IMPRECISION

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Moths orienting in a pheromone plume use visual information from ground pattern movement to proceed upwind along a zigzagging flight track. Groundspeed and track angles left and right of the wind direction appear to be kept constant if the wind varies. In the concept of "reversing anemomenotaxis"[1,2] it was supposed that moths compensate for the differences in wind-drift by adjusted alterations of their course, and the zigzag structure of this menotaxis was claimed to be caused by an internal -"self-steered"- program of "counterturning".

After having analyzed the orientation behavior of male gypsy moth using a "flight simulator"[3] we found an alternative explanation for the above peculiarities[4]. In this simulator the forces exerted by the moth during tethered flight are sensed and used to control speed, direction of motion and size of a projected ground pattern. The visual situation of the moth then corresponds to free flight with respect to all three axes of translation and their yaw-axis of rotation. Wind can be simulated by superimposing a translatory component to the moving pattern.

In our experiments, the course angle at all wind speeds was scattered unimodally around due upwind, which, in fact, is incompatible with menotaxis. Nevertheless, the distributions of the corresponding track angles were always clearly bimodal. This surprising issue, however, can be explained if only the complex trigonometric relation between course- und track angle is taken into account (Fig. 1). Accuracy in determining the wind direction is a function of the wind speed, the scatter of the course will be larger if the wind is weak, and this in turn will compensate for the smaller drift. The apparent constant track angle within a large range of windspeeds, therefore, is the result of a combination of pure physics (winddrift) and the moth's inability to fly precisely upwind ("noise" superimposed on "basic orientation").

The question of how the wind direction is detected could be answered by manipulating the ground pattern itself (Fig. 2). When only stripes transverse to the wind were offered to the moth, course angles of +55° or

-55° were stable, whereas with longitudinal stripes only, the due upwind or downwind direction was held. Drift causes the images of ground pattern to flow obliquely over the retina. This motion can be resolved in its longitudinal (L) and its transverse (T) component. The moths presented with any of this special pattern types chose a direction in which T was zero. The results, therefore, do not support the assumption that $\sqrt{(T^2+L^2)}$, or any other function combining T and L, is kept constant. Rather, upwind flight is achieved by two independent control circuits. One of which minimizes the transverse component according to a common optomotor response, whilst the other keeps the longitudinal component at small positive values.

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Fig. 1 Density distribution of course angles (α) and track angles (θ) of a 10 min flight of a male gypsy moth (bins 5° wide). Superimposed: theoretical distribution of track angles (θ), if the course angles (α) scatter around due upwind according to a Gaussian density distribution and if only the slope function of α versus θ (lower part) is taken into account. This function depends on the ratio of the moth's airspeed to windspeed (long dashes 2.0; dots 1.4; short dashes 1.1). In the depicted sample this ratio was 1.1 for both, the theoretical and experimental case.

Fig. 2 Transverse (T) and longitudinal component (L) of the apparent ground pattern motion plotted as a function of course angle (α) at different patterns, offered to the moth: complete ground pattern (top), only stripes transverse to the wind (lower left), only stripes in line with the wind (lower right). Density distributions of course angles (α) as measured during 10 min flights of male gypsy moths are depicted below the corresponding slope functions.

Fig. 1

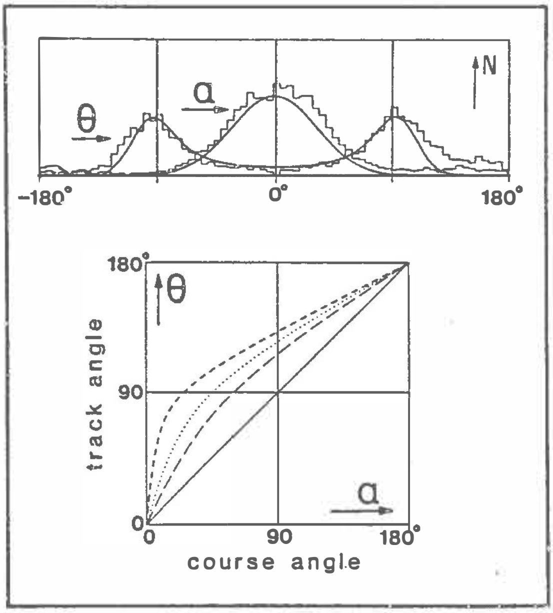
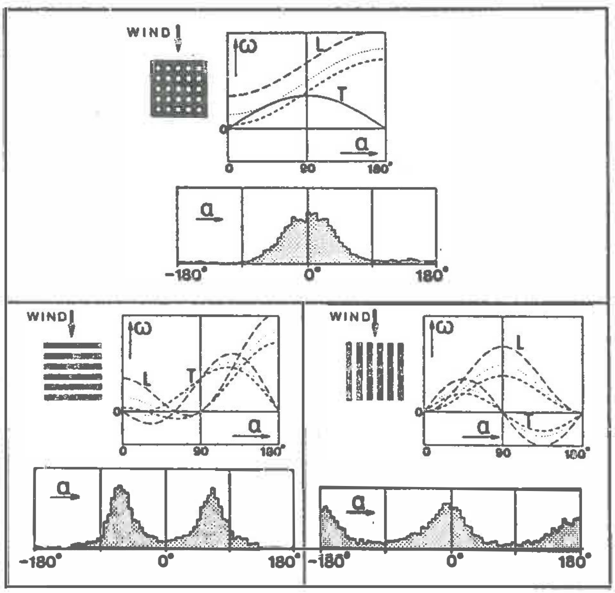

N
θ
α
-180°
0°
180°
180°
θ
track angle
90
0
α
0
90
180°
course angle

Fig. 2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BEHAVIOUR OF SMALL ERMINE MOTHS IN OVERLAPPING PHEROMONE PLUMES

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Studies of male moth responses to pheromone, released in well defined plumes in a fligth tunnel have provided information of great interest, but how relevant is the flight tunnel situation to what actually goes on in the field ? Under natural circumstances numerous plumes from calling females might overlap and these plumes can belong to females of one or more species. Under artificial circumstances with mating disruption you obtain a similar situation. In both cases the overlap of pheromone plumes will affect the ability of males to find mates.

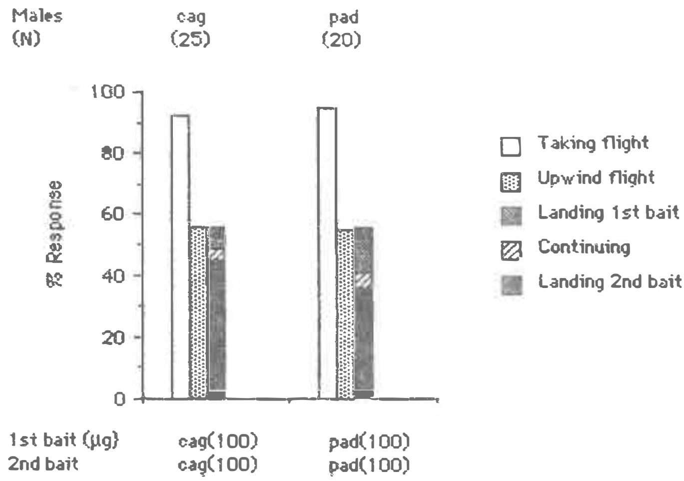
Small ermine moths of the genus *Yponomeuta* generally use delta 11-unsaturated pheromone components. Nearly all of the species have E11- and Z11-14:OAc as primary pheromone components, and the E/Z-ratio and species specific additional components are believed to be of importance for reproductive isolation(Löfstedt & Van Der Pers 1985, Löfstedt et al 1986). In the present set of experiments, the following synthetic peromones (µg applied on rubber septa, Arthur Thomas Co.) were used:

	Y. cagnagellus	*Y. padellus*	*Y. vigintipunctatus*
14:OAc	37	-	60
Z9-14:OAc	-	5	-
E11-14:OAc	2	34	20
Z11-14:OAc	100	100	100
E11-14:OH	-	-	1
Z11-14:OH	-	-	5
Z11-16:OAc	-	400	-

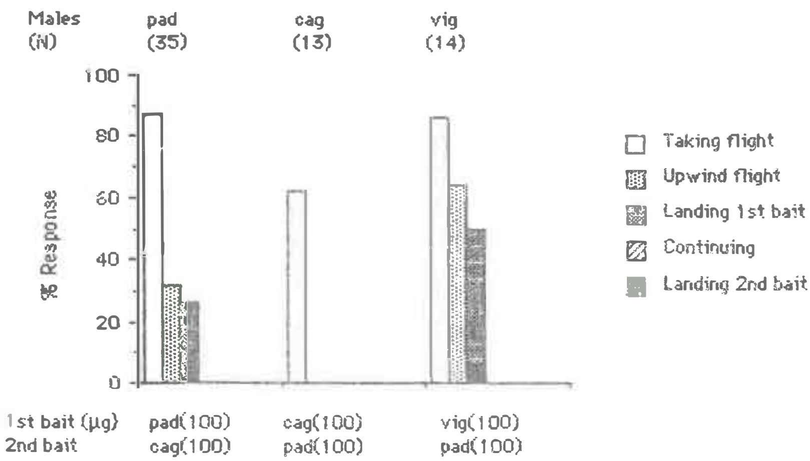
The 100 µg dosage used(assigned on the content of Z11-14:OAc), had been found to be optimal for male attraction in earlier flight tunnel experiments(Löfstedt, unpublished).

I performed some flight tunnel experiments in which a second pheromone source was placed one meter upwind of the first odour source, which in turn was positioned one meter upwind of the point were males were released(For principal experimental design: see Lundberg & Löfstedt, in press). The experimental design was stimulated by the work of Perry and Wall(1984), who showed that upwind pheromone sources interfer with downwind ones in the field, a phenomenon that was investigated experimentally in the flight tunnel as well as theoretically by Lundberg

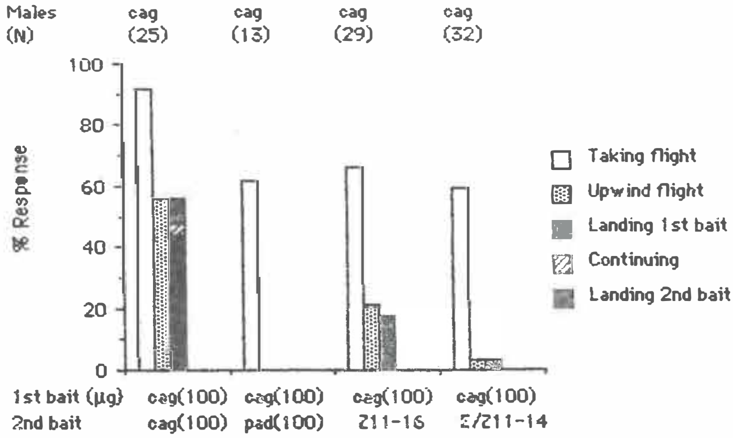
& Löfstedt (in press). We found working with the ermine moth *Y. cagnagellus* that upwind sources can indeed outcompete downwind ones, and that this phenomenon is dosage dependent. If the concentration of the upwind source was reduced to one third of the downwind one, most of the males stopped at the downwind source. I now obtained a similar result with *Y. padellus*:



When a conspecific pheromone was placed in the first position and a pheromone for another species in the upwind one, I found that *Y. padellus* has a more severe impact on *Y. cagnagellus* than vice versa, and that *Y. vigintipunctatus* is not as much influenced by *Y. padellus* as *Y. cagnagellus* is:



What features in the *Y. padellus* pheromone influence *Y. cagnagellus*? Is it primarily the E/Z-isomer ratio, or is it the additional pheromone components ? In new experiments with *Y. cagnagellus* pure Z11-16:OAc and a mixture of E11-14:OAc and Z11-14:OAc(same amounts as in the *Y. padellus* bait) were assayed as upwind baits:



It appears that *Y. cagnagellus* is influenced by Z11-16:OAc but even more by the "wrong" E11/Z11-14:OAc ratio in the *Y. padellus* pheromone.

Y. cagnagellus has a 3-component pheromone with a narrowly defined E/Z-ratio. *Y. padellus* has a 4-component pheromone, and *Y. viginti-punctatus* has a 5-component pheromone. It is then tempting to suggest that species with "simple" pheromones should be more sensitive to "noise" in the communication channel, naturally occuring or artificially introduced with the purpose of mating disruption. Effort to develop commercial systems for mating disruption would then have the greatiest prospects for success if they are directed towards species with "simple" pheromones or pheromones with well defined ratios between compounds. In that case mating disruption might be achieved by two different mechanism; competitive attraction of males to synthetic pheromone sources, and disturbance of the critical ratio between compounds. In contrast disruption of mating in species with multicomponent pheromones, might be dependent on very well defined synthetic pheromone blends, as the males are able to distinguish the pheromone plumes of calling females from an incomplete, artificially applied background of pheromone components.

Löfstedt, C, Herrebout, W.M., and Du, J-W., *Nature* **323**,621(1986)
Löfstedt, C. & Van Der Pers, J.N.C. *J. Chem. Ecol.* **11**, 649(1985)
Lundberg, S. & Löfstedt, C. *J. Theor. Biology*(in press)
Perry, J. N. & Wall, C. *Phil. Trans. R. Soc. Lond* **B 306**, 19-48(1984)

Adoxophyes orana: influence of environmental factors on places of mating and on release rates; consequences for mating disruption.

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Evidence increases that mating disruption in A. orana by application of relatively small amounts of synthetic pheromone (1mg/h.ha) is due to attraction of males to the pheromone dispensers and possibly also to modification of their behaviour there ("confusion").

In this conception the degree of disruption depends on:
I. the degree to which the dispensers compete with the calling females and
II. the degree and duration of confusion that is brought about near the dispensers.

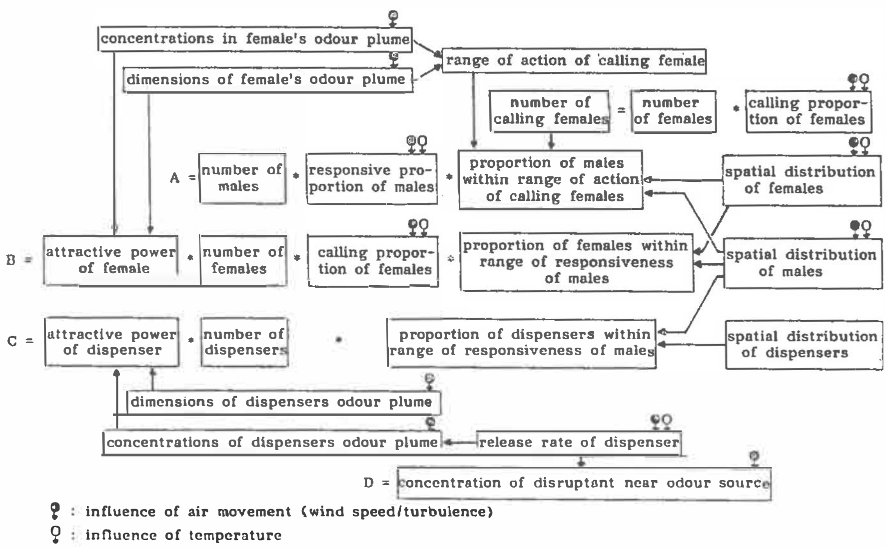
If at a certain place and time
A. is the number of males which actually may respond to the pheromone,
B. is the over-all attractive power of females and
C. is the over-all attractive power of dispensers,
then the number of matings will be proportional to the number of males A and to the share of the female moths in the over-all attractive power of females and dispensers together: $\frac{B}{B+C}$, at least in so far as the position of the males coïncide with the ranges of attraction of females and dispensers.

This coïncidence as well as the values of A,B and C depend, besides on other factors, on environmental factors like habitat structure and micro climate. Of the last temperature and air movement (wind speed, turbulence) are important and may interfere at many levels, as indicated in the scheme below. Air movement acts upon each A,B and C in at least 4-6 ways and temperature does in 2-4 ways.

The concentration of disruptant D near the dispensers, that may be important for degree and duration of confusion, also depends on these factors. See fig.1.

As wind and temperature influence the spatial distribution of both calling and responsive moths, especially the altitude of activity, not only the number of dispensers but also their distribution (height) will determine their competitive power and thus the level of mating disruption. See fig.2.

As the mating rate is proportional to A*B/(B+C), the theoretical relation between mating rate, population density and dispenser density may be computed. See fig.3. The dependence of mating disruption on population and dispenser density and on altitude of population and dispenser distribution, shows up clearly there.



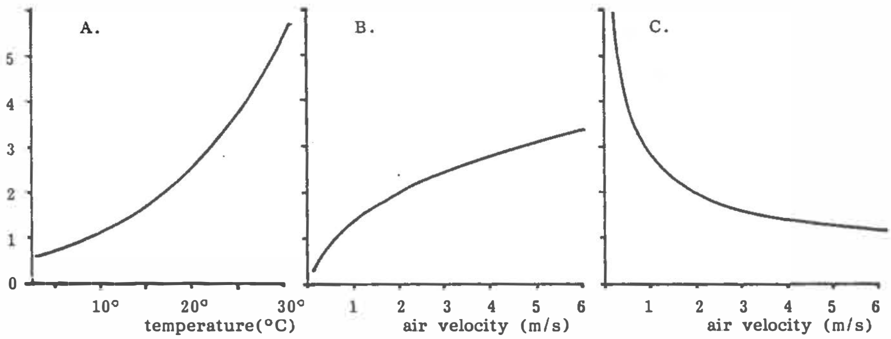


Fig.1. A: Relative release rates of dispensers at different temperatures. B: Relative release rates at different air velocities. C: Relative concentrations near a dispenser at different air velocities. (Measured by recovery of vapor, released from dispensers under controlled conditions.)

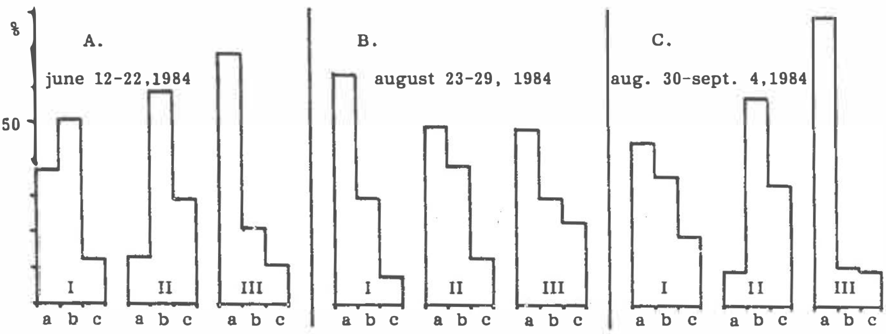


Fig.2. I Relative distribution of catches by virgin female traps.
II Idem by attractant traps, indicating the spatial distribution of responsive males.
III Relative distribution of the ratios of catches by virgin females and by synthetic attractant, indicating the ratios of attractive power of females and dispensers.

Altitudes: a: 275 cm, b: 175 cm, c: 75 cm.

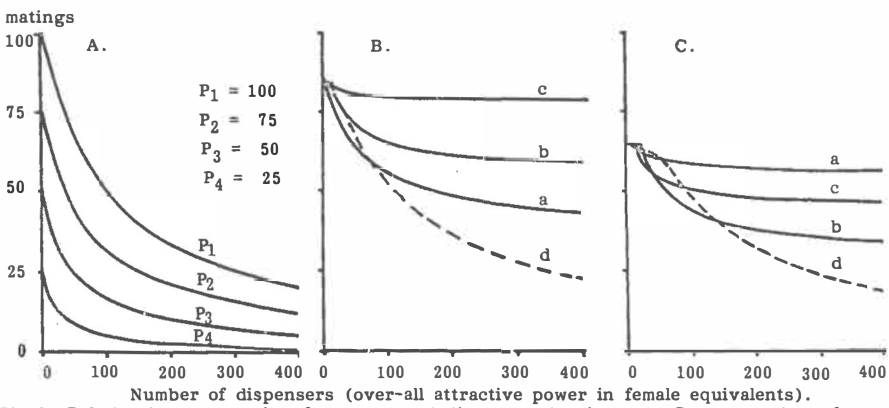


Fig.3. Relation between mating frequency and dispenser density, A: P_{1-4} = number of responsive males = number of calling females. B and C: P = 100, with all dispensers at a: 275, b: 175, c: 75 cm, or d: evenly distributed over these three altitudes, for the two situations indicated in fig. 2B and 2C (the spatial distribution of calling females is assumed to be similar to that of the responsive males).

Orientation disruption and dispersal studies in lighthrown apple moth (LBAM) in New Zealand.

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An organophosphate insecticide resistant strain of *Epiphyas postvittana* Walker (Lep.:Tortricidae) has shown no tendency to spread through an apple growing district of New Zealand[1,2].

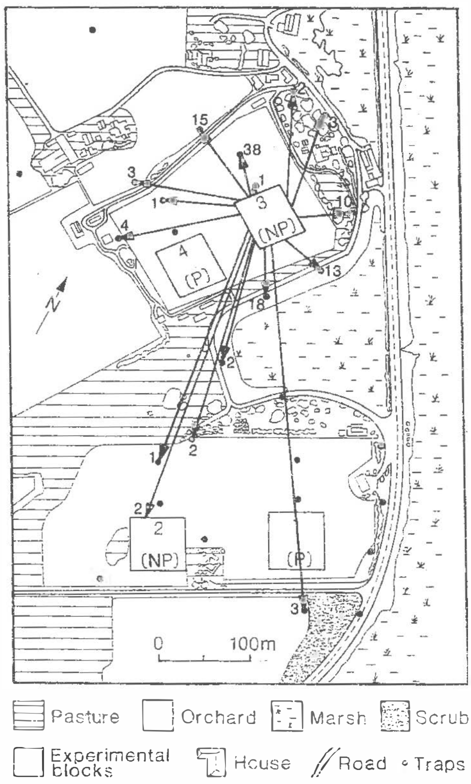
1. A mark-release-recapture and pheromone confusion trial involved releases of 1000 males into 0.3 ha blocks with or without Shin-Etsu Chemical Co. pheromone dispensers (Fig. 1).

2. No males were recaught in pheromone hlocks (1 & 4), but elsewhere 30% were recaptured in female or pheromone baited traps (Table 1).

3. Males dispersed up to 400 m across orchards and scrub, and pheromone did not affect dispersal, which was not directional (only Block 3 is shown).

4. Further work on mating disruption is underway, as part of the resistance management programme which aims to prevent the spread to nearby orchards.

Dispersal of male LBAM from Block 3 (No Pheromone)



Male LBAM trapped after release of 1000 per block

	Blocks 1 & 4 (Pheromone)		Blocks 2 & 3 (No Pheromone)		External Orchard	Scrub
Marked						
Wild	0	0	179	103	17	91
Lab	0	0	71	58	3	3
Unmarked	0	0	11	3	19	103

[1]Suckling, D.M. *et al.* 1984. Insecticide resistance in the lightbrown apple moth : A case for resistance management. Proc. 37th N.Z. Weed and Pest Control Society Conference 248-252.

[2]Suckling, D.M. *et al.* 1985. Pheromone use in insecticide resistance surveys of lightbrown apple moth (Lepidoptera : Tortricidae). *J. Economic Entomology 78*: 204-207.

The Courtship and Mating Behaviour of the Apple Clearwing Moth, Synanthedon myopaeformis

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The apple clearwing moth is a pest of increasing importance in commercial apple orchards. For this reason, experiments to develope pest-control methods to preserve the ecosystem were carried out, along with other biological and ecological studies.

The film illustrates the courtship and mating behaviour of the moths as observed in this research.

The larvae of the apple clearwing moth live under the bark of apple-trees, where their voracious feeding destroys vascular bundles and cambial tissue. Due to changes in the measures employed in the culture and cultivation of modern apple orchards, favourable conditions for these Sesiidae have been created.

Controlling the larvae using chemical insecticides is extremely difficult, if not impossible, on account of their living habits.

The pest population can be reduced considerably by means of a biotechnical process, called the Confusion Method, by which pair selection is interrupted by the application of synthetic female pheromones.

These pests can only be successfully controlled if we have thorough knowledge of their behavioural patterns, thus for this reason, a detailed investigation of the courtship and mating behaviour of the apple clearwing moth was carried out.

The adult Synanthedon myopaeformis is active during the day. It is blackish in colour and has a conspicuous red ring on the fourth abdominal segment.

The female moth begins to release pheromones on the very first day. During this time, she remains motionless on the surface of the leaf, with her abdomen bent from the fifth segment upwards and her ovipositor extended.

The male perceives the pheromone and flies towards the female. Once he has reached her, he hovers above her and positions himself lengthways to her body. In most cases, the male now begins to attack the female's abdomen with stab and thrust-like movements. It could be proved that the red abdominal ring is used as a positioning mark in this procedure. By analysing individual shots, it was observed that the male aims for and hits the red ring with his extremities during his attempts at copulation, whilst he tries to reach the female's ovipositor with his valvae open and extended. If he is succesful, the male will spin around on his own axis, in a flash-like movement, until he has turned a full 180° away from the female. Copulation then takes place. The mating couple will remain in this position for up to 1 1/2 hours.During this time, the spermatophore is transferred, after which the female begins with the oviposition.

The above illustrates the ideal behavioural pattern. Failure can, however, occur at any stage of the process. The female may, for example, fly away from the male at the very first thrust. Often, too, the ovipositor is not reached during the thrusting movements, which last only a fraction of a second, because the male's extremities touch the zones either above or below the red ring. Even when the male has managed to clasp the female's ovipositor , it could be seen in a few isolated cases, that the female attempts to free herself from him.

In every case, however, the male renews his attempt to copulate, provided the female's calling behaviour does not cease, that is, as long as pheromones continue to be released, since only such females are attractive to the male.

Analysis of the film presented us with important evidence about the positioning behaviour of the Synanthedon myopaeformis and gave an indication of the suitability of the Confusion Method in controlling the apple clearwing moth. It was shown that long-range pair selection is effected chemically, by the release of pheromones. For positioning at close range and the copulation process itself, the visual component plays an important role. The latter can, however, be disregarded when the Confusion Method is employed.

BIOLOGICAL OBSERVATIONS DURING MATING DISRUPTION EXPERIMENTS OF *LOBESIA BOTRANA*

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I - MALE ACTIVITY AROUND DISPENSERS

1 - In little plots (10 X 10 m), 64 X 20 mg E 7 Z 9 DDA/plot swarms of male around the disruption dispenser (20 mg). No male flying near the trapping dispensers (0,1 mg).

2 - In large vineyard (10 ha), 600 X 40 mg E 7 Z 9 DDA/ha 3 or 4 males flying around disruption dispenser (40 mg). No male flying around the trapping dispenser (1 mg), no male catched in the sexual trap.

II - FEMALE ACTIVITY IN PHEROMONE IMPREGNATED ATMOSPHERE

In cellophane little sacks with dispensers of 1,10 and 1 000 µg of E 7 Z 9 DDA, all the females are in calling posture as soon as they are removed out of illuminated to twilight conditions.

III - BAIT TRAPPING IN AND AROUND A VINEYARD

(no mating disruption, low population of moths)

	Vineyard										Total
Females	8	6	7	14	2	12	3	1	2	5	60
Virgin	4	0	0	3	1	3	0	1	0	1	13 (20 %)
	peach trees		walnuts		maïze		lupin				
Females	2	5	8	2	3		1				21
Virgin	0	2	1	2	2		0				7 (33 %)

The virgin females can fly out of the vineyard

IV - Distribution of mated females in vineyard and in vicinity (encircled)
(number of mated females and per cent of total in bait traps).

Mating disruption 10 ha

(26 76 %) — 26 60 % — (16 48 %) — (6 43 %)

(0) 33 52 % — 40 56 % — 31 52 % — 50 54 %

♀ : 4 ♂ 10 µg : 1 ♂
10 mg : 26 ♂ 1 mg : 2 ♂
sexual trapping

70 53 % — 28 79 % — 33 43 % — 31 47 % — 21 41 %

22 55 %

prevailing winds — 47 65 % — (13 41 %)

28 67 %

(11 73 %) — (29 74 %) — (5 83 %)

Check plot 2 ha

(5 100 %) — 18 80 %

10 91 %

♀ : 52 ♂ 10 µg : 6 ♂
10 mg : 154 ♂ 1 mg : 156 ♂
sexual trapping

18 90 %

10 100 %

(3 100 %) — (6 43 %)

mated females are present in center of the 10 ha.

V - Mating disruption with compounds other than the main component

In laboratory : reduction of mating in 5 days (100 µg)

E 7 Z 9 DDA 70 % — Z 9 DDA 38 % — DDA 0
E 7 DDA 8 % — E 7 E 9 DDA 44 %

	Sexual trapping 6-19 to 7-15	8-24 to 9-10	Damages/ha ♀ in bait traps 7-15
E Z E 9 DDA 60 g/ha	5	59	149
E 7 Z 9 DDA à 95 % 16 g/ha	0	2	60
E 7 Z 9 DDA à 80 % 115 g/ha	0	6	47

Z 9 DDA and E 7 E 9 DDA have disruption effect, but lower than E7 Z 9 DDA.

BIOLOGICAL ACTIVITY OF Z9-DODECENYLACETATE FOR MATING DISRUPTION OF LOBESIA BOTRANA

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Two species of microlepidopterans are dangerous pests in grapes: the grape berry moth (Eupoecilia ambiguella) and the grape vine moth (Lobesia botrana).

Our aim is the control of both pests by means of species specific pheromones utilizing the mating disruption technique.

Z9-Dodecenylacetate (Z9-12OAc) is the main pheromone component of E. ambiguella. The direct control using this odour has been proved to be a practical method. (NEUMANN et al. 1986).

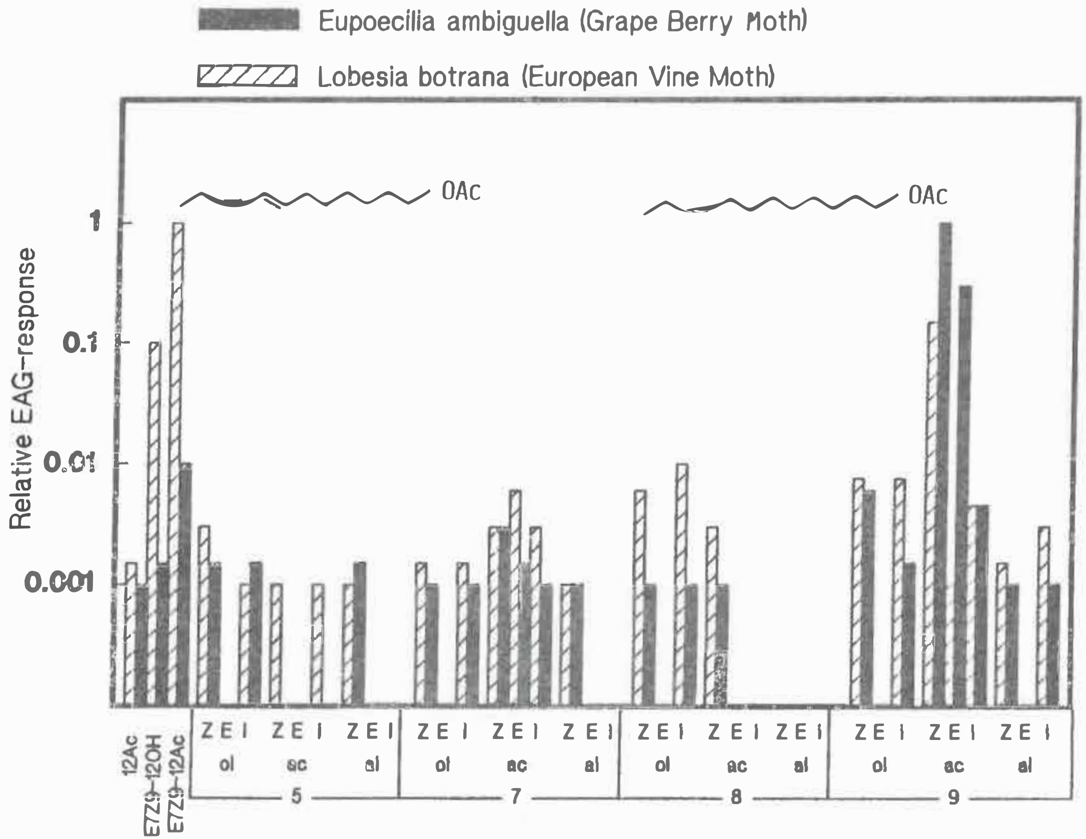
Z9-12OAc has been identified too, as a minor component in gland extracts and effluvia of female L. botrana-moths (ARN et al.). EAG-measurements with antenna of male moths gave interesting results: the EAG-response profiles exhibited the exspected high activity to the dien-acetate E7Z9-12OAc and the dien-alcohol E7Z9-12OH but unexpectedly high response rates to the monoene-acetate Z9-12OAc (Fig. 1).

In laboratory tests under various experimental designs (ROEHRICH et al., ARN et al., KRIEG) the activity of Z9-12OAc as a disruptant has been demonstrated.

On basis of field experiments (double-trap design) Z9-12OAc could be classified as a synergistic lure enhancing the attractivity of the main Lobesia-pheromone (E7Z9-12OAc) at low doses; high doses disrupted the male's insect orientation system, i.e. the male was unable to locate its conspecific female or a pheromone baited trap.

A large scale trial was carried out to control Lobesia botrana with Z9-12OAc, formulated in Hercon flakes; the number of pheromone sources (dispensers) was 150/ha or 1000/ha, the initial dose of pheromone employed was 500 g/ha (Fig. 2)

EAG-response profiles of male E. ambiguella and L. botrana to monounsaturated compounds



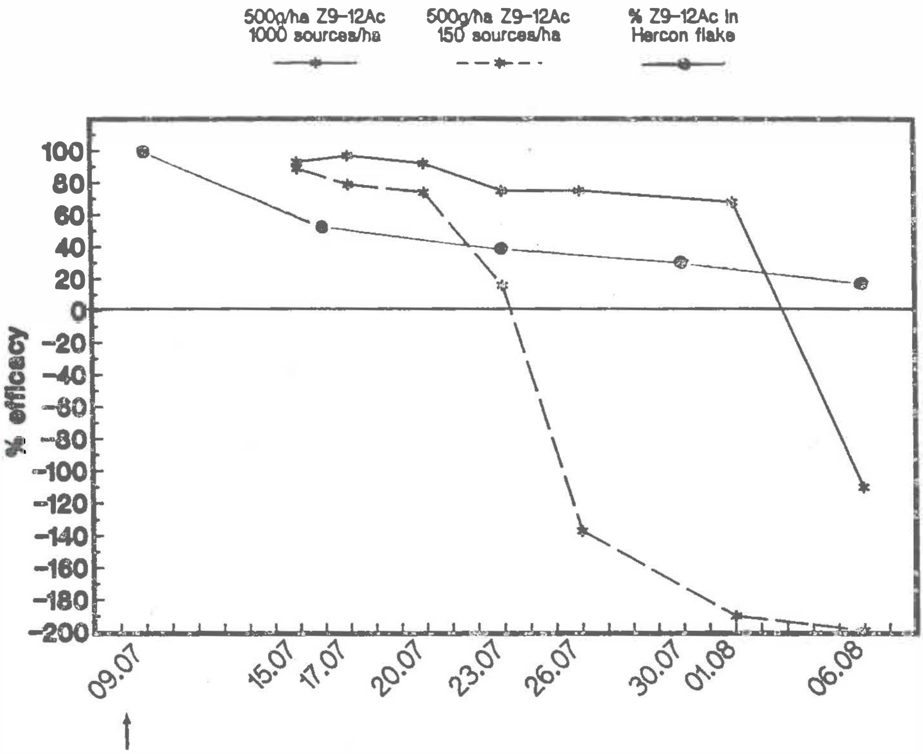


Fig. 2: Efficacy of Z9-12OAc for mating disruption of Lobesia botrana on basis of male moth captures in pheromone traps; Wachenheim, 1985, 2nd generation, treatment 9.7.

On basis of male moth catches in pheromone traps in treated and untreated areas the pheromone distributed in 150 sources per ha provided a sufficient orientation disruption effect for about a week, whereas the more homogenous distribution in 1000 sources gave more successful results: for up to three weeks the degree of desorientation was greater than 80 %.

The experimental design, a combination of an attractive (a) with disruptant (b) sources demonstrated the influence of 1) the distance between a and b, 2) the density of sources per area and 3) the dispenser placement to optimize the mating disruption technique (Table 1).

The same design of source placement within a pheromone treated area (150 g/ha; 150 sources) gave quite different results; the degree of inhibition was significantly reduced (Table 1).

Table 1

Relative catches of L. botrana males in traps baited with E7Z9-12OAc (a) and surrounded with sources of Z9-12OAc (b) (figures indicate relative strength of disruptant source; 1=35 mg)

source arrangement along vertical axis	a-b									
	front	-								1/4**
	back	-								1/4
	left	-		1	2		1			
	right	-	1	1	2		1		1/2*	
	above	-				2	1	5		
	below	-				2	1			
% catch in untreated area		**100**	**80**	**47**	**4**	**24**	**12**	**17**	**9**	**9**
% catch in disrupted area (150 g Z9-12OAc/ha; 150 sources)		**100**	**124**	**73**	**-**	**-**	**48**	**103**	**52**	**58**

*inside trap **at trap

The following explanations are possible; firstly: an activation of the males due to their exposure in a suboptimal odour atmosphere, which triggered more searching flights and thus increased the chance to locate more female sources; or secondly: a reduced sensitivity of the pheromone perception system (habituation): on basis of two receptor cells which has to be proved, one may speculate that the monoene-cells are blocked whereas the dien-cells were full in action.

ARN et al.: pers. comm.
KRIEG: unpubl. results
NEUMANN et al.; 1986: Agriculture News
ROEHRICH et al.; 1976: C.R. Reun. Pheromones Sex Lepid.

Attraction, inhibition and source displacement: Field tests on the synergism of pheromone gland constituents with the codling moth *Cydia pomonella* (L).

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Key words: attraction, inhibition
gland constituents, source displacement, codling moth

To outline the synergism between different pheromone constituents bio-traps were baited with sources of one of three components (I, II, III) found in the pheromone glands of the codling moth (Cydia pomonella) (1, 2). (I = 9.75 mg E8,E10-dodecadienol, E8,E10-12:OH "codlemone" on hercon dispensor, purity more than 99.5%; II = 1 mg E8,E10-dodecadienyl acetate E8,E10-12:Ac "antipheromone" (3) on rubber dispensor, purity more than 99 %; III = E8-dodecenol E8-12:OH; purity and formulation like II (4)).

The traps were arranged 2 m above ground in the trees of an apple orchard (2 ha) in South Bavaria (Rosenheim) so that the distances between two adjacent traps were 0 (2 odor sources in one trap), 5, 50, 500 and 1000 cm and the distances between two of such pairs (e.g. I:I, I:II, I:III, II:I, II:II, etc) were at least 15 m. For control unloaded traps were randomly distributed over the orchard, also in direct contact with the above combinations. Some codlemone traps (I) were further placed at distances of more then 50 m.

The numbers of male codling moths captured in the traps from July to October 1985 are shown in Table I. In reference to unloaded control traps, each of the compounds reveals to be attractive to male codling moths (Table I). Whilst nearly constant trapping rates are observed over the wide range of distances between 50 and 1000 cm the attractiveness of codlemone traps is strongly reduced by II and III when placed at distances less then 50 cm.

In accordance with proposed microdynamics of odor distribution (5) and electrophysiological (EAG- and single cell) recordings (Kafka i. prep) the data can be explained by a rather precisely timed cooperation (synergism) of at least two, most probably, however, three differently specialized types of receptor cells.

Table I. Male codling moths captured in traps I, II, III exposed at different distances (d cm) from the traps as indicated in the first line. (I = E8,E10-12:OH ("codlemone"); II = E8,E10-12:Ac "antipheromone"; III = E8-12:OH; - = not tested (s. text).

	I					II				III			
d	0	5	50	500	1000	0	5	50	500	0	5	50	500
I	73	62	-	-	71	21	39	50	69	13	40	72	69
II	21	6	2	9	-	8	4	-	-	12	5	3	-
III	13	29	13	17	-	12	12	17	-	17	10	-	-

In view of applied methods in male disruption the foregoing data favour the assumption that a given amount of attractant-inhibitor (like II or III) will render more success when distributed in the fields of infestations at higher rates of odor sources (e.g rich on odor concentration gradients) than at small ones.

We thank Mr Lutz Kasang for his skilful assistance.

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DISRUPTANT TESTS FOR EUPOECILIA AMBIGUELLA AND LOBESIA BOTRANA

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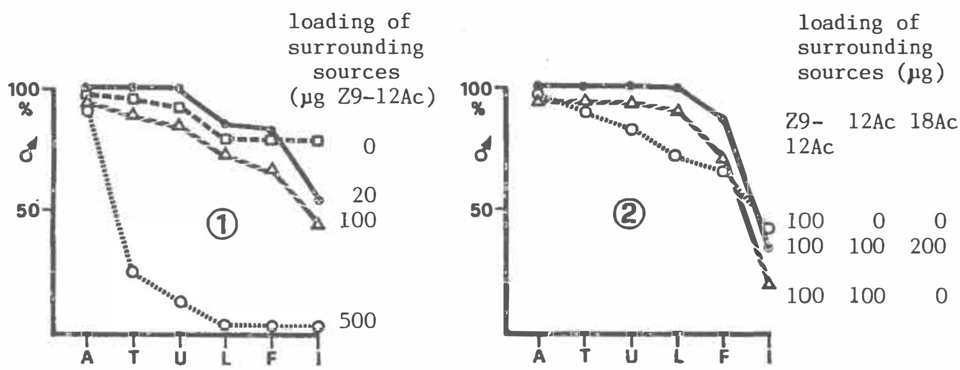
Tests are needed to determine the disruptant activity of chemicals and to evaluate formulations for field use. We have done some preliminary experiments in the wind tunnel and the field with two vineyard tortricids.

Eupoecilia ambiguella

In a procedure similar to that described by Sanders (1981), a cartridge containing 3 calling females was surrounded at 8 cm distance by four sources of the test chemical on rubber caps; plumes converged ca. 30 cm downwind. Males (40 per data point) were released 1.5 m downwind.

Orientation to the females was suppressed by Z9-12Ac (Z-9-dodecenyl acetate), the main sex pheromone component (Fig. 1). At high dose, this effect is manifested by a suppression of takeoff.

To determine if a better attractant makes a better disruptant, we also tested blends of Z9-12Ac with 12Ac (dodecyl acetate), and with both 12Ac and 18Ac (octadecyl acetate) (Rauscher et al., 1984, Arn et al., 1986) (Fig. 2). In the presence of the saturated acetates, fewer males flew directly to the females than with Z9-12Ac alone; however, more individuals located the females on following attempts. The data seem to indicate that the saturated acetates encouraged resumption of upwind flights.

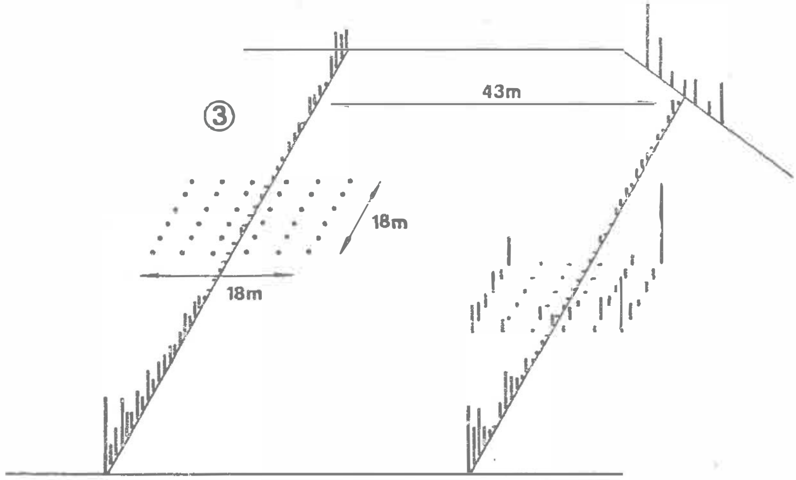


A = activation, T = takeoff, U = upwind orientation, L = landing overall (on female and/or surrounding sources), F = landing (eventual) on female source, I = initial landing on female source.

In a vineyard, 36 disruptant sources were placed in an 18 x 18 m grid and disruption measured by catches in traps placed at 1.5 m intervals in a line across the plot and 20 to 30 m beyond. Treatments were:

1) Z9-12Ac (0.1 % E, 1 mg on a rubber cap),
2) Z9-12Ac + 12Ac + 18Ac (1:1:2) in a trap without sticker,
3) Z9-12Ac + 12Ac + 18Ac (1:1:2) in a trap with sticker.

Treatment 3 was chosen to determine the added effect of male elimination. Fig. 3 shows examples of a result with sticker (right) and one without (left). There was a tendency for disruption to improve from 1 to 3.

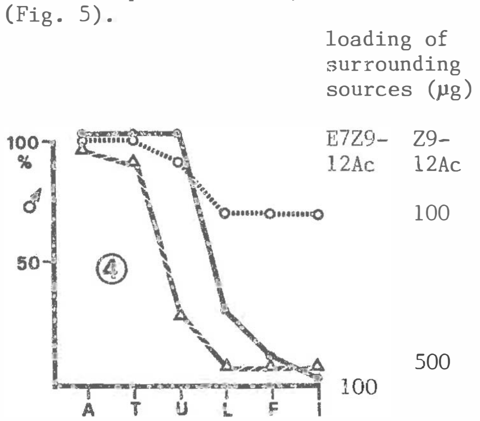


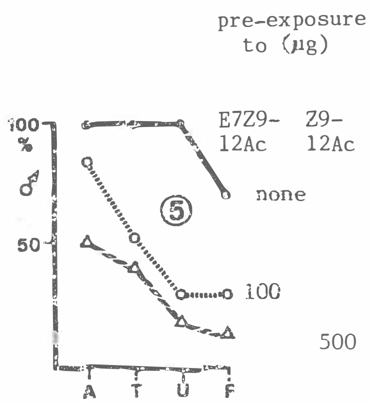
Lobesia botrana

Two different tests were employed to compare the disruptive effect of the main pheromone component E7Z9-12Ac (*E*-7,*Z*-9-dodecadienyl acetate) with that of Z9-12Ac, minor component of the *L. botrana* female blend.

In a five-source test as above, E7Z9-12Ac suppressed landings at the females to low levels. A similar effect was obtained with Z9-12Ac at a dose 5 times higher. However, suppression in this case occurred at upwind orientation instead of landings, indicating different mechanisms of disruption for attractants and non-attractants (Fig. 4).

In a second test, males were pre-exposed to chemicals in the holding tube for 60 sec before release, with calling females as the only odour source. As in the previous case, both E7Z9-12Ac and Z9-12Ac suppressed orientation (Fig. 5).





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EXPERIMENTS TOWARD DISRUPTING PHEROMONAL COMMUNICATION IN DACUS OLEAE

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R-(-)- 1,7-dioxaspiro[5.5]undecane is the major component of a four-substance, potent, long-range male attractant of *Dacus oleae* Gmelin, the olive fruit fly, the other three substances being a-pinene, n-nonanal and ethyl dodecanoate. S-(+)- 1,7-dioxaspiro[5.5]undecane is a female arrestant and aphrodisiac. The racemic mixture of this major component is relatively easily synthesized and is undergoing extensive testing for practical uses. Below are the results of some experiments designed to test possibilities of disrupting pheromonal communication and mating.

EAG studies showed that pheromone receptors of *D. oleae* can be adapted by continuous stimulation with the appropriate substances. Male olive flies confined in an atmosphere permeated with the racemic form of the major pheromone or with the complete pheromone mixture did not respond to either in 2-hr long laboratory olfactometer tests. Some response appeared after the first hour of the tests but never reached normal levels. Confinement in an atmosphere permeated with female pheromone gland extracts for 2-3 hours prior to the tests resulted in reduced response during the first 30 min of the test and a gradually increasing response thereafter, reaching normal levels at the end of the two hours.

Males and females under visual contact confined in an environment permeated with synthetic or natural pheromone mated regularly.

Males deprived of their pheromone receptors did not respond to pheromones in olfactometer tests. Similarly treated insects under visual contact with females mated regularly. Females deprived of their pheromone receptors did not mate under similar conditions.

In cage tests male response to a pheromone source decreased with increasing density of equal concentration of pheromone sources in the cage, but never reached the high levels required for practical results. Densities of 1, 4 and 8 sources per cage were tested. In similar tests, male response to a stronger source was not affected by various densities of pheromone source in the cage (cage dimensions 1.2x0.7x0.3m).

In field tests with wild or laboratory-cultured insects, male response to pheromone traps decreased with increased trap or pheromone source density. Reduction of male response also increased with the size of the experimental plot. Catches per trap at non-competitive density (over 200 m. apart) were up to 9 times higher than those at a density of 1 trap/tree with a pheromone concentration of 25 mg/source resulting in an average evaporation rate of 0.2 mg/dispenser/day. Maximum male response reduction, however, never reached the 95% level with source densities up to 16 per olive tree of a medium size, compared to male response at a density of 1 source per tree.

In small-scale field tests, pheromone source concentration did not affect male response at density (1,4,8,12,16 sources/tree) and concentration (10,25,100 mg/source) ranges tested. Results obtained from two small-scale (100 and 200 tree orchards with incomplete isolation) disruption experiments with 5 sources/tree each containing 25 mg of the pheromone mixture, showed a slight reduction in the percentage of mated females, increase in the fly population density and increase in fruit infestation level compared to the test orchards. Population density increases could be the result of the arrestant effect of the S-(+)- enantiomer of the major pheromone on the females, which resulted in the increase of the fruit infestation level.

Contrary to some promising results reported from Spain on the disruption of this pest, the data presented here are not encouraging as to the future of the technique. Perhaps higher pheromone source densities and concentrations will change the picture.

STEREOMERIC INHIBITION OF PHEROMONE RESPONSES IN MALE TOBACCO BEETLES

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Simultaneous release of threo-4S,6S,7S-serricornin [S S S] and erythro-4S,6S,7R-serricornin [S S R] at a ratio of 1 : 0.01 failed to reduce the pheromone activity of S S S [10^{-3} µg] for male tobacco beetles [Lasioderma serricorne F.], whereas the exposure of S S S and S S R at a ratio of 1 : 0.1 markedly suppressed the pheromone activity of S S S ; i.e. the aggregation time of male tobacco beetles at this ratio was ~60% shorter and the number of mating attempts was ~66% smaller than the respective parameters following exposure to S S S alone. At an equimolar ratio of S S S and S S R, both aggregation time and attempts of mating were ~97% lower than the respective parameters resulting from exposure of male L. serricorne to S S S alone. Male tobacco beetles usually displayed avoidance responses upon approaching the 1 : 1 mixture of the above antagonistic stereomers. At a ratio of 1 : 10 of S S S : S S R, the pheromone activity was completely disrupted, as revealed by lacking aggregation and mating attempts of male tobacco beetles. 4S,6R,7S-serricornin [S R S], another erythro-stereomer, partly subdued the pheromone activity at ratios of 1 : 1 and 1 : 10 of S S S and S R S, as evident from a respective reduction of ~30 or ~43% of the aggregation time as well as a respective decrease of ~50 or ~56% of the mating attempts of male L. serricorne observed in presence of S S S alone. 4S,6R,7R-serricornin [S R R] being a threo-stereomer like S S S revealed neither pheromone nor pheromone antagonist activity. The molecular structure of the forementioned compounds is shown in Figure 1.

It may be concluded that the sex pheromone activity of S S S for male tobacco beetles is strongly antagonized by the addition of S S R and weakly suppressed by the presence of S R S, while it is not affected by the addition of S R R [Fig. 1]. The antagonistic interaction between S S R and S S S can be ascribed to the olfactory influence of the steric change at the assymetric centre C - 7, i.e. the mirror image position of hydrogen and hydroxyl occurring in the above erythro- and threo-stereomers. The weak antagonistic interaction between S S S and S R S probably results from the olfactory influence of the altered position of hydrogen and methyl at the assymetric C - 6. In consideration of the structural similarity of 4S,6S,7R-serricornin and 4S,6S,7S-serricornin as well as the dependence on a certain ratio between both stereomers for antagonizing the pheromone effect, one is tempted to assume competitive inhibition. The results suggest that racemic serricornin, consisting of S S S, S S R, S R S and S R R in certain proportions, will be devoid of pheromone activity for male tobacco beetles. In fact, we have shown that male L. serricorne failed to aggregate and to mate in presence of racemic serricornin [levels of 10^{-5} to 10^{-1} µg] as well as in presence of 1 : 1 or 1 : 10 - mixtures of S S S and racemic serricornin. This implies that serricornin containing more than ~ 10% of 4S,6S,7R-serricornin should not be used for trapping male tobacco beetles in storage biotopes.

Each experiment was carried out with 10 unmated males of Lasioderma serricorne [27 - 30 days after pupal-adult ecdysis] per dosage and stereomer [8 repetitions]. A given stereomer or mixture was exposed for 15 min. to the above insects in the central region [diam. ~ 1 mm] of a paper arena [diam. ~ 75 mm] conditioned at 30 ± 0.1°C.

The authors are grateful to Prof. Dr. K. Mori [University of Tokyo] and Dr. T. Chuman [Japan Tobacco and Salt Public Corporation] for kindly providing the compounds used in this study.

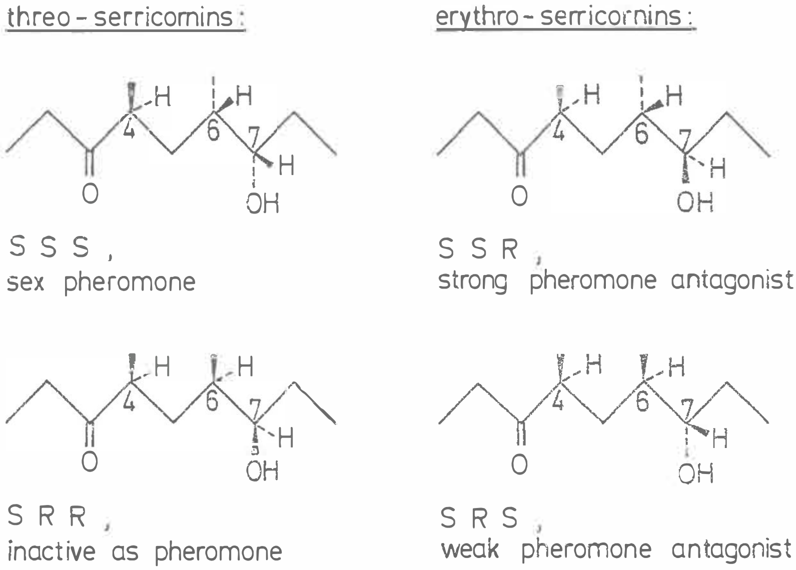

Fig. 1. Relationship between the stereochemical structure and physiological activity of threo- and erythro-serricornins for male tobacco beetles.

The Development of a Lure and Kill Technique for Control of the Egyptian Cotton Leafworm, SPODOOTERA LITTORALIS.

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Much work has been done to try to control the Egyptian Cotton Leafworm *Spodoptera littoralis* by mating disruption using its pheromone.

At TDRI we have been working on this topic for a long time, mostly using a microencapsulated formulation which has been applied conventionally. We were able to achieve disruption as measured by trap catch at a rate of a.i. of 40g/ha, but this is an uneconomic level at today's prices for the pheromone. However in 1983, we recorded encouraging results in a small trial with a laminate flake formulation applied at a rate of 10,000 flakes/ha and 12.5g a.i./ha. It therefore appeared that if its pheromone were applied as point sources, disruption of *S. littoralis* might be possible at an economically and commercially viable level of a.i.

We began to test point sources of pheromone as a means of disrupting this insect, in cotton fields in Egypt, using a microencapsulated formulation. At first the microcapsules were placed directly onto the cotton as a discrete "blob". These took some time to dry and consequently many rolled off the leaves before they were dry. Later the blobs were applied to filter papers and allowed to dry before the filter papers were stapled to the cotton. The blobs were placed in the cotton at rates of 40,000, 20,000 and 10,000/ha at levels of a.i. between 40 and 10g/ha. Disappointingly, the best results achieved in these trials as measured by trap catch were no better than when 40g a.i./ha was applied conventionally and they were often not as good.

However, we were also looking at what the insects were doing in relation to these sources in the treated plots, using low light level video equipment. At rates of application of the blobs greater than 10,000/ha, very little activity could be seen. At 10,000 and 5000/ha and at only 5g a.i./ha, trail following was evident with insects approaching and landing on the filter papers and examining the blob. The average contact time with the blob was about 3 seconds, with most approaches being to the lower levels of a.i. Chemical analysis of the blobs later showed that release of the pheromone was very slow compared with a sprayed application.

Work being carried out in a wind tunnel in TDRI showed that *S. littoralis* males will readily fly up to and land on a filter paper sprayed with 0.125mg of microencapsulated pheromone and will remain in contact with it for an average of more than 60 seconds.

We decided to abandon the blobs as being impractical and use sprayed filter papers to field test reduced numbers of point sources at reduced levels of a.i./ha to see:

1. if this would improve levels of disruption; and,
2. bearing in mind the problem of what the insects do after they have examined a source and moved on, and the work of Haynes and Baker in the USA on the behavioural effect on Pink Bollworm of a short encounter with insecticide, if the incorporation of an insecticide onto the pheromone source would further increase the effect.

We treated plots at numbers of point sources from 10,000 down to 1250/ha and levels of a.i. down to 1.25g/ha. Each of these trials included replicates in which the point sources consisted of pheromone only and pheromone plus insecticide.

We were also becoming increasingly worried about the value of trap catch as a measure of effect and decided to use tethered virgin female moths as an additional test of efficiency.

The results showed a trend towards lower numbers caught in traps and fewer mated females as numbers of point sources and levels of a.i. decreased.

In every case, the addition of the insecticide to reduced trap catch over the first 5 days by up to 70% when compared with plots treated with pheromone only.

Night vision studies showed that there was increased trail following as numbers of point sources per area decreased. They also showed that the inclusion of the pesticide did not inhibit approaches to or landings on the sources. Sprayed filter papers were up to 10 times more attractive to the male moths than the blobs and the males were up to 50 times more likely to land on such a source.

We have recently looked at 1000, 500 and 200 point sources/ha using insecticide spiked sources only.

The results of these trials have not yet been fully analysed, but trap catch and mating of tethered virgin female moths suggest that 500 point sources is about 20% better than 1000 point sources. A further reduction to 200 point sources/ha appears to result in a loss of effectiveness by about the same %.

Preliminary bioassays of insecticide treated sources have shown that exposure of the males to them for 10-20 seconds can kill up to 100% of the insects within 24 hours. Knock-down and disorientation effects are considerable after 2-4 hours. When survivors are placed with virgin female moths, they are less likely to mate than control insects.

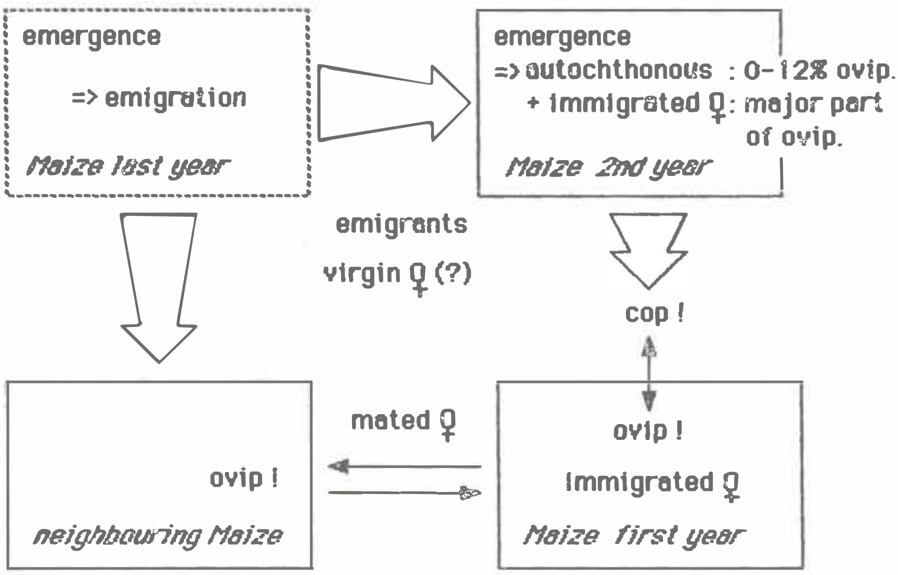
We plan to continue this work, in the laboratory and in the field. In the laboratory, to find the most effective pheromone/insecticide combination and dispenser, and examine more closely the effects of exposure of moths to these sources on their subsequent fecundity. In the field, to define more clearly the number of sources necessary and to find out what their effect really is on wild populations of the Cotton Leafworm.

CORDILLOT Francis

Population movements and oviposition flights of the European Corn Borer (Ostrinia nubilalis Hbn.; Lep.: Pyralidae) in maize.

Understanding of the dispersal flight and oviposition behaviour is crucial for effective pest monitoring. In order to optimize mating disruption techniques in integrated pest management we need more informations on the flight, mating and oviposition behaviour mainly of the female moths.

The main questions are:
-How do immigration and emigration rates change in time ?
-What is the estimated shape of the dispersal, ´fan´ or ´plume´?
-When, for how long and how far do the adults migrate ? In which ontogenetic stage do they actually migrate ?
-What proportion of egg-masses stem from autochthonous females as compared to immigrated ones ?



In the above graph there are two kinds of arrows:

adaptive dispersal: - (Obligate) migration ?
- Long-distance displacements ?
(-> distances unknown)

appetitive flights: -Short-range daily displacement
(-> around the field or to the next, indep. of wind-direct.<15 km/h)

Preliminary results:

-The proportion of the autochthonous ovipositions seems not to exceed 12% for a cornfield in the consecutive year. Most egg-masses actually stem from immigrated moths.

-Preovipository flight distances are unclear.

-Mated females fly more directional than virgins towards maize. A population exchange of mated females between neighbouring cornfields has been observed. Additionally, local to and fro flights within the same night into and out of the cornfields are confirmed.

-There is still a controversy about the mating site, but mating outside of the cornfield seems to be more probable. This should have consequences for the placement of traps and pheromones.

-The higher the distance to the nearest field with maize last year, the lower the infestation rate.
The infestation rate of a maize field is correlated with the infestation rate of the closest maize field of last year.

Discussion:

It still remains unclear what range of stimuli triggers take-off for the first flight and what stimuli govern the consecutive flight orientation. Experiments are needed to evaluate the temperature and light-intensity thresholds for flight. There is also a lack of knowledge on the ontogenetic change of chemotactic response of both sexes. Notably in females from emergence, preovipository phase, mating, oviposition to interovipository stages. In males, we ignore the commencement of olfactory reaction to sex pheromones.

The sensitivity to these environmental factors may vary from one country to another (e.g. America and Europe), even between localities within a country (e.g. different pheromone strains in the northern and southern part of Switzerland).

A method for trapping ECB moths is described in:

CORDILLOT F. & DUELLI P. (1986) A directional light trap for monitoring migration rates of night-flying insects. *Mit. Schweiz. Entomol. Ges.* *(in press)*

SAMPLING AND DETECTION METHODS FOR ORGANIC TRACE COMPONENTS IN AMBIENT AIR

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The concentration range for organic trace components in ambient air vary with at least a factor of 10^6 (pg to µg/m^3 respectively ppf to ppb). Furthermore, big differences in the volatility are present. Therefore the sampling technique has to be adapted for the compound group of interest. Different methods such as cryosampling, the use of small adsorption tubes filled with polymeric materials and high-volume sampling on polyurethane foam will be discussed.

When labile compounds with limited life time are collected, both sample extraction and clean-up have to be carried out very carefully to avoid sample decomposition. Low-temperature extraction methods using liquid CO_2 or Freons and group fraction by high performance liquid chromatography will be shortly presented. Additionally selectivity and sensitvity can be gained using sophisticated detection methods such as negative ion chemical ionization mass spectrometry. Some examples will be given.

The dispersion of volatile compounds in the environment can in many cases be controlled and simulated using easily detectable tracer compounds. A complete field set-up for the measurement of SF_6 and $CBrF_3$ consisting of a field gas chromatograph and time programmable samplers will be presented. Detection limits of 1 ppt are possible.

Measuring pheromone release by individual females

P. WITZGALL

I.N.R.A., Brouessy

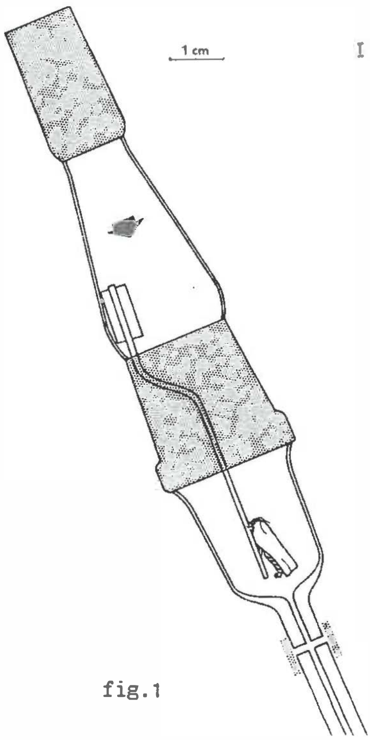

fig.1

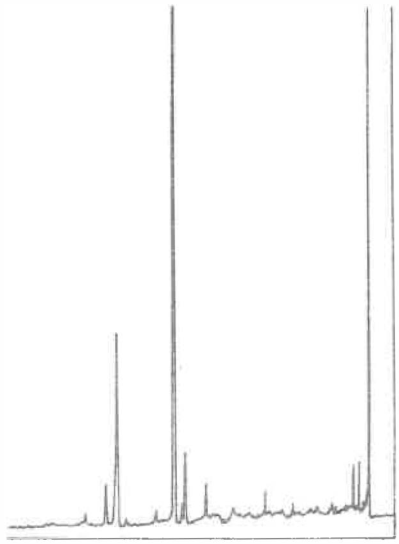

fig.2

The glass-adsorption collection device shown above (fig.1) permits GC analyses of pheromone blends released by individual calling females during short intervals (fig.2: Cacoecimorpha pronubana; 10 min).

- A constant air-flow (2,5 l/h) prevents adsorption of pheromone on the insect.
- The collection of pheromone in a capillary glass tube (ID 1mm ; length 10 cm) minimizes pollution and allows efficient elution with small quantities of solvent (5 µl). Solvent evaporation is not required (SHANI & LACEY 1984).
-The lower holding chamber and the capillary tube can be rapidly exchanged without disturbing the calling female.
-The calling female rests on a small platform (<1cm2) and has nc contact with the holding chamber (CHARLTON & CARDE 1982). The everted gland is next to the outlet.

Over 80% of the pheromone emitted from an artificial source is recovered from the capillary tube; less than 3% is adsorbed in the lower holding chamber.

CHARLTON,R.E.& CARDE,R.T. J.Insect Physiol. 28, 423-430, 1982.
SHANI,A.& LACEY,M.J. J.Chem.Ecol. 10, 1677-1692, 1984.

The Behaviour of Pheromone Molecules in the Air

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Over distances of tens of meters from a pheromone source the main factor causing the reduction of pheromone concentration is turbulent diffusion, molecular diffusion works too slowly to have a significant effect. This means that other materials of various molecular weights can be used to simulate the flow of pheromone molecules.

Because turbulence has random direction and strength, mixing is highly uneven. In trials with visible tracers, smoke for example, this can be seen in the patchy and filementous form of the plume. With appropriate tracers it is possible to measure the fluctuating concentration in a plume by sampling the air and determining the quantity of the tracer in the sample volume.

Results of work with tracers all show the fluctuations having the same overall form . The concentration "signal" is highly intermittent with groups of spikes separated by periods of zero concentration. A flying insect would be subject to bursts of stimulating pheromone-laden air separated by clean air. The bursts would be varied in strength and duration. Some bursts contain undiluted source material.

The consequence of this is that insects will be subject to occasional stimuli very much stronger than the local mean concentration (the average ratio of burst strength to local mean is about 20).

A new type of tracer detector measures flux as opposed to concentration and makes measurements of the tracer "signal" more in keeping with an insects experience of a pheromone plume. The flux probes measurements suggest that bursts are stronger but shorter than shown by concentration measuring devices. The occasional strong burst would in this case be even more marked.

Tracer measurements show, however that the burst lengths and the distances between them do not greatly vary with distance from the source. It seems likely, therefore that it is the frequency of arrival of the relatively strong bursts (which does decline with distance from the source) that determines the region over which a pheromone source is effective.

CHEMICAL PROTECTION OF PHEROMONES, CONTAINING INTERNAL CONJUGATED DIENE SYSTEM, FROM CHEMODEGRADATION.

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Pheromones used in pest control are chemodegraded under field conditions. Some of the chemical processes that may occur include isomerization of double bonds, oxidation and hydrolysis, as affected by heat, light, oxygen and humidity (irrigation, rain).[1]

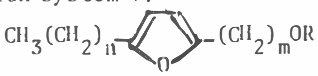
Three pheromones containing internal conjugated diene system were studied:

(*Z*,*E*)-9,11-tetradecadienyl acetate [(*Z*,*E*)-9,11-C_{14}OAc] (I)

(*E*,*Z*)-7,9-dodecadienyl acetate [(*E*,*Z*)-7,9-C_{12}OAc] (II)

(*E*,*E*)-10,12-hexadecadienal [(*E*,*E*)-10,12-C_{16}ald]* (III)

These systems, under field conditions, are both photoisomerized to a mixture of the 4 possible geometric isomers (Table 1) and oxidized to give a furan system V:[2]



Va: m=6,8,9; n=1,2; R=Ac
b: m=7; n=0; R=H

Table 1. Photochemical isomerization of I,II and IV exposed to sunlight

Pheromone	Without antioxidant					With antioxidant (BHA)				
	Period (days)	% composition (*Z*,*E*)	(*E*,*Z*)	(*Z*,*Z*)	(*E*,*E*)	Period (days)	% composition (*Z*,*E*)	(*E*,*Z*)	(*Z*,*Z*)	(*E*,*E*)
(*Z*,*E*)-9,11-C_{14}OAc	7	75	5	-	20	25	25	15	< 1	60
(*E*,*Z*)-7,9-C_{12}OAc	3	-	87	-	13	45	14	18	4	64
(*E*,*E*)-10,12-C_{16}OAc	10	5	5	-	90	25	10	10	-	80

A rapid photosensitized isomerization (by Rose bengal) yields an equilibrium mixture, similar to that obtained by radical reactions (Table 2), which is followed by $^1O_2$ oxidation to yield cyclic peroxides, as the intermediates in the furan formation.

Table 2. Photosensitized (with Rose bengal) isomerization in sunlight

Pheromone	Period (minutes)	% composition (*Z*,*E*)	(*E*,*Z*)	(*Z*,*Z*)	(*E*,*E*)
(*Z*,*E*)-9,11-C_{14}OAc	75	15	12	-	73
(*E*,*Z*)-7,9-C_{12}OAc	100	12	12	< 1	76
(*E*,*E*)-10,12-C_{16}OAc	30	14	14	1	71

*Studied as the corresponding ester (*E*,*E*)-10,12-hexadecadienyl acetate (IV).

Catalytic isomerization of the diene system with I_2 in dark, is probably a radical reaction, as it is slowed down by antioxidants, which react as radical scavengers (Table 3).

Table 3. Effect of antioxidant (BHT) on the isomerization with I_2 in dark

Pheromone	Without antioxidant					With antioxidant (BHT)				
	Period (hrs)	% composition (*Z,E*)	(*E,Z*)	(*Z,Z*)	(*E,E*)	Period (hrs)	% composition (*Z,E*)	(*E,Z*)	(*Z,Z*)	(*E,E*)
(*Z,E*)-9,11-C_{14}OAc	24	14	15	1	70	26	52	12	6	30
(*E,Z*)-7,9-C_{12}OAc	26	11	12	2	75	25	6	72	1	21
(*E,E*)-10,12-C_{16}OAc	6	13	14	1	72	4	9	9	-	82

A UV absorber [λ_{max} 288(14,770), 360nm(9,090)] is effective in slowing down both the direct sunlight (in the presence of an antioxidant, Table 4) and the photosensitized isomerization, of any tested isomer, to the equilibrium mixture (compare with Table 1).

Table 4. Effect of UV absorbers on the direct sunlight photoisomerization

Pheromone	UV absorber E-4360					UV absorber E-8021				
	Period (days)	% composition (*Z,E*)	(*E,Z*)	(*Z,Z*)	(*E,E*)	Period (days)	% composition (*Z,E*)	(*E,Z*)	(*Z,Z*)	(*E,E*)
(*Z,E*)-9,11-C_{14}OAc	23	86	7	1	6	27	48	23	1	28
(*E,Z*)-7,9-C_{12}OAc	30	-	85	-	15	32	9	63	1	27
(*E,E*)-10,12-C_{16}OAc	30	3	3	-	94	20	10	10	-	80

A mixture of 10% of UV absorber and 10% of an antioxidant in the pheromone solution protects the diene system from isomerization. For field studies we have measured the relative stability of the pheromone on carriers as compared to solution (Table 5).

Table 5. Comparison of (*Z,E*)-9,11-C_{14}OAc stability on different carriers

Source	Pheromone	BHA	E-4360	Exp.time (days)	% composition (*Z,E*)	(*E,Z*)	(*Z,Z*)	(*E,E*)
Solution	100%	10%	-	17	47	16	-	37
Solution	100%	10%	10%	17	92	2	-	6
Cardboard	100%	10%	-	25	60	16	-	24
Cardboard	100%	10%	10%	24	78	10	-	12
Cigarette filter	100%	10%	-	21	55	20	-	25
Cigarette filter	100%	10%	10%	21	59	20	-	21

A preliminary field study of mass trapping of *Spodoptera littoralis* with (*Z,E*)-9,11-C_{14}OAc, stabilized with either BHA or BHT and UV absorber (E-4360), showed better results than those of UOP stabilization.

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MALE DISORIENTATION TRIALS WITH A PARTICULAR FORMULATION

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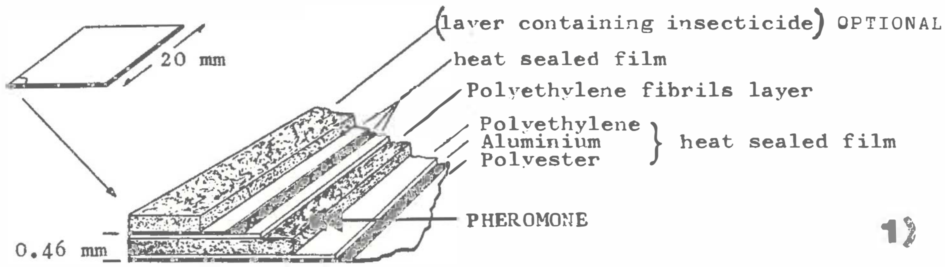
After some years of confusion- trials carried out with pheromone formulations such as wettable powders or rubber macro-dispensers leading to contrasting practical results, we began to work with low doses of pheromones released from discrete sources. For this purpose we designed a new dispenser (Figure 1) made of a layer of felted polyethylene fibrils coated with a heot-sealed aluminium- polyethylene film, so that the pheromone is released from the edges only. We used a standard square shape with 20 mm sides and 0.46 mm thickness.

In some trials one face of the dispenser was treated with a pyrethroid in the attempt to combine the attractant effect of the pheromone with the killing effect of the insecticide.



1)

In disorientation experiments we used dispensers chorged with 0.5 to 5 mg of pheromone; with these quantities we get a linear release rate and an attractiveness of more than 3 months. By simply varying size and paper thickness the new dispenser also works with high attractant doses (up to 100 mg/dispenser).

All the dispensers proved highly attractive for the target species in trapping checks carried out with our sticky trap Traptest ® and our funnel trap Mastrap ® .

In the table our trials with main results are summarized.

The attempt to kill males with insecticide-treated dispensers was a real success for E. kuehniella (Fig. 2). Surely this can be ascribed to the behavior of the males which touch the attraction source again and again.
In experiments in big cages with adults of both sexes and only one dispenser we got 100 % killing of males and 30 % of females, probably because mated with contaminated males.

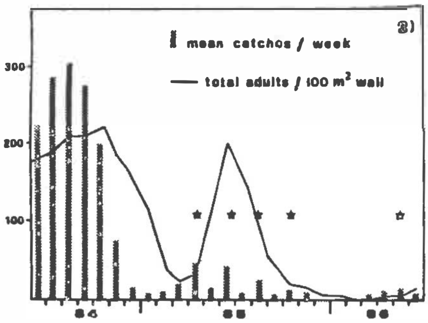
We know that other species do not have the same behavior.

For instance L. botrana males do not touch the dispensers so results could be obtained only with fumigant insecticides. We also got poor results with this species when the attempt was made to attract males away from the vineyard.

Another problem we met, with C. pomonella for instance, is the laminar trend of the pheromone trails. In apple orchards with very high trees when the dispensers were placed at 1.5-2 m from ground level, the confusion was complete at this height but there were no effects on the tree canopy at 3-4 m or more.

In the case of Prays citri we got a good catches inhibition and an acceptable damage reduction (Fig.3). In the treated field the infestation was delayed, the maximum blossoming (the second ten days of September) was protected and only the late flowers were attacked.

Ephestia kuehniella



Prays citri

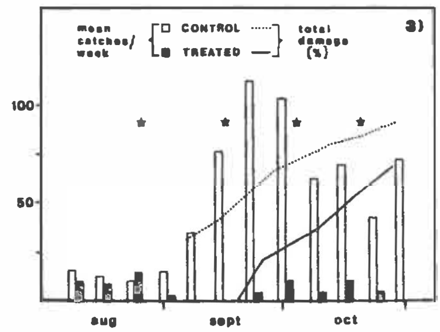
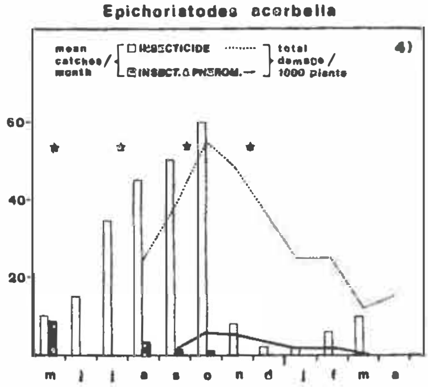


Fig. 2 and 3: ★ == pheromone application.

In the case of E. acerbella we observed a remarkable synergism when insecticide sprays and disruption method are used together. We got a very high catches inhibition and the damage in the pheromone-treated field was considerably lower than in the check, an insecticide-treated field (Fig. 4).

In the confusion trials on Cydia molesta we observed a very high inhibition of catches, but the damage reduction was not as good as we expected (Fig. 5).

Epichoristodes acerbella



Cydia molesta

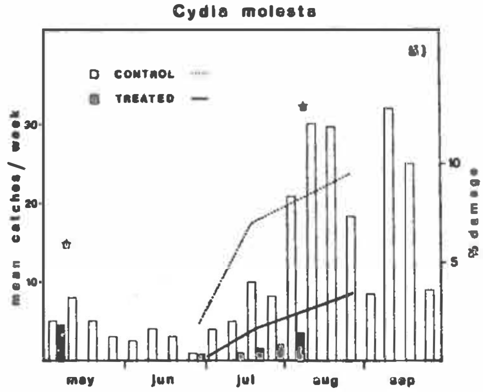


Fig. 4 and 5: ★ == pheromone application.

TABLE : Main results of male disorientation trials

SPECIES	pheromone applied (g/ha)	dispensers per hectare	number of applications	trial period (months)	inhibition (%)	damage reduction (%)	REF
Cydia molesta	2	1000	2	4	97-99	60-80	1
Cydia pomonella	2	200	2	6	80-85	not significant	
Epichoristodes acerbella	10	2000	4	12	97-98	87	1
Lobesia botrana	1	500	1	2	75-85	not significant	
Prays citri	0.2	400	4	2	87-96	75 (infestation delayed)	2
Ephestia kuehniella	$0.2/1000m^3$	$100/1000m^3$	4	12	99-100	insectistasis (under economic threshold)	3

Generally, for all the species we noted a better control working in the same field for consecutive years. Moreover, the possibilities of success are surely greater in a field where a biological or integrated control has already been carried out.

We can conclude that using low pheromone doses with this new discrete long-lasting dispensers it is possible to achieve very interesting results for some insect species. As in most cases, the success of the method depends on the well-known factors such as the population density, the experiment scale, the possible reinfestation by mated females and so on.

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RELEASE RATES OF PHEROMONE FROM HERCON VINYL PLASTIC LAMINATE DISPENSERS

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These graphs are regression lines, calculated from the results of a B.A.S.F. analyse of dispensers sampled in orchard every week, in 1983, 1984, 1985. They allow to schedule the date of changing the dispensers according to temperature.

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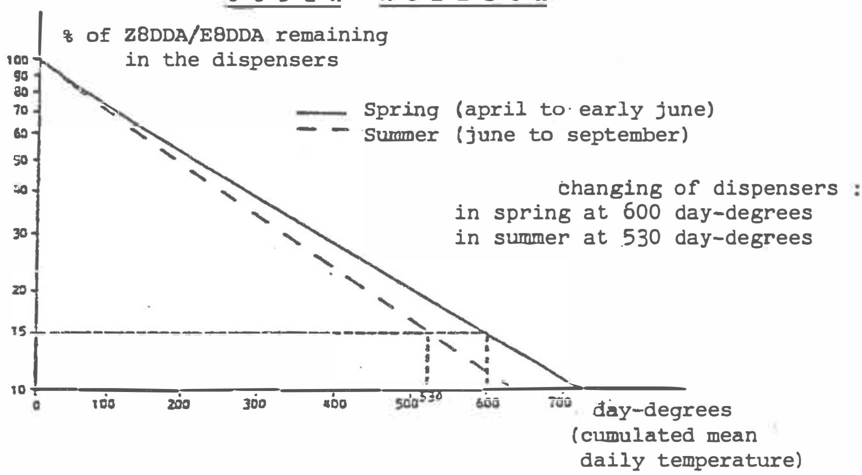

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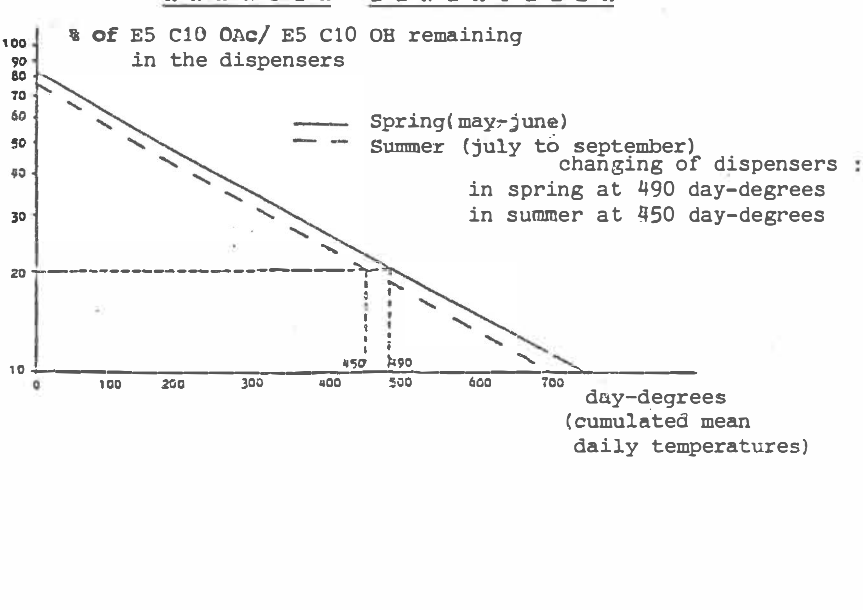

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