IOBC/WPRS

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

OILB/SROP

Groupe de Travail "Utilisation des Phéromones et Autres Médiateurs Chimiques en Lutte Intégrée"

PROCEEDINGS WORKING GROUP MEETING

San Michele all'Adige (Italy)
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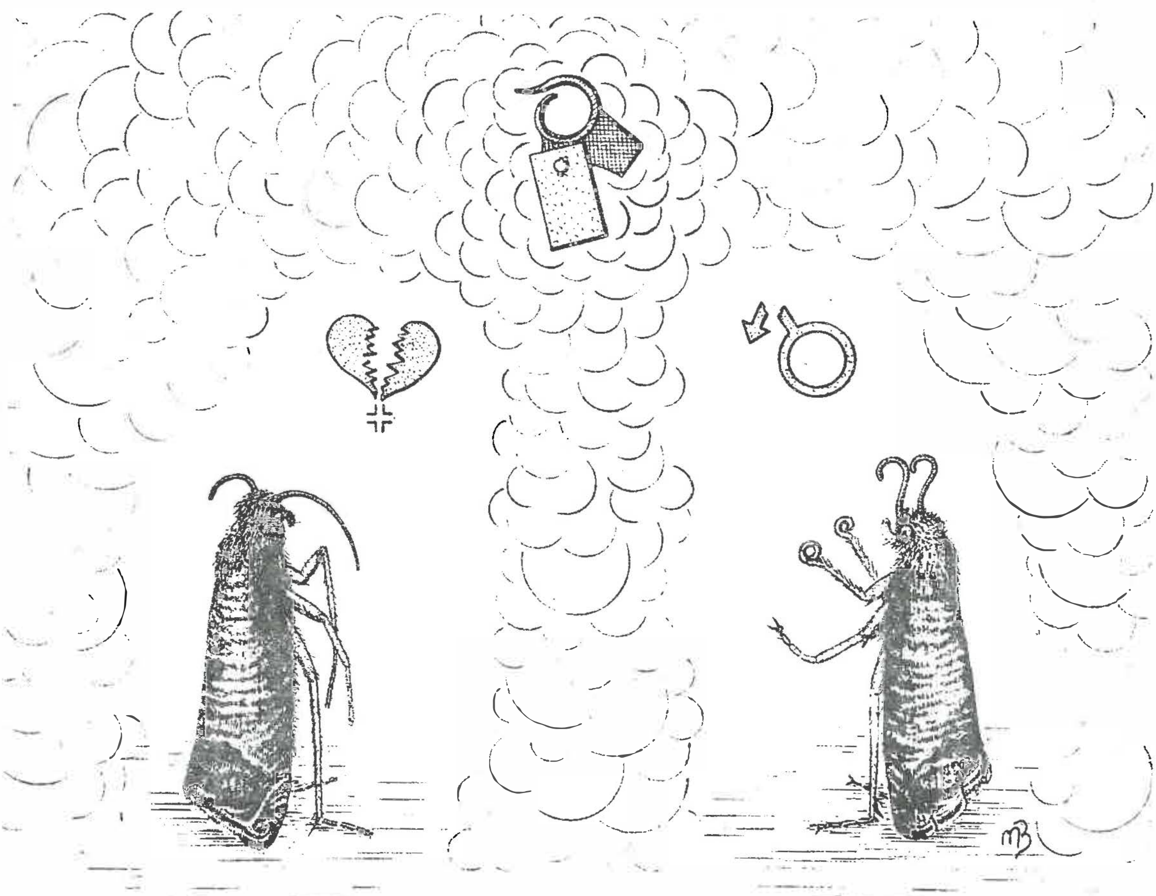

This drawing has been made by dr. M. Baggiolini, great initiator of much of the present work on pheromone applications and Integrated Pest Management in Switzerland and in IOBC/WPRS

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ABOUT THIS BOOK

Mating disruption is a control method against 2 vineyard and at least 8 orchard pests of Europe, and many more if we consider the whole world. What the reports of San Michele workshop cover are not just pilot experiments; many represent years if not decades, of practical field work supported by careful evaluation of crop damage. That the results are overall positive is a strong encouragement for those who believe that the use of natural products instead of pesticides should in the long term improve the quality of life. It would seem that with some technological improvements mating disruption could even became economical and competitive.

On the other hand, we cannot neglect the fact that mating disruption has not been effective in every case. Some failures can be related to inadequate performance of dispensers. Other explanations such as high population densities or migrations are more difficult to confirm by valid scientific techniques. But how could we understand all the failures if we don't even know how mating disruption works?

The discussions during the conference and informal encounters left little hope that further progress could be made by placing dispensers and counting worms. During the last hour the conclusion emerged from the audience that we should put into practice what has been developed and at the same time collect basic information to improve the current system. This means taking the following steps:

1) Implement mating disruption at its current technological state in integrated production,

2) study the mechanisms of mating disruption in order to optimize active ingredients and application techniques,

3) improve the reliability of controlled release formulations

Wädenswil, September 1992

Heinrich Arn

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Chairman: **Dr. Henrich Arn**

MATING DISRUPTION ON ITS WAY TO PERFECTION: SOME THOUGHTS

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ABSTRACT

Mating disruption is effective against a number of species but needs to become more reliable and economical. Improvements can be made in the knowledge of the mechanisms, specifications for the active ingredients and development of formulations. The key to this are quantitative data on insect behavior and airborne chemicals.

INTRODUCTION

In 1963, Babson and Wright each published a paper in which they proposed to control pests by permeating the air with synthetic sex pheromone, thereby preventing the males from finding the females. This technique, now called mating disruption, has been demonstrated to be effective against several species of Lepidoptera and registered for use in plant protection around the world. Its introduction into practical agriculture, however, has been slow. Critics say that mating disruption is too expensive and unreliable to find wide acceptance. What can we do to improve this situation?

There will always be limitations to the use of pheromones in pest control. It may never be possible to totally suppress mating in a pest population because there might be mechanisms of orientation other than those mediated by pheromones. Furthermore, a crop treated with pheromone can always be infested by gravid females from the outside; therefore, continuous supervision is in order. And insecticides will often remain more economical than species-specific control techniques, e.g. in case a pest complex.

On the other hand, many failures of mating disruption reported in the past have been caused by technical problems that can be solved: Dispensers were placed too late in the season, failed to release sufficient material or were used up before the end of the flight period. A major improvement in mating disruption technology can be expected when we begin to understand the importance of chemical composition and purity of the active ingredients, and learn how to use them in a most effective and economical way.

THE ACTIVE INGREDIENT

The term "pheromone" has been coined for a blend of chemicals which is secreted by an animal and produces a behavioral effect in individuals of the same species. Over the past three decades, sex pheromones of hundreds of insect species have been identified. However, our knowledge is still improving, and so there is hardly an identification that could be assumed to be final. This means that for some time to come a synthetic pheromone will only be an approximation of the natural material.

In many cases mating disruption has been achieved with incomplete pheromone preparations, e.g. one or a few components of a pheromone blend, a technical product containing some impurities, or a mixture of chemicals acting against several species. Other research has focused on pheromone analogs for which patent protection may be easier to obtain than for natural products, or which may be less expensive, less susceptible to degradation by environmental factors or - still a dream - more active than the natural material. Some examples are formates isosteric to aldehydes or fluorinated compounds. We can thus distinguish between three active principles:

1) The optimized blend; the closest possible approximation to the pheromone emitted by the female.
2) An incomplete pheromone: a pheromone component, an off-blend, an impure product, a

multispecies formulation.

3) An analog or mimic.

Experts do not agree about the best choice for an active material. Some argue that unless the exact copy of the natural pheromone is used, there is a risk that the male will recognize the calling female. On the other hand, encouraging results have been obtained with single pheromone components or off-blends. The controversy will probably continue for as long as we do not fully understand the mechanisms leading to mating disruption.

MECHANISMS OF MATING DISRUPTION

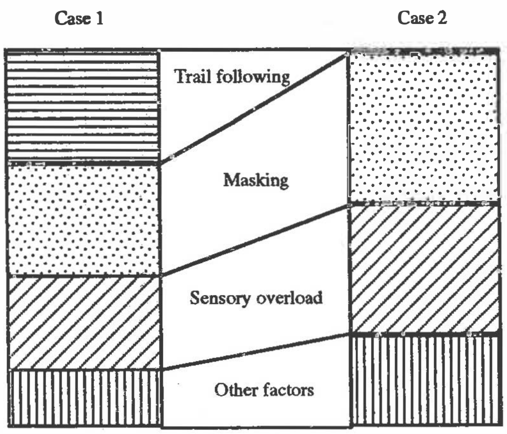
What makes successes and failures difficult to predict is that mating disruption is operating by various mechanisms. The most important are:

1) False-trail-following: Males are repeatedly attracted to the artificial odor sources competing with the calling females.
2) Masking of female odor plumes: Males cannot distinguish between female odor plumes and the background created by artificial sources.
3) Sensory overload: Stimulation by the synthetic material causes a reduction of responsiveness at the level of the receptor system (adaptation) or the central nervous system (habituation).

Some authors also believe that females can perceive their own pheromone, and that in its presence the calling or mating behavior could be affected.

The contribution from each of these mechanisms to mating disruption may largely depend on the nature of active ingredient, its concentration and its distribution in space and time. Trail following, for example, is caused by an attractant and cannot operate effectively with an incomplete pheromone. It also depends on the release rates of the dispensers which have to be within an optimal range. Masking, on the other hand, probably increases with the strength of each source as well as the overall amount of chemical per hectare. Sensory overload can be effective outside of the insect's responsive phase, and may therefore be the only mechanism to take advantage of a dispensing system operating around the clock.

It seems logical to assume that a candidate disruptant chemical lacking one of the qualities would need to be applied at a higher amount:



Contributions from various mechanisms add up to mating disruption (hypothetical); 1) an attractive, 2) a non-attractive ingredient.

BIOLOGICAL TESTS

Practical entomologists know that the only reliable test for a pheromone formulation is a field experiments carried out over several hectares for several years. While this experimentation is required to prove efficacy, it can hardly be used to screen compounds or optimize dispensers.

A convenient technique to be used on a smaller scale is to treat a surface of 10 to 100 m square with dispensers and place a trap with pheromone or virgin females or, in a more stringent test, tethered females (mating stations) in the center of the plot. One of the problems is that the degree of mating disruption, calculated from concurrent catches or matings in the check plots, is only valid if the population density is the same throughout.

For evaluation of chemicals and dose effects, laboratory bioassays are more convenient. Various experimental designs have been described in which males were observed flying to calling females under the influence of test chemicals. A comparison of results obtained with these tests could provide information on the weight of different mechanisms. Since trail following is one of them, improvements in the chemical knowledge of the pheromone and the attractancy of blends are equally useful. Other tests could be used to check for additional mechanisms.

Test procedures for mating disruption and the mechanisms to which they could be related:	False trail following	Masking of odor plumes	Sensory overload	Other
1) Mating of tethered females in the field surrounded by dispensers	+	+	+	+
2) Male captures in the field with pheromone traps surrounded by dispensers	+	+	+	
3) Male flight in the wind tunnel to female or pheromone surrounded by dispensers	+	+	+	
4) Male flight to female in the wind tunnel in uniformly permeated atmosphere		+	+	
5) Male flight to female in the wind tunnel after previous exposure to test chemical			+	
6) Optimizing attractant source for males	+			
7) Calling behavior of female in presence of chemical				+
8) Mating of pair in confined space with test chemical			+	+

DEVELOPMENT OF FORMULATIONS

A formulation for mating disruption must release the active material into the atmosphere throughout the space and time of insect mating activity. In most species the amount has been in the range of 5 mg of pheromone per ha. Between the extremes of a totally uniform distribution and the release from a few strong sources there is obviously an optimum which needs to be determined for every species.

The production of a convenient and inexpensive formulation capable of releasing the active ingredient throughout the season is a challenge industry is still facing. Some of the difficulties are protecting the chemical from heat, solar radiation and oxygen and avoiding unnecessary loss from evaporation during the hot periods when the insects are not active.

An important step in the development and evaluation of formulations is the measurement of release rates of dispensers and concentrations of airborne pheromone. A major breakthrough in recent years has been the development of an electroantennographic measuring device for field use.

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MATING DISRUPTION IN THE EXPERIENCE OF ISAGRO - ENICHEM AGRICOLTURA

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Earlier Work

In the course of our researches about pheromone utilization in the direct control of pests by mating disruption, we started considering the formulations for the conventional spraying equipments, like wettable powders[1]. The difficulties arising from low persistency of formulates in the field, the high cost of active ingredients and the registration concern pushed us to discard this approach.

Later our attention was focused on male disorientation with low pheromone dosages (2-10 g/ha) and on the attracticide method[2]. The results of several trials, performed even on wide areas, were generally not satisfactory, with the exception of the IPM trials against *E. acerbella* on carnation flowers[3] and the trials against *E. kuehniella* in mills, where the attracticide method showed its efficacy within one generation of the moth[4].

Dispenser Design

After the appearance on the market of systems working with large dosages of pheromone (>100 g/ha), potentially able to control higher densities of population, we conceived a simple dispenser, apt to held high amounts of semiochemicals, especially suitable for the pheromone of codling moth, which presents some difficulties in the release and chemical stability.

The macrodispenser, in its "standard" form, is hence made by a 50x30x2.7 mm resin-treated filter paper, equipped with a Nylon hook for the hanging on branches.

This dispenser may be impregnated with the pheromone of *C. pomonella*, with that for Leafrollers or with a mixture of both, as necessary.

In the attempt to improve the dispenser performances we observed the modifications on the rate of release induced by variation of dispenser size and the addition of inert co-formulants.

The protection of the active ingredients from atmospheric agents has been investigated exposing various formulations to continuous UV-irradiation; our tests confirmed the requirement of the combined action of both anti-oxidants and UV screeners and suggested their minimum amount to get a satisfactory protection.

The question of the necessary amount of pheromone has been studied observing, during various years of experimentation, the performances in the field of dispensers containing different quantity of semiochemicals.

Two series of dispensers were periodically weighed and analysed by GLC to follow the release process; data have been corrected for the moisture content by weighing empty dispensers.

The release from a dispenser loaded with 600 mg of codlemone, designed for a single application, was limited only to about the 50% of material, wasting the 25% for degradation and the 25% remaining caged into the substrate.

Thus we considered the opportunity to make two distinct applications during the season, using dispensers loaded with a lower amount of pheromone. Release and efficacy trials showed an optimal loading between 300 and 350 mg of codlemone and the dispensers were able to work well for a period ranging from 45 to 65 days, utilizing the 65-70% of loaded material.

Later Work

During the last 2-3 years the experimentation of the mating disruption technique against *C. pomonella* and apple Leafrollers was carried out directly by Organisations and Farmers Associations, with the aim to test in a realistic way, the true potential and the flexibility of the method when delegated to the users.

In 1991, for instance, more than 30 trials have been carried out in orchards ranging between 1.5 to 12 ha, most of them around 2 ha, presenting a great variability in agronomical and climatic characteristics.

Two applications of dispensers, the first in April-May and the second in July, were performed in every orchard distributing an average of 300 dispensers per ha excluding the external protection border. Each dispenser was loaded with 350 mg of codlemone in the case of codling moth or 350 mg of codlemone plus 300 mg of a mixture of (Z)- and (E)-11-C_{14}:Ac in the case of combined mating disruption against *C. pomonella* and Leafrollers. The ratio of cis- and trans-isomers varied according to the prevalent species of leafroller present in the area; for the same reason we employed also Z9-C_{14}:Ac for Trentino, Switzerland and Austria.

Each dispenser contained also 300 mg of an anti-oxidant and 100 mg of an UV screener.

According to the curves of the release rate, the dispensers perform a regular duration of 45-65 days, in agreement with the climate and the exposure. After this limit, the release of codlemone is progressively reduced to zero; the tetradecenyl acetate is released regularly up to 90 days, then it slows down gradually.

During the first 40 days of exposure the release rate was close to 5 mg per dispenser per day, that is 60 mg/ha/h, in the case of codlemone; slower is the release of (Z+E)-11-C_{14}:Ac: about 3 mg per dispenser per day, that is ca. 37 mg/ha/h.

Results and Discussion

The 1991 season was particularly favorable to the development of codling moth and troubles were recorded in some trials. Anyway, the following observations were confirmed:

- working for several years on the same orchard, the situation tends to improve if the starting popolation is not too high. In 1990 the suggested threshold for the density of population was fixed at 5% of infested fruits at the harvest in the preceding year; the 1991 trials proved that in the presence of conditions particularly favorable to the development of pests, the threshold should be more careful.
- the orchard size is a crucial factor, because the implementation of an effective external belt is more and more expensive as orchard size decreases and, usually, it is not possible to perform completely. The "border effect" is not

only due to mated females immigration but also to an inevitable lowering of pheromone concentration in the borderline.

- the presence of centers of aggregations such as warehouses, lights, not treated trees etc., is hardly neutralized with a higher concentration of dispensers; the local infestation tends to expand in the whole orchard.
- the risk of infestation due to other pests is still present in most fruit-growing areas; unexpected chemical treatments are often necessary.
- the uncomplete control during the first generation may lead to an infestation which can be unobserved, but which will be the basis for an explosive development of the pest in the second generation. This fact has been often ascribed by users to a too short persistency of dispensers, but it depends mainly from the unbalanced ratio between the density of population and the concentration of pheromone.

To give an idea of the extremely different situations we got during the last season, we report here some representative cases:

- apple orchard in Gemerello (TO), 2 ha, 4th year of mating disruption: in 1988 and 1989 were performed some chemical treatments in support on 50% and 20% of the area[5]; in 1990 and 1991, no need of insecticide spray, no damage from codling moth, only 1% from leafrollers;

- apple orchard in S. Alberto (RA), 3 ha, 2nd year: in 1990 <1% damage by codling moth, chemical treatment against *A. pulchellana* which made 10% damage at harvest; in 1991, it was necessary to perform chemical treatments in support against both codling moth and leafrollers; at harvest 2% damage by *C. pomonella* and 5-10% damage by *P. cerasana*;

- apple orchard in Meldola (FO), 2 ha, 2nd year: in 1990, 10-15% of damage by codling moth; in 1991, performed an early season treatment, damage at harvest 20% by codling moth and <1% by leafrollers;

- apple/pear orchard in Legnago (VR), 5 ha, organic farming, 1st year of mating disruption: in 1990, performed 9 treatments with *Rhyania speciosa*, damage at harvest 30-50% by codling moth; in 1991, performed two spring treatments and two at the end of the season with *R. speciosa*, at harvest 10% damage by *C. pomonella* and <1% by leafrollers;

- apple orchard in Rovereto (TN), 4 ha, 1st year: in 1990, traditional pest management with damages below the tolerance; in 1991, performed localized treatments on some part of the border, at harvest 2% damage by *C. pomonella*.

As one can see, in most cases the results are quite logical, but bewildering events occur too as in the cases of Meldola and S. Alberto where we registered the unforeseen outbreak of *C. pomonella* and the appearance of a different species of leafroller.

Conclusions

Among the fruitgrowers, the mating disruption on apple induces some uncertainties, which rather than dissipated are more radicated as more data become available.

The major drawbacks attributed to the method are:

- it is difficult to find orchards with the required characteristics of size, isolation etc.
- the infestations of *C. pomonella* are often unpredictable;
- there is a high probability of appearance of other pests

like *C. molesta*, *C. capitata* or leafrollers with a pheromone blend different from (Z+E)-11-C_{14}:Ac as *S. ocellana* in Trentino or *G. lobarzewsky* in Switzerland and Austria;

- there is a frequent need to perform chemical treatments in support, due to the above situation or to a late explosion of codling moth or leafrollers populations;
- the cost of application is still high and not yet comparable to the traditional pest management costs.

Considering these negative points, the application of the mating disruption method is scarcely justified on a commercial orchard, whose products cannot be satisfactorily prized.

The situation is totally different in the case of the "organic farms", which currently in Italy represent about 1% of the total production of apples-pears, for about 1000 ha, and in the case of the farms "in conversion", that is passing from the traditional or integrated pest management to the organic farming regime. These fruit-growers are in the position to adequately prize their products; often they are connected to distributors or to transformation industries utilizing even the rejected fruits, provided they are totally residue-free. The price of organic apples or pears is often three- or fourfold the normal price of traditionally-grown fruits.

For these producers the control of codling moth is the major problem, since the *Bacillus thuringiensis* preparates are inactive, viruses are not allowed and the natural products such as *Rhyania speciosa* and *Azadiracta indica* are expensive, with low persistency and show a moderate activity. The mating disruption, even with its limitations, remains the most valuable alternative, also from an economic point of view.

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AVOIDING PITFALLS IN CONFUSION: A REVIEW ON MATING DISRUPTION

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In more than ten years of development work with pheromones, on more than 5000 hectares of trial area in Western Europe, BASF together with government institutes have been able to collect a considerable amount of know-how on the mating disruption technique. In the process it has been observed again and again how some experimentators fall into the same pitfalls. The problem is that the experimentator tries to handle the pheromone, using the mating disruption technique, as if it was an insecticide. After all, its not always easy to back off from an approach that has served well during maybe even 20 to 30 years of trial work.
It will be discussed some of the factors that are crucial quite specifically in mating disruption, but whose importance is perhaps sometimes underestimated.

1. Population density

For instance, one decisive criterion for successful mating disruption - the population density - often is not properly understood and respected. It boils down to this: the mating disruption technique is most successful when the population density in the plot approaches zero, since this also means the chance of male and female accidentally meeting each other likewise approaches zero. The consequences of this statement are clear, but somehow the logic in it is difficult to accept. The refrain we most often hear is either "But it must work as well at higher infestations or population densities, too, just like insecticides", or "The method must be safe".

But, haven't we discovered that soil herbicides, for example, can only work properly if the soil is moist? Why do we think we can expect more of the pheromones and ignore the preconditions for their use?

We could perhaps develop more understanding of the term "population density" if we ask ourselves the question, just when do the females make use of the pheromones to attract males. The answer is, only when the distance between male and female is so large, that other methods of locating a mate can no longer function. Or in other words, when the population density has reached such a low level, that pheromones are necessary to find a mate.

The female sexual pheromones thus can be used for the mating disruption method only when they are also necessary for the females, which is only when the population density is too low. If we then also consider the factor of time, by which I mean the fact that males and females are active and flying for 2-3 weeks (as in the case of the males of <u>Lobesia botrana</u> and <u>Cydia pomonella</u>), then it is easy to imagine that a male can come by chance within the range of a female and pick up her scent (Neumann 1992). This scent ~~certain~~ly is so concentrated up to a distance of 10 to 50 cm, that any surrounding pheromone atmosphere would not be able to compete or cover it up. Even beyond 50 cm, the scent will carry as far as 1 to 3 meters, depending on prevailing winds (think of the smoke of a cigarette), with concentrated pockets of scent that disperse only slowly in the surrounding pheromone atmosphere (Murlis 1981). To minimize the probability that a searching, flying male comes across the scent of a female, the population density must be kept extremely low.

The population density can be measured only indirectly today by way of the previous generation's infestation level on shoots and fruits (not forgetting the windfall!). Population density itself is dependent on a variety of factors, such as flying or living space of the insects, growth pattern of the crop, etc.

According to practical experience, we recommend that the following infestation thresholds of the previous generation must not be exceeded for the listed doses, if pheromones are to work successfully in the subsequent generations:

Table 1:

Crop	Pest	Dose g/ha/month	previous generation? which?	Threshold (Initial popul.) %
Grapes	Eupoecilia ambiguella Hbn.	50	1st gener.	10
	Lobesia botrana Schiff.	25 - 35	1st gener.	4 - 5
Apples, pears	Cydia pomonella L.	25	last generation of last year	1 (incl. windfall)
	Adoxophyes orana, F.v.R. Archips spp. and others	25	last generation of last year	1 (fruit) 5 (shoots)
Peaches	Cydia molesta Busck	30 - 35	last generation of last year	1 (fruit incl. windfall) 3 (shoots)

In the case of summer fruit tortrix, another pitfall is to assess only the damage on the fruit. The infestation (population density) on the shoots is just as decisive. Another pitfall is to confuse the infestation threshold listed here with the damage threshold, whereby this also varies from region to region. Take the grape-berry moth for example: it is 5% for the second generation in more northern regions, up to 20% in southern latitudes, but between 0-2% for table grapes in the far south of Europe.

2. Insecticide use and beneficial fauna

The experimentator, or later the commercial user, will often find himself in the situation of not knowing the initial population, or of finding it higher than the listed level. In this case, one or more targeted insecticide applications are necessary to reduce the population density. Following such an insecticide application, the efficacy of it must be assessed in order to determine whether the population density truly has been adequately lowered. This step is frequently omitted, in the false assumption that an insecticide treatment can never fail (another pitfall).

There is a lot of resistance to the idea (and sometimes it is even rejected) that when using mating disruption for the first time, it must be preceded by an insecticide treatment to reduce the insect population. The argument comes that this would hurt the beneficial fauna. It is forgotten that in the past the affected area was regularly treated with insecticides, and the recommended insecticide treatment would be only the last in a long series of insecticide sprayings. Thus in fact the build-up of the desirable beneficial populations would begin only one generation later. (Of course, the 1st generation of the respective pest would be treated twice in this case: as a juvenile with insecticide, and as an adult with pheromones.) If the insecticide treatment in question were to be omitted, however, the success of the mating disruption technique could be delayed for a couple of years. The need for an insecticide spraying might well arise after all.

Often another approach is observed: if the control is poor for the first generation, the experimentator waits for the results in the second generation, in the hope that mating disruption will work then. There is little justification for this. Although the beneficial fauna may have made a comeback in the meantime (Schirra et al. 1991), and the pheromone atmosphere may be better protected by fuller vegetation (especially in grapes) and therefore be more concentrated, this is counteracted by the likelihood of an increased reproduction rate for the pest.

3. Population development

The success or failure of the initial pheromone treatment depends not only on the momentary population density, but also on the way it is developing. For example, is a high population density decreasing as time goes by because of natural biotic or abiotic factors, or is just the opposite happening? Figure 1 shows an example with E. ambiguella (Kast et al. 1991), in which an insecticide (B.t.) was used successfully to reduce the expected high infestation, on the basis of a high damage level (up to 43%) in the foregoing 2nd generation. Several favorable factors came together here, however. Firstly, the treatments could be timed precisely because of continual monitoring of egg and larval development; secondly, temperatures were favorable; and thirdly, the population was falling naturally. The 20-40% infestation observed in the 2nd generation theoretically would have caused an increase in infestation in the 1st generation of the next year amounting to perhaps 60 to 2000 larvae/100 flower clusters. Instead, an infestation of 28 was counted in the control, which can be interpreted as a natural decrease in the population density.

Figure 1: **Influence of population density of E. ambiguella on the effectiveness of pheromones**

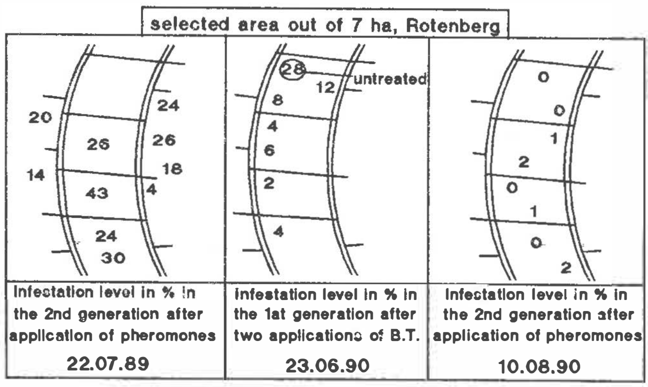


Figure 2: **Effect of initial population density (1st Gen. E. ambiguella) on the performance of first time use of pheromones**

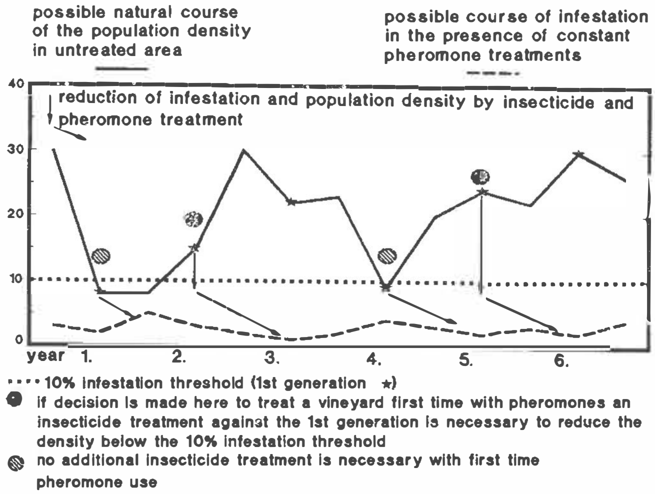


Figure 2 presents a theoretical example of potential regional population fluctuations, while also showing under which circumstances a first use of pheromones can be successful. It also shows that continued use of pheromones is likely to lead to success.

A mathematical example can show just how quickly population development can result in critical levels, even with only a few adults. A 2% infestation level, or 2 larvae per 100 clusters, could mean one female and one male. One female, depending on fertility or the number of laid eggs and the success rate for hatched and penetrating larvae in the following generation, can be responsible for the infestation levels listed in Table 2.

Table 2: Potential infestation from one mated female (%)

penetrated larvae / No. of laid eggs	100%	50%	25%	10%	5%	2%	1%
50	50	25	12.5	5	2.5	1	0.5
100	100	50	25	10	5	2	1

If we use our experience with L. botrana to set an infestation threshold of 4-5% (so that 5% infestation is not exceeded in the 2nd generation), the following assumption would have to be noted. If two adult females were to develop from 5% infestation, only 1-2% of the hatched larvae (at 50-100 laid eggs) should be able to succeed in burrowing into the grapes (providing an entryway for Botrytis). In the case of 100 laid eggs and a 5% burrowing or penetration rate, this would already mean damage of 10%. When the experience shows, that 4-5% infestation in the first generation leads to less than 5% in the second generation, then the natural factors that reduce the population thus must be considerable. The numbers show that just an additional 1 or 2 females suffice to raise the infestation above the damage threshold!

This example makes it clear just how much care must be taken to stay below the listed infestation thresholds for the previous generation.

Still another aspect must be considered in viticulture. If both species are present, and we take into account the infestation thresholds of 10% for Eupoecilia and 4-5% for Lobesia, then the sum of both infestation levels can easily rise above 5%. The conclusion is that the joint infestation may not be permitted to exceed 5% in the 1st generation when both tortrix species are present.

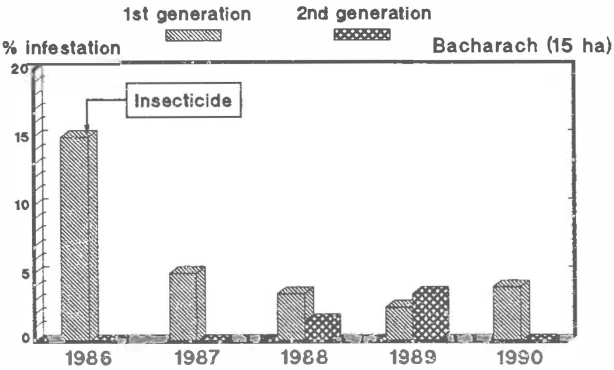
It was found in the trials on mating disruption which employed intensive, repeated assessments throughout the trial area that there were extreme differences in infestation intensity between the individual plots. Possible explanations include differences in microclimate, in the varieties, row spacings, cultural measures and so forth, but also differing approaches by the vinegrowers and fruit growers. The use of constantly changing insecticides in the plots, more or less flexibility in observing spraying dates, varying treatment of ground vegetation can result in very different infestation figures or population densities. This also illustrates the need for the even distribution of assessments throughout the entire treatment area. Only in this way infestation pockets can be located that could cause the population density to rise beyond the set level. And of course the influence of wind and immigration of mated females on the infestation levels in the border areas also is a relevant criterion.

4. Immigration

In the case of insecticides, the population density is reduced after every treatment. In the case of pheromones, the population density is kept constantly low.

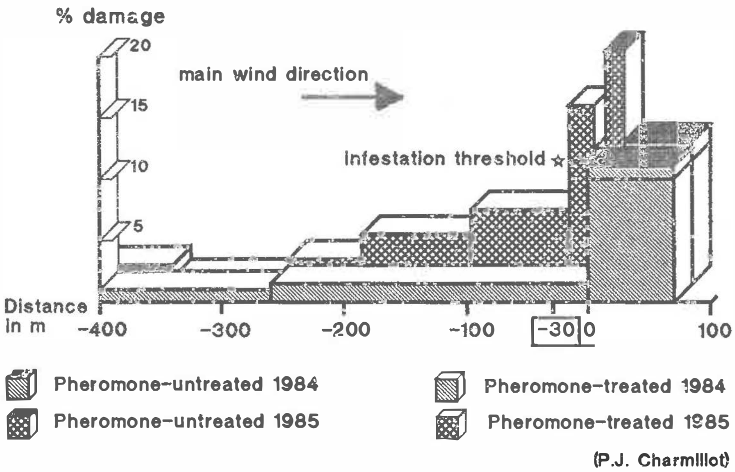
In fact, it would seem we could even gradually approach the zero level, since the probability of a chance mating gradually decreases as population density diminishes. This is not observed in practice, however (Figure 3). A slight infestation is found for each new generation, which most likely is due to immigration.

Figure 3: Control of grape berry moth (E. ambiguella) by using the mating disruption technique during several years



The term "immigration" will probably ring a bell for every research worker; it is generally assumed that mated females travel about 30-40 meters, though they don't always do so. Infestation assessments during pheromone trials permit such deplacement (site changes) to be traced. It is easy to determine that in most cases there is no notable deplacement, such as in the case of Eupoecilia ambiguella, where deplacement is limited to perhaps 2-3 vines away. But then the question arises whether this is generally true for every species. We have plenty of data indicating that the species behave differently. We certainly all agree that L. botrana is much more active than E. ambiguella. But E. ambiguella can show varying sorts of behavior, too. Charmillot (1987) was able to show this in trials (Figure 4).

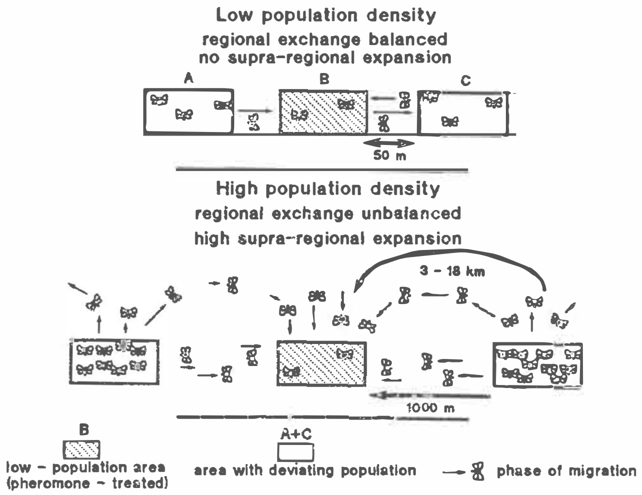
Figure 4: Damage pattern induced by different migration distance of E. ambiguella in different years



The first generation was the subject in each instance here, and the question was, what made the difference between the two years? The difference was the temperature. The temperature during the active phase of the animals seldom rose above 9-10°C in 1984, while in 1985 more comfortable temperatures of 13-15°C prevailed. These optimal temperatures of course encouraged the activity of the animals. Moreover, the lack of vegetation on the vines meant there was almost no barrier to flight. The infestation checks in 1985 showed immigration across 170 m from the untreated part of the vineyard into the treated part. But damage beyond the 5% threshold was observed only to a depth of 30 meters.

Besides favorable temperatures, it is known that a high population density, or rather a high population pressure can be the trigger for intensified dispersion behavior. Low population pressure probably results only occasionally in more modest movement from site to site within a shorter range. Under conditions of high population pressure, it seems likely that this would happen not only to a greater degree, but also over a greater distance, perhaps more than 1000 m, as has often been recorded with L. botrana in Germany (Louis, personal communication). It may also be assumed that increased population pressure also leads to behavioral changes in the animals. Mated females, for example, switch to dispersive behavior, move to higher air spaces and let themselves be carried by wind to new territory several kilometers away. Such behaviour was observed by the author in cases of high infestation density of leaf miners in apples. This sort of flight behavior would certainly result in uniform colonization of an area, since immigration comes from above and not from some side (Figure 5).

Figure 5: Population dynamic, model



Trials as well as commercial applications of pheromones would seem to confirm this. In 1990 in peaches in the Italian province of Ferrara, for example, there was a sudden, uniform increase in infestation, especially of the last generation; this coincided with a high infestation pressure in the region. An average infestation of 20% was recorded in the insecticide areas, that then also was found in the pheromone areas. Similar observations were made in 1990 with the 3rd generation of L. botrana in Bordeaux (Stöckel, pers. commun.) and with the 2nd generation in Wallis (Schmid, pers. commun.).

In peaches it is quite generally observed that late varieties suffer the most severely from an infestation of the last generation of C. molesta. The best explanation could be that early and middle varieties are not irrigated once they have been harvested. So new shoots and fruits don't develop.

The mated females still in the area find no place to lay their eggs and must immigrate to find one. The obvious place is of course the late varieties.

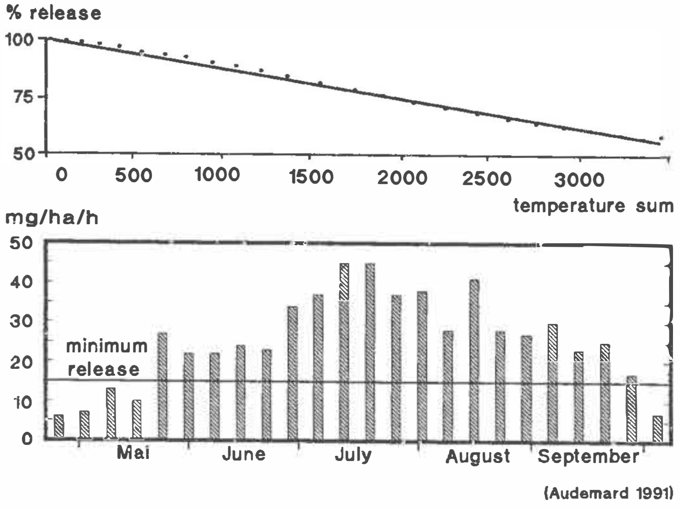
The same could very well apply for apples, where the female codling moths must leave the early apple varieties for the later ones.
One other important point must be made. Higher population pressure could result in increased flight of males and unmated females, taking them into neighboring areas with thinly canopied trees or bushes, into other fruit crops with a similar microclimate. There the females mate but fly back to the original crop site to lay their eggs.
This is why we recommend treatment of such neighboring areas to a depth of 30 meters.

No treatment is possible when the neighboring areas include other free-standing, tall apple trees, that frequently exhibit a high infestation density. In such a case, either the higher infestation in the disruption plots in the proximity of the tall trees must be tolerated, or a supplementary application of insecticide must be made, or the tall trees must be removed farther away and replanted at a more distant site.

5. Formulation and application rate

All of the various factors just described are of course also influenced by the dose level of the pheromones and the type of formulation involved, or the dispersion rate, and the way it develops throughout the active phase of the species involved. Theoretically there is the possibility of increasing the reliability of successful use of the mating disruption technique by increasing the release rate, which confines the active space of the signaling females (Linn et al. 1986). The cost of pheromones, however, makes this unfeasible in commercial applications. A nearly linear rate of dispersion is important, however, to maintain a fairly steady, sufficiently high pheromone concentration in the atmosphere. It is subject to the influences of vegetation level, growth pattern, tree height, wind direction and velocity.
BASF employs a formulation that disperses in a good linear pattern. Audemard was able to show this very well, with consideration of the temperature sum (Figure 6).

Figure 6: Codling moth pheromone (E8,E10 - 12OH) release in comparison with the temperature sum



In general it is found that the theoretical concept of completely dispersing a certain amount of pheromone into the atmosphere over a certain length of time is very difficult to put into practice. The chemical behavior of the pheromones at our disposal varies too greatly; environmentally safe plastics are not always suitable for each targeted dispersal rate. Moreover, the plastics may possess still undisclosed parameters that influence diffusion.

It suffices to say that it is almost an art to develop the right dispenser that will provide the optimum level of steady pheromone dispersion for every climate zone. Optimum means here that an excessive quantity is not used to achieve the desired release rate.

Conclusion

Numerous factors such as population density, fluctuation of population, immigration and also formulation and the possible impact on the performance of the mating disruption technique have been discussed here. In spite of straightening many relevant parameters for the success of the method, sometimes an uncertainty remains about a reliable control.

Nevertheless, the experience gained during several years from trials conducted successfully on several thousand hectars, as well as from the commercial use in different countries in Western Europe have proved the effectiveness of the mating disruption technique for the rational control of tortrix pests in grapes, peaches and apples.

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MATING DISRUPTION: IDEAS ON BREAKING THROUGH THE GLASS CEILING? (CAN WE JUMP-START THIS TECHNOLOGY?)

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ABSTRACT

In the United States, corporations have been judged to have established glass ceilings through which certain groups of employees do not get promoted. Senior executive positions are generally on the upper side of the ceiling. Women and minorities are generally those groups most likely to identify a glass ceiling that prevents them climbing up the corporate ladder. They can see the senior executives but can never join their ranks.

This paper seeks to present the idea that a glass ceiling is preventing the ongoing advancement of mating disruption, both in science and in commercialization. We can demonstrate a high degree of efficacy yet this is not consistent and commercialisation seems to be a very difficult task. The author believes that mating disruption has reached a point where further breakthroughs will only occur with the infusion of new ideas and completely new perspectives.

INTRODUCTION

In the early years, sections of the agricultural industry and the public were led to believe that large scale replacement of pesticides would be possible through use of pheromones with which insects could be made to 'jump through hoops'. This has not happened, and many of us have concluded with Pickett (1991) that "pheromones alone will... be insufficiently robust for the purpose of most agricultural production systems". I would add that many characteristics of pheromones also make them insufficiently robust for the purposes of agricultural chemical marketing programs.

DISCUSSION

Pacific Biocontrol Corporation recently sent a questionaire to over 45 disruption fellows in 8 different coutries asking them to rate discussion topics on the basis of interest and importance. Five discussion topics were presented, with 3-4 sub-categories listed under each research category. Results of this survey are presented throughout this paper to provide a basis for discussion on potential avenues for research that will lead to breakthroughs in both understanding and commercialization of this technology:

Rating by research area	Average 0=lowest, 5=highest
Principles of mating disruption	4.05
Implementation and Evaluation	3.86
Monitoring	3.78
Formulation and dispensers	3.60
Economics	3.60
Pheromone Molecules	3.29

Survey participants clearly identify an understanding of the mechanisms of disruption to be the most important topic. A greater understanding of mechanisms should lead to improvements in pest management applications. Nevertheless discussion of the mechanisms of disruption seems to have reached a plateau. How far have we come since Bartell (1982)?

Principles of mating disruption

When asked to rank the subject headings under the topic of principles, survey participants responded as follows:

Principles	Score	Rank in total survey (of 21)
Female response to pheromone: dispersal, fecundity and oviposition	4.34	1
Effect of high pheromone concentration on insect movement	4.32	2
Male response to pheromone: false trails, masking, sensory effects	4.02	4
Disruption with off blends, analogues and antagonists	3.52	17

Most of the research on mechanisms of disruption has been focussed on behaviour of the male moth. There is still a lot from studies of male responsiveness to pheromone blend quality and male flight patterns, in particular with reference to pheromone concentration. Most of this research is conducted in the laboratory, with little validation from corresponding field observation. Are we just standing still? Is there enough cross-over between the basic pheromone behaviourists and pest management scientists trying to understand mating disruption in the field?

Survey participants have identified the female response to pheromone, and the effect of high concentrations of pheromone as being the most important subjects. Very little is known with respect to these two subjects. At the Neustadt meeting of this workgroup, Sanders (1986) advised that 'an understanding of the interactions among locomotion, calling, oviposition and dispersal of female moths is as essential to understand disruption as is male behaviour'.

Semiochemicals modify behaviour at all stages of the insect life cycle. Understanding and targeting other facets of behaviour may be complementary to mating disruption based control strategies. It will also be important to understand temporal and spatial characteristics that govern the chemical mediation of these behaviours :

Unfertilized female interaction with environment	**Female calling**
Male response	Mating
Fertile female interaction with environment	Oviposition responses
Larval feeding preferences	Movement

Implementation and evaluation

The topic rated second by survey participants was that of implementation and evaluation. A move in subject area from principles to application.When asked to rank the subject headings under the topic of implementation and evaluation, survey participants responded as follows:

Implementation and evaluation	Score	Rank in total survey (of 21)
Research protocols: designing and evaluating experiments	4.02	4
Mating disruption and IPM: developing a systems approach	3.80	9
Commercial protocols: optimizing the potential for grower acceptance	3.75	11

Mating disruption research continues to be black magic rather than a science. Scientists face difficulty in publication of results due to lack of conventional statistical design. It is very difficult to replicate disruption experiments due to the large amount of acreage required by current protocols. This leads to high costs in terms of formulated product, manpower and potential crop loss. Further, use of experimental compounds is strictly regulated on large acreages, leading to the paradox of regulation prior to establishment of the optimum formulation. The supplier bears the cost of formulation and regulation, the research collaborator the cost of manpower and the collaborating primary producer the cost of potential crop loss.

Are optimum research protocols being used in assessing disruption programs?. Could more information be obtained more rapidly using smaller plot sizes, increased replication and intensive monitoring? Current protocols evaluate male response to pheromone lures and crop damage. Yet, the essence of disruption is the mating success rate of the female insect? Immigration, male response and crop loss are secondary. Biocontrol research cooperators have shown clear differences between formulations and dose response relationships in plots no larger than 50x50m. This research combines direct field observation (during the active mating period) and monitoring with feral female traps (virgin female baited traps, tethered females, clipped wing females and mating tables) and pheromone traps.. Female based monitoring systems are very sensitive to differences in formulation efficacy.

With diminishing resources both in the public and private sector, it is imperative to design research protocols where one gets the 'most bang for the buck'. In the same way as fruit production, we should endeavour to increase our return per acre. Should this be called '***high-density***' research?

Development of a systems approach requires a comprehensive understanding of pest and crop ecology as well as human sociology. Implementation of these systems requires comprehensive 'personalized' end-user protocols. Mating disruption is not a robust control technology, but rather a strategy that can only massage pest behaviour with an expectancy of beneficial results.

'As with any management tool, the operational use of pheromones must be considered in the context of an integrated pest management system. Viewed in too much isolation, too much may be expected and too much promised, **and if expectations are not met, support for future essential research may be withdrawn**' (Sanders, 1989).

Initial expectations for disruption have not been realized, and this has created a residual of negative attitudes both in the research and the commercial sector.. For example, a US biotechnology company recently conducted a survey of University of California entomologists and extension personnel. Over 75% of those interviewed considered MD as a technology in the research and development phase. Less than 10% of those interviewed were able to think of any commercial scale use of mating disruption in California. Yet, mating disruption of oriental fruit moth on peach and nectarine has been commercial since 1987, and pink bollworm since 1978. In 1992, mating disruption of OFM was the foundation of pest management control programs on over 10% of California peach acreage. Do both public and private sectors of the pheromone industry need to improve their public relations?

Biocontrol has been very careful in positioning codling moth disruption. Rather than market a codling moth control product, the company has marketed a new pear or apple pest managment system. Intensive user education and technical support has been necessary. As indicated to the horticultural press, 'We strongly suggest that anyone using [Isomate-C for codling moth] needs to not look at it as a stand-along technique (Stover, 1991)'. Profitability has been set with break-even goals in the initial years of product introduction. The company has developed a series of end-user protocols, attempting to massage these protocols for each specific region of product use. Considerable attention has been given to secondary pests and beneficial arthropods, and the likely population dynamics of each as one takes an orchard through the transition from conventional broad spectrum to pheromone based control systems.

Monitoring

When asked to rank subject headings under the topic of monitoring, survey participants responded as follows:

Monitoring	Score	Rank in total survey (of 21)
Using and interpreting pheromone traps in disrupted blocks	4.09	3
Interpreting pheromone traps baited with variable dose rate septa	3.82	7
Use of other devices: bait pans, light traps, virgin female traps	3.43	18

Increases in our understanding of mechanisms will come through advances made in the art of monitoring. Mating disruption affects more than just a male moth response to a pheromone source. Has monitoring progressed much over the past 20 years? Considerable duplicative effort in the Pacific coast is now focussed on evaluation of high dose lures (10-15mg/lure) in trapping studies designed to correlate male response to high dose lures with fruit damage in the field.

It is clear that synthetic pheromone traps are user-friendly tools well understood by both researcher, pest management specialist and the farmer. Does the male cause fruit damage? What does one learn about the complete system by measuring the presence of an insect in a sticky trap? Does presence of male moths correlate with presence of mated ovipositing females?

An equal amount of research effort needs to focus on development of monitoring tools that measure female response, is mating delayed, is fecundity reduced, is oviposition taking place? Where does mating and oviposition take place in both space and time?

How can we do this? (I do not think this is quantum physics.):

1. Direct field observation of insects

Mating disruption interferes with the communication between male and female insects. We can start to understand this effect by observing field behaviour in the presence and absence of pheromone. Little information on female behaviour can be gained from measuring male response to pheromone traps. In 197?, Lingren advanced the understanding of PBW disruption through direct field observation of PBW mating behaviour and oviposition. Similar research has also focussed on field behaviour of noctuid insects (Heliothis/Helicoverpa and Spodoptera), however few direct observations have been made with respect to tortricid behaviour in fruit and vine crops.

Tortricids are small in size and permanent crops have very large and dense canopies. Pheromone traps are easy to use and researchers continue to depend on inferences drawn from male response to a pheromone source. Perhaps the use of field cages could facilitate nocturnal studies with small insects. We need to break through this glass ceiling and look at the whole system from a higher vantage point.

2. Use of light traps.

Prior to the introduction of pheromone traps, light traps were a principal pest management monitoring tool. Light traps capture everything, including both male and female representatives of the target pest. In recent years, however, they have been all but abandoned, due in part to difficulty of use compared to pheromone traps (more messy and more insects) and selectivity of capture (advanced physiological age of females). Technical difficulties also arise due to lack of power sources in the field.

The disruption system will be understood most completely when information is generated from as many different sources as possible. Population assessment based on light trap captures should be used in conjunction with data from other techniques. Any technique should capture relatively the same set of insects from treated and untreated fields. Any differences, especially in percent quality of physiological state, are likely to be highly significant.

3. Use of food baits, with subsequent dissection of females to establish mating status and physiological state.

Like light traps, food bait lures were very important monitoring tools prior to the introduction of pheromone traps. They also capture both male and female moths. However, it is now often argued that food lures are of very limited value as they capture females of advanced physiological age, mated and having laid many of their eggs. The point is that food lures capture females, and through comparison between treated and untreated fields one can clearly establish relative differences in mating success and oviposition capacity.

Further, in a study from 1986-1988, food bait traps were used very effectively in a grid pattern to measure OFM mating disruption success in the interface between treated and non-treated fields. Through sexing and dissection of females, correlated with fruit maturity, this study clearly documented the movement of mated females from an untreated field into an adjacent treated field when fruit in the treated field started to ripen (Kirsch Weakley and Zalom, unpublished results).

Similarly a grid of bait traps for CM was able to measure higher population levels and increased mating success in edges of pear orchards compared with very low captures within the fields (Kirsch Weakley and Zalom, unpublished results). Such a grid could potentially be developed as a tool to predict breakdown of control in field edges, either due to immigration or due to increased mating success. It is generally in field edges where disruption programs start to breakdown (see also comments in section on pheromone molecules).

North american mating disruption workers seem to be very reluctant about using bait traps. This is likely due to the messy nature of these traps, mostly based on mixtures of frementing sugar-water solutions, and due to inconsistent trapping capacity. Careful research could establish the attractive components in the headspace of such solutions and these could then be formulated as solid lures. Do flowers only attract mated females? It is possible that certain blends of attractive volatiles could select for capture of specific physiological status, eg. pre-oviposition, oviposition or extended host searching (movement between hosts).

Finally, when targeting both male and female insects, it is very likely that these attractive component blends could even be formulated into baits that would attract the insect to a lethal toxicant dose. This would move semiochemical control technology into the mainstream, away from simply manipulating male behaviour to prevent female oviposition.

Formulation and dispensers

When asked to rank subject headings under the topic of dispensers, survey participants responded as follows:

Dispensers	Score	Rank in total survey (of 21)
Factors affecting release rate	4.00	6
Multi-species disruption: opportunities and problems	3.68	12
Methods of application: economics, efficacy, acceptance	3.61	14
Characteristics of controlled release devices	3.11	20

Mating disruption is dependent on sufficient atmospheric permeation with synthetic pheromone components. I am sure that my colleagues on this panel will be discussing this subject in considerable detail. I am a clear example of what I see as one of the hurdles in disruption science, an entomologist with limited understanding of chemistry, the flip side of the chemist with limited understanding of entomology. The extent of disruption is much influenced by the factors that affect release rate. Some of my colleagues in the US have coined the term 'under-disruption' for those formulations which do not release to the expected degree when placed in the field.

Multi-species disruption will be necessary to implementation of this technology in many cropping systems. This is being practised by BASF for CM and LR in pome fruits and for OFM and Anarsia in stone fruit; by ShinEtsu for two tortrix species in tea; and by various researchers in cotton (Pink bollworm, Spiny bollworm and others.). Often, such disruption systems are aimed at management of closely related species in the same crop (Heliothis zea and virescens; Synanthedon pictipes and exitiosa; Choristoneura, Platynota, and Argyrotaenia leafrollers).

Multispecies disruption is not clearly understood. How much interaction is there between pheromones specific to each species? What behaviour does this interaction induce? What is the effect on reduced mating success in all target species? Small plot field studies using virgin female techniques could be undertaken to assess if there are dose response relationships in the amount of pheromone required to suppress a certain percentage of mating, comparing the minimum amount of pheromone required when pheromones of different species were released from the same point with that required when pheromones of different species were released from different points within the same canopy.

Optimum positioning of any disruptant formulation is poorly researched. At Biocontrol, we maintain that the success of disruption is very dependent on the correct placement of dispensers. With our tree fruit products, we guide users to place dispensers in the upper part of the canopy, that part of the crop where moth activity is believed to be highest (as demonstrated by pheromone trap catch studies, location of fruit damage and historical literature records.) We only have very limited understanding of the mating behaviour of the pest, and limited knowledge of the behaviour of disruptant pheromone plumes or clouds within the crop canopy. If one could couple a clearer understanding of mechanisms (both female and male) of disruption together with a more precise measure of pheromone behaviour in the field, it is likely that one could optimise the placement of pheromone formulations. This would need to evaluate both vertical placement in the canopy, as well as distribution of the pheromone sources horizontally within the crop (perhaps higher application rates on edges, lower application rates in the centre).

Economics

When asked to rank subject headings under the topic of economics, survey participants responded as follows:

Economics	Score	Rank in total survey (of 21)
Cost & benefit analysis: mating disruption, insecticides and IPM	3.82	7
Impact of natural enemies in pheromone-treated blocks	3.64	13
The impact of secondary pests	3.59	15
Role of mating disruption in resistance management programs	3.38	19

Disruption-based economics are of principal importance to the end-user, and of much less concern to the disruption scientist concerned with understanding basic mechanisms. However, economics and uncertainty are probably the two major factors limiting widespread use of disruption based systems. Why pay $130/acre for CM control with strings attached, when the same $130 will buy CM control with a bang? Should we continue to design disruption products for key pests only to see minimum rates of adoption due to factors that have little to do with direct product efficacy? Can pheromone products only gain market share when subsidized by formulators (sold for uneconomic return) and/or government (research and extension scientists)? This is clearly unsustainable.

Survey participants clearly support development of detailed cost-benefit studies It would appear that only one study has been published, that on pink bollworm in Arizona (Stone et al 1986). Pheromone based pest management systems are now well established for oriental fruit moth, grape berry moth, codling moth, tomato pinworm, diamondback moth, beet armyworm and tea-tortrix. It is important that economic studies assess these systems. Such cost-benefit analysis would need to account for all direct and indirect factors? It is not appropriate to simply compare the cost of insecticide for the key pest with the cost of pheromone. Formulae will need to be developed to measure the cost of enhanced natural control of secondary pests, the cost of changes in economic damage sustained by secondary pests, the cost of changed agricultural practice, irrigation, thinning, pesticide application, the changes to perceived or actual quality and marketability of harvested produce and the changes in environmental and human quality, especially that of farmer labour.

How does one value in economic terms a sense of well-being? In many ways, similar economic models are being developed to quantify the cost of insecticide resistance (Clark and Carlson 1990), or the cost of environmental development programs (World Resources Institute 1992). World Bank or US AID economic impact studies may be required to measure, in economic terms, the loss of wilderness prior to approval of funds for development projects. Creative economists can likely use similar economic models as part of cost-benefit analysis studies that evaluate both direct and indirect economic factors.

Pheromone molecules

When asked to rank subject headings under the topic of pheromone molecules, survey participants responded as follows:

Pheromone molecules	Score	Rank in total survey (of 21)
Measuring pheromone concentrations in crop canopies	3.80	10
Stability and longevity of pheromones in the environment	3.59	16
Modelling pheromone plume structure in the environment	2.49	21

It is difficult to understand that the same survey participants would give the highest priority to the further understanding of mechanisms at the same time as giving the lowest priority to understanding the behaviour of pheromone molecules. These two areas of research are completely interdependent. Bartell (1982) already states that 'the actual mechanism (of disruption) will be determined largely by the release technique used'. It is this author's belief that the development of more robust systems is dependent on more complete behavioural knowledge: firstly, behaviour of the insect - the understanding of mechanisms underlying communication, both in the female and the male, and secondly, a more complete understanding of the behaviour of pheromone molecules in the field.

The recent developments in measurement of pheromone concentrations in the field, both chemical air-sampling and biological electro-antennograms will lead to significant improvements in our understanding of field phenomena. Ogawa (1990) gives us a simple explanation for edge effects. Measured concentrations of pheromone in the edges of tea fields are <50% of those in the centre of the field, and 30% lower than those required to maintain disruption at an economic level (Ohtaishi, 1991). All of us are very eager to learn of results from field applications of the Kaiserslautern portable EAG (Koch 1990).

Perhaps my greatest disappointment is the low importance that survey participants attach to modelling pheromone plume structure in the environment. Biometeorologists have developed a number of very detailed models with respect to air movement within and between the crop boundary layer interface (eg. Gao et al. 1989; Shaw 1984). These models have been applied very effectively in pest management systems that require prediction of small particle dispersal, in particular plant pathogens (Aylor 1978).

SUMMARY AND EXHORTATION

Is mating disruption a leading edge technology? Or are we losing the edge? Mating disruption has certainly come of age, but the adult is not robust. Where do we go from here?

It should be possible to build a very robust disruption system if one can

a. Predict movement of the pheromone under known meteorological conditions, and validate such predictions through either chemical or biological measurement of pheromone concentrations

b. Develop a very clear understanding of the mechanisms of disruption through careful detailed behavioural understanding of both male and female insects

c. Design formulations, use guidelines and crop pest management systems that address the characteristics from a. and b. and incorporate the limitations of chemistry and the ecology of cropping systems.

and d. Integrate mating disruption technology with strategies that manipulate the broadest range of target pest behaviours.

At this point it seems appropriate to suggest that development of multidisciplinary teams are likely to be an ideal way to address these requirements. Entomologists, behavioural scientists, ecologists, chemists, economists, and meteorologists are all needed in developing a complete understanding of these factors.

Will we break through the glass ceiling? Is disruption a leading edge technology, or are we just losing the edge?

I would like to encourage lively discussion amongst all of us over the coming week, so that we can walk away revitalised and refreshed in our endeavour to build those disruption systems that will stand alone. It is time to break through the glass ceiling. For if expectations are not met in the short term, support for future essential research and product development will be withdrawn'

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PHEROMONE DISPENSERS AND FACTORS AFFECTING THEIR EFFICACY

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ABSTRACT

Restricting the focus to pheromone dispensers which are disseminated throughout the crop by hand placement, various dispenser concepts are discussed in relation to the factors which affect their efficacy. The most important technical parameters of pheromone dispensers are release rate, longevity, blend integrity and the stability of both the active ingredients and the device. These parameters are examined in relation to the type of polymer used in the manufacture of the dispenser; the chain length, functionality and unsaturation of the pheromone molecules and other abiotic and biotic factors.

INTRODUCTION

All hand placement pheromone devices may be said to consist of two parts, a reservoir and a barrier, and the two most important parameters which regulate the release of the pheromone from such a device are [a] the concentration of the pheromone in the reservoir, and [b] the barrier thickness. However in some dispensers the reservoir is also the barrier (eg. rubber septa, PVC rods); in other dispensers, the reservoir is partially filled with air and also partially sealed (eg. the hollow fiber system); in others, the reservoir while being partially filled with air is completely sealed (Mitsubishi Rope, Biocontrol Isomate system, BASF ampoule system and the Consep Membranes Biolure system); and in still others, the reservoir is also a barrier, but in addition there are also one or more distinct barrier layers (Hercon trilaminate system and the NoMate Spiral system).

Other factors which affect the transport of the pheromone components from the reservoir through the barrier include, the type and stiffness of the polymer, codiffusants, molecular weight and functionality of the pheromone molecule, the size of the dispenser and abiotic factors.

POLYMER TYPE AND CROSS-LINKING

Polymers such as polyethylene, polypropylene, polyvinyl chloride, polyvinyl acetate, acrylated polyethers and all co-polymers of these materials have been used in the manufacture of pheromone devices. Mylar, Celcon and polyesters which are impermeable to pheromone type molecules have also been used in pheromone devices. Cyclodextrins, starch and xanthan gums could have some utility in pheromone release systems but as yet have not been thoroughly investigated.

As the pheromone diffuses through the polymeric barrier it reorients portions of the chain in order to accomplish its migration; hence the greater the degree of cross-linking the slower the release rate. This is exemplified in the work of Smit et al. (1991) who working with acrylated polyethers, have shown that by cross-linking their high molecular weight polyether with tripropyleneglycoldiacrylate at 40% and 80% they reduced the amount of codlemone emitted by a factor of 46% and 80% respectively. Cork et al. (1989) have similarly reported manipulation of the release rates of a pheromone blend of triunsaturated acetates and alcohols by adjusting the proportion of various plasticizers.

CODIFFUSANTS

Codiffusants, when used in pheromone dispensers can affect the release rate either positively or negatively. The rate is altered because the barrier structure is changed by softening or swelling, or even solution of the polymer. The use of codiffusants is exemplified by the work of Wilk (1991) using a dispenser consisting of an impermeable polymer backing bonded to a polyethylene/ polypropylene copolymer. The thickness of the barrier should be less than 6 mil. In the example the barrier has an area of 20 cm^2 and the attractant is used as an ethanol solution.

% a.i.	codiffusant	membrane thick (mil)	release rate mg/day	field life (days)
10% trimedlure	none	0.8	22	27
10% trimedlure	0.1 g limonene	0.8	38	21
8% codlemone	none	0.8	22	36
8% codlemone	0.1% limonene	0.8	28	28
11.5% OFM mixt.	none	2.0	8.6	93
11.55 OFM mixt.	0.1% limonene	2.0	10	77

These data indicate that limonene accelerates the release; use of PVP was shown to retard release. Another feature of this system would appear to be that neither the concentration of the attractant not its structure has much influence on the release rate.

MOLECULAR WEIGHT AND FUNCTIONALITY OF THE PHEROMONE

Since Graham's Law of Diffusion states that diffusion is inversely proportional to the square root of the molecular weight it would appear that as the molecular weight of the pheromone increases the release will decrease. Although this is true within a class of chemical compounds moving through a barrier, a more accurate description is that other factors, including solubility and molecular shape most certainly influence the release rate. Heath et al. (1986) reported that it is possible to predict release rates of pheromones from rubber septa based on the retention times of the compounds from a liquid crystal column.

The dispenser mentioned above in the cited work of Cork et al. (1989) is reported to have elution characteristics of a polar chromatographic column where an aldehyde is released faster than an acetate; but an alcohol, although of similar molecular weight to the aldehyde is released at approximately the same rate as the acetate because of its polarity.

SIZE OF THE DISPENSER

Generally, the greater the surface area of the dispenser, especially those of the matrix type, the greater the amount of active ingredient emitted. To exemplify the effect of area on release rate, the example is from a Shin-Etsu patent (1987). The premise is that it is necessary to emit a pheromone at a constant rate, equal or greater than 0.6 mg/day/dispenser for at least 3 months. In this case the preferred embodiment is a polymeric tube with an inner diameter at least 0.8 mm and large enough to hold at least 100 mg of pheromone, the tube is sealed at both ends.

It is assumed that the pheromone concentration immediately around the dispenser is very small; if the release rate at t°C is ΔM, then:

$$\Delta M = P_t \times S \times C$$

where P_t is the vapor pressure of the pheromone at t°C; S is the outer area of the device and C is the concentration of the pheromone in the barrier wall. Since P and S are known then C becomes the determinant factor for the release rate. There are two other factors to be considered, one is the equilibrium swelling of the barrier polymer which should have a numerical value between 2% and 6% by weight at 20°C; the second factor is the ratio of the surface area of the device in mm^2 and the weight (mg) of the pheromone charge in the device. Ideally this ratio should be in the numerical range 4-11. Shin-Etsu tested this empirically by producing a device made from a 97%/3% mixture of polyethylene and polyvinyl acetate, which had a length of 200 mm and an outer diameter of 1.60 mm [area=1005 mm^2]. The inner diameter of the tube was 0.96 mm and it was charged with 120 mg of codlemone, which gives an S/W ratio of 8.4. For this polymer mix the equilibrium swelling was 3.2%. Such a device was found to release codlemone at greater than 0.6 mg/day for greater than 90 days.

ABIOTIC FACTORS

As temperature increases so does release rate, it has been determined for example, that the release of gossyplure from a hollow fiber increase by a factor of 1.8 - 2.0 for an increase of 10 centigrade degrees. Wilk (1991) has published data describing the use of solvent pairs and ingredient concentrations he has affected the rate release over different temperature ranges.

The data shown in the table was obtained using a pheromone charge of 0.7 grams of a 10% solution of grandlure in ethanol, to which had been added 2.9 grams of DC-200. This silicone oil is completely miscible with ethanol about 50°C but less soluble at lower temperatures.

Temperature °C	Appearance of dispenser charge
58	clear - homogeneous solution
50	cloudy solution
45	cloudy solution
32	Two layers - 4 mm EtOH / 20 mm DC-200
26	Two layers - 6 mm EtOH / 20 mm DC-200
14	Two layers - 8 mm EtOH / 21 mm DC-200

As the temperature increases, increasing the miscibility of the grandlure solution and the DC-200, the more grandlure comes into contact with the silicone oil which has a negative effect on the release rate. At lower temperatures, the components undergo increasing degrees of separation allowing for a faster release.

The deleterious, degradative effect of UV light on pheromone stability has been well documented. However, very little work has been done on photoactivated release systems for pheromones. Liu et al. (1984) published on the preparation of propheromones of aldehydic and ketonic compounds which contained photoremoveable groups and thus regenerated the carbonyl pheromone.

Weatherston and Miller (1985) reported that pre-exposure of non-stabilized celcon fibers to sunlight affected the release rate of their subsequent charge.

From these two reports it might be possible to use protected derivatives as the active ingredient in a light transparent matrix whereby the pheromone would be photogenerated then released from the matrix, allowing labile pheromones to be utilized after dark. the use of UV erosion of pheromone containing matrices might be similarly used in copolymers where one of the polymers is UV stable and the other is not.

It is to be hoped that this brief discussion on dispenser concepts and factors affecting pheromone release from such dispensers will assist in the development of better, user friendly and profitable pheromone release systems.

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CHECKMATE: A NEW CONTROLLED-RELEASE TECHNOLOGY FOR THE CONTROL OF INSECT PESTS BY MATING DISRUPTION METHOD.

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CHECKMATE TECHNOLOGY

CheckMate is the patented system of Consep Membranes Inc. for dispersing pheromones. This system consists of a rate-controlling membrane through which the active ingredient diffuses, a reservoir containing the active ingredient and a protective impermeable backing and reservoir housing.
The release of the pheromone occurs by diffusion at a consistent, constant release rate, as long as the active ingredient in the reservoir retains its activity. Release rates can be tailored to suit the properties of various active ingredients merely by altering the thickness and nature of the polymeric rate-controlling membrane. Duration of release is also flexible and can be adjusted by controlling the quantity of active ingredient and its rate of release.

DEVELOPMENT IN ITALY

In 1990 the first field-trials at a scale of 1.0 ha were conducted at two sites in Italy. Following the encouraging results, a large field-test program has been finalized in different regions of Italy with CheckMate CM and CheckMate OFM, the manually-applied disruptant products for the control of Codling Moth (*Cydia pomonella*) in apples and Oriental Fruit Moth (*Cydia molesta*) in peaches. This program was carried out in collaboration with University research institutes and Plant protection offices. In 1991 20 ha of field-tests were carried out in peaches and 20 ha in apples in different climatic regions of Italy.
In 1992 18 ha of peaches and 30 ha of apples have been destined to the experimental trials. Similar development programs have been finalized in other European countries (Switzerland, Spain).
For CheckMate OFM the application rate recommended is 48.6 gm per ha with 270 dispensers per ha. The average rate for 90 days is 22.5 mg/hr/ha.
For CheckMate CM the number of dispensers recommended is 300 per ha. The nominal application rate is 31.5 gm per ha. The average rate for 60 days is therefore 21.8 mg/hr/ha.
For all the field-trials, the following monitoring program was recommended:

- pheromone-baited traps;
- in-season visual fruit inspections at least after each major flight;
- harvest assessment of fruit damage;
- secondary or occasional pests monitoring.

In several cases weekly weighting of dispensers was carried out and the graphed field release established.

DISCUSSION OF RESULTS

The first results have been very encouraging and they confirm the effectiveness of the mating disruption method in the control of these important insect pests (Tab. 1 and 2).
Nevertheless, the disruption method failed to control sufficiently the insect pests in some cases. The main reasons for the insufficient efficacy were for CheckMate OFM:

- too small and not homogeneous peach orchards; in the fruit tree regions of Italy is difficult to have the large and homogeneous orchards needed by this method (at least 3 ha size).
- very high population pressure in some regions of Italy. Maybe the normal rates of dispensers should be increased in these cases.
- presence in almost all the Italian peach zones of high populations of Peach Twin Borer (*Anarsia lineatella*). In 1992 we started the development of a CheckMate mating disruption method for this insect.

Regarding CheckMate CM the main concern has been the non efficacy of the pheromone dispenser in the summer high temperatures. The development of a new dual release type of dispenser that we used in 1992 tests seems to have solved this problem. In fact, the USA 1991 studies showed that Codlemone was consistently released from the dual dispensers during the intervals studies.
A total of 60% of the pheromone was released during the spring test, 90+% of the pheromone was released in the late summer test.
A heat unit (day degree) based model is in development in the USA to describe product release and longevity under any combination of high and low temperatures.

REGION	VARIETY	SURFACE (HA)	% DAMAGE	REPLACEMENT DISPENSERS (DAYS)
EMILIA-ROMAGNA	Beby-Gold 1 Beby-Gold 2	1.8 1.8	3.8 3.1	77 77
MOLISE	Vivian	1.5	0	97
CAMPANIA	M.Aurelia Francesca	2.0	0.5	77
PIEMONTE	Flavorest	1.16	0.079	63

Table 1. Field-trials 1991 with CheckMate OFM on peaches in Italy.

REGION	VARIETY	SURFACE (HA)	% DAMAGE	REPLACEMENT DISPENSERS (DAYS)
TRENTINO	Golden d. Red delic. Summared	3.4	1.5-0.4 1.3-0.1	52
PIEMONTE	Ozark Gold	0.7	0.2	40
LOMBARDIA	Stark Golden	1.3	1.3	50
VENETO	Golden d. Granny Smith	2.0	1.7 0.3	60

Table 2. Field-trials with CheckMate CM on apple in Italy.

CODLING MOTH MATING DISRUPTION WITH A NEW MONOLITHIC CONTROLLED RELEASE DEVICE.[1]

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Mating disruption trials against the codling moth were carried out with a newly developed, highly versatile controlled release dispenser in apple orchards in Spain. In this polymeric device stabilization of the pheromone can be achieved by adding anti-oxydants and UV-absorbers to the pheromone/prepolymer mixture before curing. The release characteristics of the dispensers can be adjusted by varying the polymeric composition, the pheromone loading or the surface/volume ratio of the dispensers. Furthermore, these characteristics can be adapted to the type of pheromone and to the release circumstances.

In 1990 and 1991 field trials at a scale of 0.6 - 1.0 ha. were conducted at two sites in Spain. Dispensers in the form of flat square wafers were set out at densities of 500/ha containing approx. 100 gr codlemone altogether. Population development of the moth was monitored by using pheromone traps, live-female traps and larval band traps. Fruit damage was assessed in samples up to 2000 apples per plot during the season and at harvest. A strong reduction (76 - 100 %) in numbers of males flying was observed in all pheromone plots. The number of diapausing larvae was reduced to 50 - 98 % compared to the untreated plots. In areas with low population densities fruit damage was less than 1 % in all plots. At a site with higher population densities the damage in the 1990 trial was 3.36 % in the pheromone plot, 3.13 % in the standard (chemically treated) plot and 6.53 % in the untreated plot. In 1991, with a very high population density, 7.8 % was found in the pheromone treatment, 2.1 % in the standard plot and 76.2 % in the untreated control. The damage in the pheromone plot was mainly inflicted by the third generation of the moth presumably from inflying moths from neighbouring apple orchards. Presently, we are adapting this type of dispenser in order to achieve season-long control and commercially acceptable damage levels.

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[1] This project is sponsored by Denka International

EVOLUTION AND PRESENT SITUATION IN THE PRACTICAL USE OF THE METHOD OF SEXUAL CONFUSION WITH BASF DISPENSERS AGAINST THE MAIN PHYTOPHAGES IN FRUIT-GROWING AND VINE-GROWING.

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ABSTRACT

Since 1979 BASF has been testing the method of sexual confusion for the fight against insects.
In Italy the first field experiences began in 1986 and have been carried out on peach against C. molesta.
Since 1988 trials for the control of C. pomonella L., A. orana F.v.R., A. podanus Scop., P. heparana D. et S., A. pulcellana Hw. etc. have been carried out, while the trials against L. botrana and E. ambiguella of grape have begun in 1989. After 8 years of study we have well developed the method of sexual confusion and we are going to put on the market the dispensers for peach, apple and grape. The area treated with pheromones (as experimental or sold product) have increased up to 1992, which presents the following situation: peach 2825 ha, apple 80 ha, vine 270 ha.
From our experience during these years, the main observable aspects in experimentation and in the practical application of this method can be summarize as follow:

- The application and management of this method can be applied on large scala, even if these applications must be actually controlled by technicians, during their different stages.
- This method, if right managed, can give good results comparable with the ones from other methods of integrate pest management, allowing a strong reduction of insecticide applications.
- A sufficient amount of pheromones can be diffused in the fruitgrowe, with just one application of actual dispensers, so that the males of phytophages are confused.
- Considering the eco/tox profile of this product, it has no adverse effect on the environment.
- As far as the economic point of view, is concerned this method is very expensive. We are trying to reduce all the possible wastes (e.g. the quantity of pheromone which remain in the dispenser at the end of the season) in order to reduce the cost of production.
- In order to develop the application of this method and to increase the efficacy of any other modern method of fighting, a wider knowledge of phytophages is necessary.

We kindly thank all the people who have worked at this method and have spent their time in order to make this method appliable in the modern agricultural system.

"ATTRACT AND KILL" TO CONTROL *CYDIA POMONELLA* AND *PECTINOPHORA GOSSYPIELLA*

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1. Introduction

In order to control pests by means of pheromones, a new type of slow release and sprayable "Attract and Kill" formulation was developed and tested in the field against *Cydia pomonella* and *Pectinophora gossypiella.* The formulation contained the pheromones and the insecticides concerned. To protect the pheromones of UV-light the formulation was developed on the basis of a liquid UV-absorber.

The formulation to control *Cydia pomonella* contained codlemone as pheromone and furathiocarb as insecticide. In 1988 a field trial was carried out in a well isolated apple orchard of 1.2ha. Each tree was treated with 6-8 100µl drops of the formulation, two times per season at an interval of 6 weeks. That meant that 0.8g codlemone and 33g furathiocarb per application and hectare were used. The "Attract and Kill" formulation was applied by hand. A big apple tree near the trial area was used as an untreated check.

The formulation to control *Pectinophora gossypiella* contained gossyplure as pheromone and cypermethrine as insecticide. In 1990 a well isolated cotton field of 14 ha in Egypt was treated with 7000-8000 50µl drops of formulation four times per season at an interval of 4 weeks. Per application and hectare 0,6g gossyplure and 25,5g cypermethrine were used. Also the formulation was applied by hand. The check area with 12 ha of conventionally treated cotton was 2 km away from the trial area.

2. Results

Quality control of the formulation

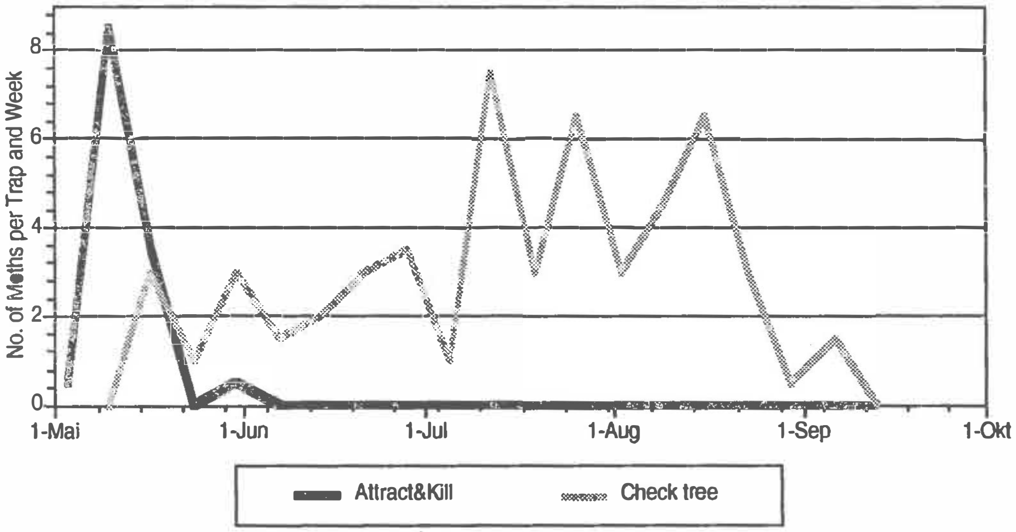
The quality of field exposed formulation was monitored in the lab using the following tests.
The release rate of codlemone and gossyplure was measured with a gas chromathograh in a weekly interval.
The kill effect of the formulation on male mothes was evaluated 24 houres after a single contact of the insects with the formulation.
The attractivity of the formulation was checked weekly in a wind tunnel.

Efficacy of the formulation

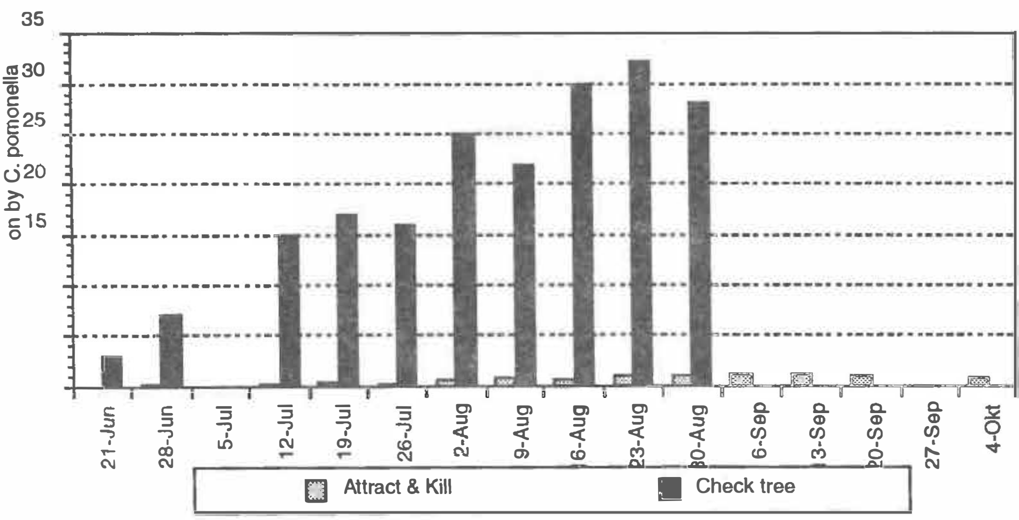
The efficacy of the "Attract and Kill" formulation was monitored in the field with pheromone traps and weekly checked on larval infestation.

2.1 *Cydia pomonella*

Pheromone traps in the "Attract and Kill" treated orchard baited with 1mg of codlemone or 2 virgin females caught pratically no moths compared to those in the untreated tree.

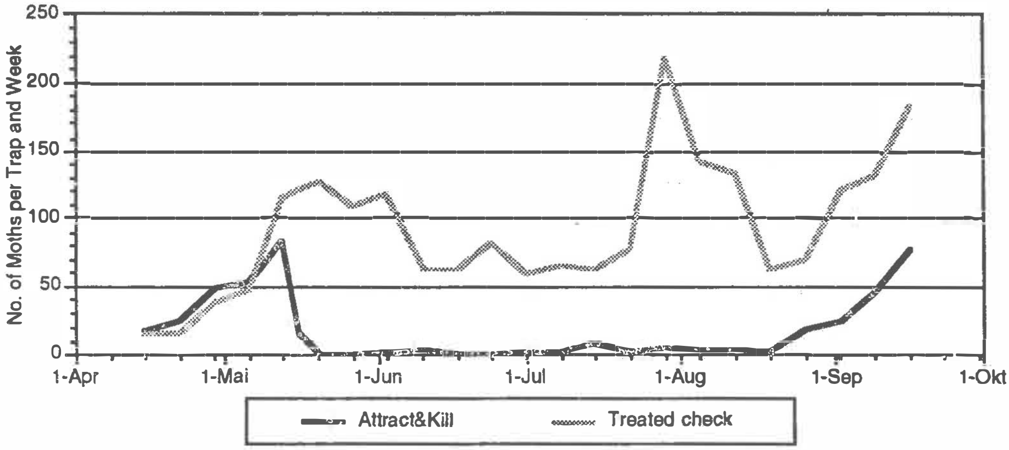


At harvest the infestation in the orchard was 0.8% compared to 33% in the untreated tree nearby and was thus below the threshold of 1%. The high damage in the check tree confirmed the constant and high population pressure of *C. pomonella* in the area.

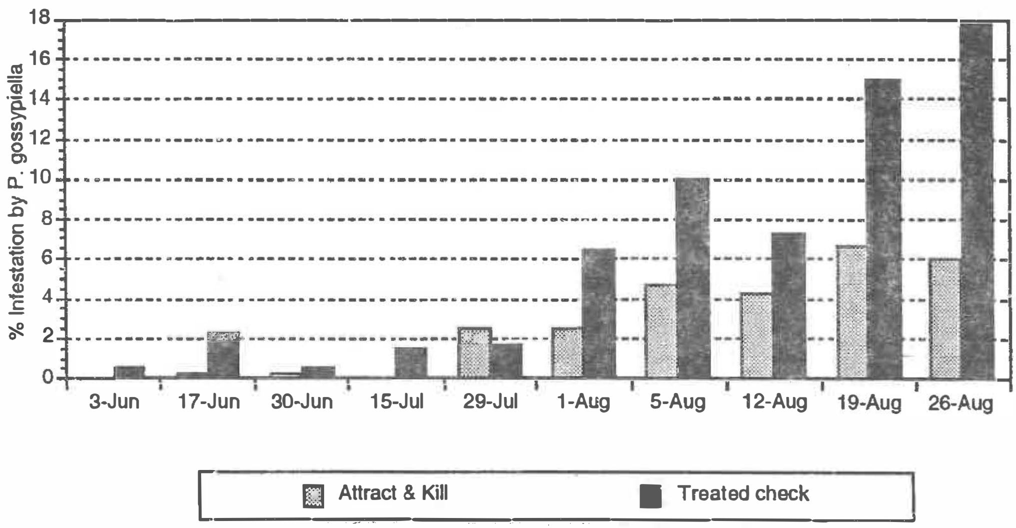


2.2 Pectinophora gossypiella

Pheromone traps in the "Attract and Kill" treated cotton field baited with 2mg of gossyplure caught much less moths compared to those in the conventionally treated field.



At the end of August the infestation on *P. gossypiella* in the "Attract and Kill" treated area was 6% compared to 18% in the conventionally treated field. At harvest the yield was 2470kg/ha in the pheromone field, compared to 2210kg/ha in the check area.



3. Conclusion

Cydia pomonella was well controlled with 2 applications at an application rate of 1.6g codlemone and 66g furathiocarb per hectare and season. Other pests were controlled with an early season application of an OP-insecticide against loopers and aphids and a treatment of Pirimor against aphids in June.

Pectinophora gossypiella was also well controlled with 4 applications at an application rate of 2.5g gossyplure and 102g cypermethrine per hectare and season. Sucking pests were controlled with an early and a late season application of an insecticide.

The advantages of the combination of pheromone and insecticide is seen in the considerable reduction of the application rate of the pheromone as well as of the insecticide and also in the targeted pesticide application, in the selectivety to the pest and in the good persistence in the field (4-6 weeks).

Topic 2: Experiments carried out in stone fruits.

Chairman: DR. HENRI AUDEMARD

MATING DISRUPTION CONTROL IN STONE FRUIT ORCHARDS

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SUMMARY

The trials and prospects of the mating disruption control of males of 3 key pest species of stone fruit trees were analysed : the Oriental fruit moth, *Cydia molesta* (Busck), the peach twig borer, *Anarsia lineatella* (Zeller), and the plum fruit moth, *Cydia funebrana* (Treitschke). This method was effective against the Oriental fruit moth ; it has been used commercially over several thousands of hectares throughout the world. This enabled us to clarify the conditions for the success of this method as well as its limitations. For the peach twig borer, the material is not yet thoroughly perfected. Use of the method for the plum fruit moth is greatly limited by adult mobility.

INTRODUCTION

In stone fruit orchards in Europe and in circum-Mediterranean regions, 3 species of Lepidoptera are the principal key pests for which integrated fruit protection was developed (Audemard, 1986). These are the Oriental fruit moth (OFM), *Cydia molesta* and the peach twig borer (PTB), *Anarsia lineatella* Zeller on peach, apricot and almond trees, and the plum fruit moth (PFM), *Cydia funebrana* Treitschke on plum trees.

Mating disruption control is an alternative to chemical control and is all the more interesting because no really effective biological means is available against these Lepidoptera.

The registration and commercial development of this control method against the OFM in Spain, France and Italy has been an unquestionable success, as it has previously been in Australia (Jones *et al.*, 1984 ; Vickers *et al.*, 1985) and, more recently, in the United States (Weakley *et al.*, 1988), and from which we can draw invaluable conclusions. As far as the other 2 species are concerned, research is continuing because major problems still exist.

ORIENTAL FRUIT MOTH

Nearly 20 years ago, in Australia, Rothschild (1975) showed that mating disruption control could be used against the OFM. He used pheromone dispensers consisting of microcapillary tubes, suspended by hand in trees at a height of 1.5 to 2 m. Since then, numerous tests conducted in peach orchards in Australia, Europe, the United States, China (Meng, 1987 ; Meng *et al.*, 1988), and Brazil (Salles and Marini, 1989) have sought to define adapted equipment and conditions of use in order to obtain registration. They also helped define a specific methodology for trials in orchards.

Assessing results in the case of the OFM was based on a series of methods (Vickers *et al.*, 1985 ; Audemard *et al.*, 1989) : sex trapping, bait trapping, last-instar larvae catches with bands, tethered females, male releases-catch, visual survey of attacks on shoots and fruits with dissection which finally provide the only definite results.

1 - COMPOSITION OF THE DISRUPTANT

The pheromone blend of the OFM is composed of 4 products : Z8-12Ac = 100, E8-12 : Ac = 7, Z8-12 : OH = 30 and 12 : OH = 6 (Cardé *et al.*, 1979). The two acetates act as long-range attractants and together with Z8-12 : OH they play a part in courtship behaviour (Backer and Cardé, 1979).

These are the 3 compounds used in the blend marketed in Australia (Casagrande *et al.*, 1987) and the United States (Rice and Kirch, 1988), at a 93/6/1 ratio. The two acetates at different ratios : 93/7, 96/4 and 88/9.9, 89.9/9.5, that is with impurities, have given good results in Europe (Audemard *et al.*, 1989 ; Neumann, personal communication). The latter has temporary approval for sale in France.

"Mating disruption" could be conducted with pheromone analogues or derivatives obtained by synthesis (Malik *et al.*, 1991). But they were no longer components of the "natural" OFM pheromone but a chemical product likely to be considered as a pesticide in a toxicological assessment.

2 - DISPENSERS - CONCENTRATION OF THE DISRUPTANT

Since the sprayable microcapsules in orchards were not sufficiently persistent (Rothschild and Vickers, 1991), dispensers were designed which were hung in the trees. The designs tested were (Audemard *et al*, 1989), (1) the Isomate^R and Confusaline^R 20 cm-long polyethylene tube filled with 75 mg of attractant, (2) the Rac 5^R polymeric bulb filled with 400 to 500 mg of attractant, and (3) the Hercon^R laminated strip with 39-42 mg/inch^2 of attractant. We should also include Conrel^R hollow fibres, an older method (Cardé *et al.*, 1977 ; Rothschild, 1979).

The variations in the release rate of the disruptant according to the cumulated degree-days for the 2 acetates were compared. The comparison showed that for the duration and regularity of disruptant release, the tube and the bulb were superior to the laminated strip (Audemard *et al.*, 1989).

The minimum concentration required was 6 mg/ha/hr in Australia (Vickers and Rothschild, 1985) for the blend of the 3 components. It was 20 mg/ha/hr in Europe, both for this blend (Casagrande *et al.*, 1987) and for the 2 acetates (Audemard *et al.*, 1989). In Rumania, a dose of 8 mg/ha/hr was indicated (Iacob and Iacob, 1986). It should be stressed that adding Z8-12 : OH alcohol lowers the effective dose to 15 mg/ha/hr in France, as shown by Charlton and Cardé (1981). A determining factor in the choice of the disruptant is of course the cost of synthetizing the blend.

3 - CONDITIONS OF USE

3.1. - Quantity of disruptant per hectare, number of applications

The required quantity of disruptant per hectare, as determined in tests, depended in part on the characteristics of the dispensers. Installing 1,000 Isomate dispensers/ha made it possible to release the required dose of disruptant for 12 weeks. This entailed setting the dispensers twice with 75 g of disruptant, that is 150 g/ha to cover the whole season (Casagrande *et al.*, 1987 ; Rice, 1987 ; Kyparissoudas, 1989). This theoretical dose per hectare did not include any possible reinforcing of the peripheral outlay which we will examine later. For the Rac 5, setting up 500 dispensers, only once, covers 24 weeks, which is a minimum theoretical dose of 200 to 240 g/ha (Audemard *et al.*, 1989 ; BASF France, undated ; Balduque *et al.*, 1988 ; Molinari and Cravedi, 1990). Both types of dispensers gave the same good results (Audemard and Gendrier, 1990).

3.2. - Outlay and orchard characteristics

Homogeneous distribution was ensured by using a density of 1 dispenser per 10 to 20 m^2, which was much more than the 50 to 200 m^2 covered by a dispenser in the centre of apple orchards in trials on the codling moth, *Cydia pomonella* L. (Charmillot and Bloesch, 1988).

Experience has shown those orchard characteristics which unfavourably affect the method's success against the OFM : the restricted size of plots, their irregular shape, lack of protection against prevailing winds, proximity of outside sources of infestation, trees which are either too young and whose foliage does not sufficiently retain the disruptant or which are too tall (Audemard *et al.*, 1989). In addition, we were able to define recommendations for mating disruption control of the OFM (BASF France, undated). It should be conducted in orchards with a surface area of several hectares, set out in a regular shape with a small side longer than 30 m and isolated from sources of infestation by at least 100 m. If the orchard is not isolated, the neighbouring plots should undergo thorough chemical control against the OFM, reinforced with dispensers over a distance of 30 to 40 m. In all cases, extra dispensers should be placed along the borders 2.5 m apart, especially in windy areas. The ideal situation is, of course, to have support for dispensers outside the orchard such as a windbreak hedge or fruit trees of a non-host species in a nearby orchard. The larger the orchard, the less important the borders are.

3.3 - Density of Oriental fruit moth populations

The larger the initial population and the later the harvest, the more difficult it is to establish protection by mating disruption control (Audemard *et al.*, 1989 ; Molinari and Cravedi, 1990a and b). It is therefore better to establish control by mating disruption over all the flight periods and particularly after harvesting. It is also recommended to use chemical control methods against the first generation to reduce the population level, in cases where the attack at the previous year's harvest exceeded 4% or when no information is available.

Monitoring the population by regular visual survey during the season is essential. Correcting population density by one or several chemical applications is performed when the "threshold percentage" of the attack reaches 1% (Audemard *et al.*, 1989 ; BASF France, undated).

4 - Evolution of the Biocoenosis

In peach orchards under mating disruption control, a very significant increase in the number of beneficial insects was observed as well as a distinct drop, even suppression, of treatments against the European red mite, *Panonychus ulmi* Koch (Audemard and Gendrier, 1990 ; Rothschild and Vickers, 1991). However, damage was caused locally by the common earwig, *Forficula auricularia* L, the summer fruit tortix moth, *Adoxophyses orana* F. v. R. in France (Audemard and Gendrier, 1990), the PTB in Italy (Molineri and Cravedi, personal communication), and in Spain (Balduque, personal communication) and other Lepidoptera in the United States (Rice, 1987).

PEACH TWIG BORER

The sexual pheromone of the PTB is made up of 2 components : E5-10 : Ac and E5-10 : OH (Roelofs *et al.*, 1975). However, in sex trapping, the blend 5 + 1 mg per capsule gave better results in California (Rice and Jones, 1975) and in France (Audemard, 1976) where still large captures were obtained with the reverse blend 1 + 5. The fact that, in Washington State, alcohol alone proved more effective was even stranger (Roelofs *et al.*, 1975). This made us wonder whether it was indeed the real sexual pheromone.

Mating disruption control trials have been carried out in France in peach and apricot orchards (Audemard and Leblon, 1987, 1988) and in Spain (Balduque *et al.*, 1988) and in Italy (Molinari and Cravedi, 1988, 1990a and b) in peach orchards. The acetate-alcohol blend was used in the ratio 87.1/12.9 with the Hercon^R laminated strip dispenser, the quantity of disruptant being 42g/ha per application. The period of effective release, i.e. 15-20 mg/ha/hr, was only 2 to 4 weeks depending on the season. Positive results were however obtained when the population was low and the dispensers renewed at the proper time.

In the integrated control against the OFM and PTB, Rac 5[R] double bulb dispensers were used according to the conditions for the OFM, using doses of 150 to 260 g/ha. An acetate and alcohol blend was used in the ratio given above or slightly different when they were non-purified products, as for example E5-E10 : Ac/Z5-10 : Ac + E5-10 : OH/ZH-10 : OH(60/17 + 12/5). The duration of release at an effective dose was 3 months, which obviously created a problem for the simultaneous control of the 2 species, since the OFM dispenser lasted 6 months. The protection obtained was for the most part satisfactory.

In 1988, we tested bulbs filled either with acetate or with only alcohol, which did not make it possible to completely inhibit captures by sex trapping, as in the reference orchard with bulbs filled with the blend (Audemard, unpublished data). Because the PTB population was extremely low, we were not able to check the possible effect on attacks. This trial would be worth resuming.

PLUM FRUIT MOTH

Analysing secretory glands of PFM females has shown the 10 components in the sexual pheromone (Guérin *et al.*, 1986), including Z8-12 : Ac and E8-12 : Ac, which are in common with the OFM and used in the disruptants commercialized for controlling the 2 species. However, the most effective sex trapping of the PFM is obtained with the blend of the two acetates Z and E in ratios going from 96/4 to 98/2 (Arn *et al.*, 1976). These blends were used in the 16 mating disruption control trials conducted from 1973 to 1981 in plum orchards in Switzerland (Arn *et al.*, 1976 ; Mani *et al.*, 1978 ; Charmillot *et al.*, 1982) and in the 4 trials conducted in Germany (Neuffer, 1984) and in Rumania (Iacob, 1978 ; Ghizdavu, 1982 ; Iacob and Iacob, 1987). In Switzerland however, the disruptant containing from 1.3 to 2.5% of isomer E has been the most used. Some successful trials have also been carried out recently in France with the material developed for the OFM (Bourgouin, personal communication) which contains about 10% isomer E and in USSR using an unspecified composition (Sazonov and Sundukova, 1987).

Dispensers made either of polyethylene microcapillary tubes or of rubber tubes impregnated with the disruptant, were hung in the trees on the basis of 200/ha in Rumania and 50 to 300/ha in Switzerland where an outlay of dispensers surrounding the orchard, in certain cases, overlapped by 20 metres onto the neighbouring plantations. With 1 to 5 disruptant applications per season, the quantities used per hectare varied from 10 to 200 g of sex attractant.

The results obtained were irregular going from success with 60g/ha to total failure, even with 200 g/ha (Charmillot *et al.*, 1982). The necessary concentration of disruptant was at least 5 mg/ha/hr in Switzerland, whereas Iacob and Iacob (1987) indicate 7.5 mg. Assessments carried out by Charmillot and Blaser (1982) using several complementary methods (trapping, tethered females in and outside the orchard, male release-catches) have shown that the disruption spread over 30 to 50 metres beyond the treatment zone. As the quantity of disruptant was not generally implicated, it appeared that it was the great mobility of adults, favoured by host or non-host trees and shrubs, which seemed to play a very important role. Mating disruption control should therefore be limited to orchards with a large surface area, isolated and in an environment without trees or else protected by a large belt of dispensers up to 100 metres, which in practical terms seems unacceptable.

PROSPECTS

Mating disruption control of the OFM, successfully commercialized for use over several thousand hectares in some countries, should develop further. It seems that the same result could also be achieved for the PTB, at least in peach and apricot orchards. The conditions of use seem to limit this method of control of the PFM to certain situations.

Research in the field of mating disruption in stone fruit orchards could concentrate on (i) extending this method of control to other Lepidoptera species, (ii) evaluating less costly material for dispensers and analogues or pheromone derivatives (taking account of possible problems regarding toxicological evaluation), and (iii) studying the mechanisms of the disruption and the role of so-called secondary components of sexual pheromones. Why not accept a new challenge by studying the possibilities of mating disruption control against certain scale insects ?

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APPLICATION OF MATING DISRUPTION METHOD IN PEACH ORCHARDS IN ITALY (1)

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ABSTRACT

In the field of research on the mating disruption method against Cydia molesta *(Busck) on peach in Italy, trials were carried out with progressively reduced amount of pheromone applied in order to gain better knowledge on the relationship between pest population and optimum level of diffusion.*

Pheromone dispensers were placed in two nearly isolated peach orchards (1.8 and 2.3 hectares respectively),where 2-3 treatments against C. molesta *were usually applied.*

In the first year (1988) 500 dispensers - model RAK 5-6 by BASF - were placed per hectare; in 1990 the number of dispensers were 445 per hectare. In 1991 dispensers were placed only on the border trees, totalling 63 per hectare.

Large scale experimentations show that the amount of pheromone to be diffused is greatly influenced by different factors, among which population level and tree size play a major role; in some situations, mating disruption can be achieved only by diffusing an average of 60-80 mg/ha/h pheromone.

The application in Italy of mating disruption for the control of *Cydia molesta* (Busck) in peach orchards has greatly increased in importance in these last years, on the basis of the good results obtained in the experimentations started some years ago (Molinari e Cravedi, 1988, 1989, 1990, Niccoli *et al.*, 1990, Pari *et al.*, 1990, Cravedi *et al.*, 1991, Rotundo e Viggiani, 1989). The activity of our Institute in this field is reported in tab. 1.

Tab. 1 - Peach orchards in which mating disruption has been applied in programmes directed by the Institute of Entomology of Piacenza

	Emilia Romagna		Piemonte		Calabria		Totale	
	n.	ha	n.	ha	n.	ha.	n.	ha
1987	4	5	-	-	-	-	4	5
1988	9	15	6	10	-	-	15	25
1989	7	12	6	12	-	-	13	24
1990	147	359	176 *	310 *	2	4	325	673
1991	177	399	5	11	2	4	184	414

* Data include a district of 172 peach orchards (300 hectares), in cooperation with the Department of Entomology and Zoology applied to the environment of Torino University.

(1) The present work was carried out with the support of *Progetto finalizzato "Lotta biologica e integrata per la difesa delle colture agrarie e delle piante forestali"* of the Ministry of Agriculture and Forestry, the *Regional Project for the Integrated Pest Management* of Emilia Romagna and the *Phytopathological Regional Plan* of Piedmont Region

Large scale trials were possible thanks to the cooperation of technical assistance organizations, in Emilia Romagna within the *Regional Project for the Integrated Pest Management*, in Piedmont Piemonte Asprofrut, within *Phytopathological Regional Plan* of Piedmont region

Since we have a still poor knowledge of the parameters influencing the success of the mating disruption method, an eccess of pheromone is often applied in the field.

The amount of pheromone necessary to obtain mating disruption depends principally on the pest population level. Different data are reported in the literature on *C. molesta*; dispensing 20-25 milligrams pheromone per hectare per hour is generally believed sufficient to prevent fruit damage in most situations (Audemard, 1984; Audemard *et al.*, 1989).

Mating disruption is achieved if a sufficient concentration of pheromone is present in that period of the day in which adults are active, that is nearly at the sunset; Rothschild (1975) had no fruit damage dispensing 5-6 milligrams per hectare per hour during that period. The diffusion is continuous and it is affected by temperature and wind (Ioriatti *et al.*, 1987); for this reason the average diffusion must be higher than theoretical amount, to counterbalance the strong release in the hot hours. In addition, the new models of dispensers, lasting up to 6-7 months, are exposed to very changeable environmental conditions, during which the necessary amount of pheromone must be guaranteed.

The pheromone released is not necessarily correlated to the actual amount present in the air of the orchard, as the removal by wind is greatly variable; methods for measuring the concentration and distribution of the pheromone in the field were developed for some Lepidoptera (Milli e de Kramer, 1990); looking forward to having the completion for *Cydia molesta*, the diffusion measure is practically the only means to know, even if indirectly and approximately, the pheromone amount present in the orchard.

To know the level of phytophagous population is a further problem for the assessment of the optimum amount of pheromone to obtain mating disruption. There are not, at present, good parameters to use in order to give an objective indication of the number of insects in the orchard.

During the first years of experimental application of mating disruption method in some peach-growing areas in Italy, it was observed that increasing the amount of pheromone, rather than the number of diffusion points, allows to obtain a good defence of the production also in orchards where previously the method did not give satisfactory results. Also the experimentations in the following years, when the method was applied on larger scale, confirmed that in many peach orchards in Emilia-Romagna it was necessary to release an average of 60-80 mg/ha/h of synthetic pheromone to avoid damages to the production in varieties ripening after the end of July, especially when trees were more than 4 m high.

A different situation was found in Piedmont, where the experimentations carried out during 1988 and following years in Cuneo province, pointed out that an higher number of good results was possible, even though pheromone diffusion was lower than that recorded with the same material in Emilia-Romagna, because of the different environmental conditions.

The captures of pheromone traps placed in check fields in that area are on average lower than those recorded in Emilia-Romagna; this is the evidence of the lower level of phytophagous population.

Since the second year of application, two peach orchars, among the experimental ones, showed a total absence of damage. They are at Verzuolo (1,8 ha) and at Lagnasco (2,3 ha), quite isolated from other peach orchards.

It was decided to reduce gradually the amount of pheromone applied, until a renewal of the damages by *Cydia molesta*, that before the application of mating disruption method caused 2-3 insecticide treatments, would have recorded.

According to some authors, the repeated application of mating disruption method can cause a considerable reduction of phytophagous population, that in some cases would be nearly total.

Even though such a decrease has not yet happened in peach growing areas in Northern Italy, we wanted to value in which measure the absence of damage corresponds with the reduction of sedentary population, to adapt the pheromone amount to the effective necessity.

In these peach orchards double ampulla dispensers, model RAK 5-6 by BASF, were placed; in 1988 they were placed on the whole field, with higher density on border trees, getting an average of about 500 dispensers per hectare; during the following years, as no damage was recorded neither at the production nor at the vegetation, their number had been gradually reduced, and in 1991 dispensers were placed only on the border of the fields (Tab. 2).

The actual amount of pheromone released, during a 120 days period, was 233 g in 1988 and in 1992 was reduced to 13 g per hectare (Tab. 2); the changes of the dispensers, made by the company during the years considered were responsible for part of the reduction of the release rate.

In the two peach orchards considered there was no damage till the end of July 1992; at the beginning of August *Cydia molesta* larvae of the third generation caused a damage of 67,7% on fruits in the orchard at Verzuolo.

It is common knowledge that phytophagous population undergoes quantitative changes from a year to the next one and in peach growing areas it is not possible to leave this factor out of consideration: if the amount used are high in most cases, the numerous applications show that a reduction of diffused pheromone points out a higher number of critical situations.

Tab. 2 - Verzuolo (CN). Actual amount of synthetic pheromone of *C. molesta* released (g/hectare after 120 and 180 days of exposure) using a different number of RAK 5-6.

	120 days	180 days
1988	233	271
1989	230	269
1990	98	125
1991	16	19
1992	13	-

It is important also to remind that the pheromone diffusion depends on environmental conditions; the same material acts differently not only in different years, but also in different places of application; in 1990 RAK 5-6 dispensers of the same lot, undergone gravimetric analysis in four stations (two in Emilia-Romagna, one in Piedmont and one in Calabria) had showed different diffusions.

The application of the disruption method on an increasing number of orchards stresses the problem of managing, by not well trained people, a method not completely known at experimental level. On the application in large scale, the reduction of pheromone amounts is to be assessed carefully, in order to allow the best probability of success and to avoid superficial judgements on the method potentiality, based on a limited survey.

A delay in the completion of application systems is caused by the frequent variation of available dispensers characteristics, which impose experimental check during the application.

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MATING DISRUPTION OF PEACH TWIG BORER, <u>ANARSIA LINEATELLA</u> ZELLER: PROGRESS AND PROBLEMS

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ABSTRACT

Field trials for efficacy of mating disruption of the peach twig borer, *Anarsia lineatella* (PTB), have been conducted in the San Joaquin Valley of California since 1989. Trials have been variously placed in orchards of .5 to 2.0 ha. in nectarines, peaches, apricots, prunes, and almonds. Pheromone dispensers were manufactured by AgriSense, Inc., Fresno, CA; BASF, Ludwigshafen, Germany; and Consep Membranes, Bend OR. Dispenser design and load rates have varied with each manufacturer, but pheromone in all disruption dispensers have been a two-isomer blend of E5-10:Ac and E5-10:OH. Re-examination of pheromone components produced by virgin female PTB (Dr. Jocelyn Millar, University of California, Riverside) has shown that the original identifications by Roelofs in 1975 are essentially correct; the minor components identified by Millar add no significant improvement to pheromone trap catches. Field longevities of the various pheromone dispensers under central California weather conditions have ranged from approximately 50 days to 75 days regardless of load rate. Control of PTB in the various host crops through mating disruption has generally been good, with early season cultivars showing the least damage compared to untreated checks, while mid- and late-season maturing cultivars experience increasingly heavy damage, some unacceptably high. Long-term control of PTB by mating disruption will probably require at least two applications of pheromone per season.

INTRODUCTION

The peach twig borer, *Anarsia lineatella* Zeller (PTB), is a pest of stone fruits and almonds in many parts of the world. Although it occurs throughout the deciduous fruit growing areas of North America, it is a major pest in commercial orchards only in California. It occasionally reaches pest status in southern Washington peach orchards near Yakima. The standard control program for peach twig borer in the western United States has been annual dormant applications of organophosphate insecticides and oil, which also controls San Jose scale, mite and aphid eggs, and *Parthenolecanium* scale spp.

A preliminary trial using pheromones for mating disruption of PTB was carried out near Parlier, CA in 1986 to evaluate alternative controls for PTB in lieu of in-season pesticide sprays. The pheromone dispensers used in this trial were Shin-Etsu ropes containing mixed peach twig borer pheromone and oriental fruit moth pheromone in their normal isomeric ratios. The results of this initial field test were encouraging, with the pheromone treatment sustaining 1.5% PTB damage while the nearby untreated check had 31.7% twig borer infested fruit. In spite of this initial success, it was determined that the standard control program in the winter was still more economical than pheromones for PTB control, and at that time the potential market for PTB mating disruption was still considered too small for development. Consequently, no further trials for mating disruption of peach twig borer were conducted until 1989. By that time dormant sprays had come under increasing scrutiny and criticism due to drift of spray in winter fog onto non-target crops (primarily winter vegetables), and possible toxic effects on raptors and other types of birds, thus leading to a renewed interest in the efficacy and potential use of pheromones for control of PTB.

PHEROMONE DISPENSERS

The pheromone dispensers used for PTB mating disruption efficacy trials in 1989 were manufactured by AgriSense Co., Fresno, CA. These dispensers contained a nominal load of 250 mgs ai of the standard two component PTB pheromone blend (E)-5-decenol and (E)-5-decenyl acetate (15:85) in a polymer gel substrate. These dispensers were projected for a three-month field life, and were applied at 500 dispensers per ha. Release rate studies in the field showed that these dispensers did not uniformly release pheromone over a three-month period, but were expended in 50-70 days due to cracking and disintegration of the gel substrate, thus exposing a greater surface area for release of the pheromone along with some loss of gel particles from the dispenser. Laboratory work on pheromone release rates from these dispensers had also shown that only 86% of the initial pheromone load would be released; field-exposed dispensers lost ca. 60 percent of the pheromone after 35 days of field exposure and 80 percent after 63 days.

The results of the trials for PTB mating disruption in 1989 (Table 1) were erratic, probably due to the relatively short and non-uniform release rate of the pheromone from the AgriSense dispensers. Fresh dispensers were not available for the planned second field application in mid-June. However, the results were encouraging enough to warrant continued work on PTB mating disruption. Because of problems with the AgriSense dispensers and the obvious need to reformulate this particular pheromone release system, the manufacturer declined to continue working with PTB mating disruption in 1990.

In 1990 and 1991, mating disruption of PTB was continued using a standard BASF double-ampule dispenser (RAK® 5-6) containing both peach twig borer and oriental fruit moth pheromones. This dispenser (already registered in Europe) was applied in both years at 500 dispensers per ha. As in 1989, the BASF dispensers were applied only once each year at the beginning of the first PTB flight in April. The results of mating disruption using the BASF dispensers also showed good control of PTB in most field trials (Table 1). However, it became obvious that single applications of any pheromone dispenser in the hot Central Valley of California could not sustain mating disruption through the entire growing season as shown in the data for Fairtime peach (Table 1). None of the dispensers have been capable of releasing sufficient pheromone with single applications over the required five-month period (3 PTB generations) to provide adequate disruption into the late maturing cultivars. The results of the trials for disruption of PTB in 1990 and 1991 were also encouraging, particularly in view of the ambiguous results observed with the AgriSense dispensers in 1989.

Due to persistent problems in obtaining the BASF RAK® 5-6 pheromone dispensers in North America, it was decided to continue the PTB mating disruption program in 1992 using pheromone dispensers manufactured by Consep Membranes Inc., Bend, Oregon, U.S.A. These dispensers were loaded with 100 mgs of PTB pheromone and applied at 500 dispensers per ha. Field release rate studies with these dispensers in 1991 had shown that they were essentially depleted of pheromone after 60 days. Consequently, two applications of these dispensers were made in the field efficacy trials in 1992. The results of these trials are shown in Table 2.

As in previous years, the first fruit harvested in May had relatively low levels of infestation in both the pheromone treated blocks and in the untreated checks. As the harvests progressed into June, infested fruit in the checks generally increased, while the pheromone treatments held infestations to acceptable levels. One significant failure in PTB control occurred, in the 1.6 ha. apricot orchard harvested July 1, 1992. This organically-managed orchard (without fungicides) sustained severe crop losses to brown rot fungus (*Monilinia* spp.) in the three weeks prior to harvest, which greatly increased the PTB pressure on the remaining fruit and probably contributed to an increase in PTB infested fruit.

Differences in PTB infestations between pheromone treated blocks and untreated checks tended to lessen as the season progressed into late July, but orchards that had been under PTB mating disruption for several successive years generally maintained good control.

REEVALUATION OF PEACH TWIG BORER PHEROMONE ISOMERS

Comparisons of PTB pheromone trapping data from several researchers at the Kearney Agricultural Center in the spring of 1990 showed considerable variations and discrepancies in trap numbers that could not be explained through weather or known population densities. As a result of these comparisons, a research project was established to reevaluate and examine the components of natural peach twig borer pheromone produced by virgin female moths and also to identify the reasons for the extreme variations in PTB trap counts observed in 1989 and 1990. Dr. Millar has identified several minor constituents in extracts of female PTB pheromone glands as decyl acetate, (E)- and (Z)-4-decenyl acetate and (E,E)- and (Z,E)-decadienyl acetate. Decyl acetate and (E)-4-decenyl acetate were also identified in effluvia from live female moths. None of these identified compounds enhanced the attractiveness of the standard blend of (E)-5-decenol and (E)-5-decenyl acetate (20:80) in field tests (Table 3). However, the analogous compounds (E)-6-decenyl acetate and (Z)-6-decenyl acetate were identified as behavioral antagonists and suppressed trap captures (Table 4). The contents of a variety of commercial pheromone lures and mating disruption devices were analyzed and one batch of lures which had performed very poorly in field tests was found to contain the inhibitory compound (E)-6-decenyl acetate.

SUMMARY

Field trials for mating disruption of *Anarsia lineatella* using several types of pheromone dispensers containing the standard two-component blend of PTB pheromone have shown promise as an acceptable commercial control for PTB in California. The problems with continued use of dormant spray programs for control of PTB continue and are increasing, leading to greater interest on the part of growers and pest managers for this technology. Inherent problems, particularly in logistics and application, associated with use of point source or hand-applied pheromone dispensers include the cost of the pheromone for two treatments per season, with a minimum of 120 grams ai per ha. per season, may make the cost prohibitive in the short term. Also, hand application of pheromone dispensers in the upper one-third of stonefruit tree canopies 5-6 m high exacerbate difficulty of application, while hand application of dispensers to almond trees 7-9 m high becomes almost a physical impossibility. In spite of these problems, however, growers and pest control advisors continue to support the concept of mating disruption for peach twig borer in California orchards and it is anticipated that a registered commercial product will be available for application in California by 1994.

Table 1. Efficacy of peach twig borer mating distribution pheromone treatments applied to various cultivars, Parlier, Calif.

Cultivar		PTB % Infested 1989	1990	1991
Red Diamond (n)	Phero[1]	0.6	0.1	0.0
	Check	0.4	0.2	0.0
Elegant Lady I (p)	Phero	3.1	1.0	2.4
	Check	3.2	2.5	3.4
Elegant Lady II	Phero	-	-	10.5
	Check	-	-	51.3
Fantasia (n)	Phero	1.2	0.2	0.7
	Check	6.9	6.4	29.6
Fay Elberta (p)	Phero	8.0	-	5.6
	Check	26.3	-	47.3
Fairtime (p)	Phero	2.0	5.0	6.6
	Check	3.3	11.0	8.8

[1]AgriSense PTB dispensers used in 1989; BASF RAK® 5-6 OFM/PTB dispensers in 1990 and 1991.

Table 3. Trap catches in traps baited with the PTB pheromone standard blend vs. the standard blend + minor components.

Host Crop	Trap Catches (males) Lure[1]	Mean[3]
Almonds	Standard Blend	729 a
	Std Blend + Minor Comp.[2]	723 a
Plums	Standard Blend	340 a
	Std Blend + Minor Comp.	345 a
Peaches	Standard Blend	96.2 a
	Std Blend + Minor Comp.	72.5 a

[1,3]Standard blend, E5-10:Ac (400 µg) + E5-10:OH (100 µg). Six replicates per treatment, traps counted 3 times.

[2]Minor components, E4-10:Ac (5 µg), Z4-10:Ac (5 µg), 10:Ac (20 µg), Z3,E5-10:Ac (5 µg), E3,E5-10:Ac (10 µg).

Table 4. Field bioassay in almonds of standard peach twig borer pheromone blend and potential inhibitors. Caruthers, Calif., 1990.

	Attractant	Total No. PTB Collected[1]	
1	Standard PTB pheromone	7235	A
2	Standard + 20 µg E6-10:Ac.	1207	C
3	Standard + 100 µg E6-10:Ac.	496	D
4	Standard + 20 µg Z6-10:Ac.	6702	A B
5	Standard + 100 µg Z6-10:Ac.	6095	B
6	Blank septa	97	E

[1]4 traps (reps) per treatment; 8 counts from Oct. 3-22, 1990.

Table 2. Field trials for mating disruption of peach twig borer, *Anarsia lineatella*, in central California stonefruits; 1992.

Cultivar[1]		Harvest Date	Plot Size (ha)	Years-MD	% Infested
May Glo (n)	pheromone	5/19	0.8	1	0.2
	check				0.4
Sparkling May (n)	pheromone	6/2	0.8	1	0.2
	check				5.2
Blenheim (a)	pheromone	6/10	0.8	4	0.2
	check				8.4
Red Diamond (n)	pheromone	6/22	0.8	4	0.8
	check				11.6
Babcock (p)	pheromone	6/29	1.6	3	0.3
	check				0.4
Blenheim (a)	pheromone	7/1	1.6	1	21.5
	check				12.6
Elegant Lady (p)	pheromone I	7/6	0.8	4	1.3
	pheromone II		1.0	1	5.3
	check				23.2
Fay Elberta (p)	pheromone	7/22	0.5	4	3.7
	check				39.2
O'Henry (p)	pheromone	7/25	0.8	3	0.8
	check				1.6
French (prune)	pheromone	7/27	1.2	1	1.3
	check				5.5
Nonpariel (al)	pheromone	7/29	2.0	1	13.4
	check				19.8
Dr. Davis (p)	pheromone	7/30	2.0	1	2.6
	B.t. check				3.3
Starn (p)	pheromone	8/10	2.0	2	0.4
	B.t. check				1.2
Fairtime (p)	pheromone	8/18	0.8	4	9.2
	check				29.2

[1]1st applications Feb. 24-27; 2nd applications May 18-26. Consep pheromone dispensers applied @ 500/ha. in all tests except BASF in French prunes and almonds. (n) = nectarine; (a) = apricot; (p) = peach; (al) = almond.

EXPERIENCES WITH MATING DISRUPTION FOR CONTROLLING *CYDIA MOLESTA* (BUSCK) AND *ANARSIA LINEATELLA* ZELLER IN NECTARINE ORCHARDS OF SOUTHERN ITALY.

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ABSTRACT

The mating disruption technique (MDT) has been applied (1988-1991) in nectarine orchards of southern Italy (Calvi Risorta, CE) for controlling the Oriental fruit moth, *Cydia molesta* (Busck), and the peach twig borer, *Anarsia lineatella* Zeller. The experiments with MDT have been carried out in plots of about 1 ha. The traditional practice plot (TPP) was 1.7 ha.

Results have shown that the MDT application against both pests was competitive with the conventional insecticide programmes. However, further studies are needed for *A. lineatella*.

The maximum level of twig infestation detected with weekly samplings was respectively 5.6% for MDT plots and 8.0% for TPP. At harvest the infestation rate of fruits in the mentioned plots reached the maximum of 0.5% vs. 0.9%.

A side-effect of the MDT application concerning *A. lineatella* was detected. The pheromone traps for this species attracted also *Formica cunicularia* Latr. in the TPP, but not in the MDT plots, where the ant was confused as the twig peach borer.

INTRODUCTION

The oriental fruit moth (OFM), *Cydia molesta* (Busck), and the peach twig borer (PTB), *Anarsia lineatella* Zeller are pests on apricots, peaches and nectarines in the orchards of southern Italy. OFM is of primary importance. In 1988 some experiments started in nectarine orchards and continued until 1991. Preliminary data on the first trial have been published in a previous note (Rotundo and Viggiani, 1989). In the present conclusive paper we report on the results obtained over the experimental period.

MATERIALS AND METHODS

Trials have been carried out from 1988 to 1991 in nectarine orchards at Calvi Risorta (CE) Italy, cvs Maria Aurelia and Stark Red Gold, both harvested at the begenning of August.

The experiments with MDT have been carried out in plots of about 1 ha. The traditional practice plot (TPP) was 1.7 ha (Fig. 1).

In 1988 for OFM, in the MDT plot, the number of dispensers was totally of 600 (including 120 along the borders); the amount of pheromone was of 420 g/ha. The dispensers were situated in the plot on April 21, they were alternatively hung on the plants at 50-70 cm and 160-180 cm of height from the ground. Also, in the same area 3 pheromone traps were placed.

For PTB the number of dispensers/ha was of 954 (including 142 situated along the borders) and the amount of pheromone/ha was 477 g/ha. In this plot the dispensers and the pheromone traps (3) were placed on May 25.

In all the years taken into account, in the MDT plots, no insecticide and acaricide was used. On the contrary, in TPP 4 applications of pesticides were made by the farmer.

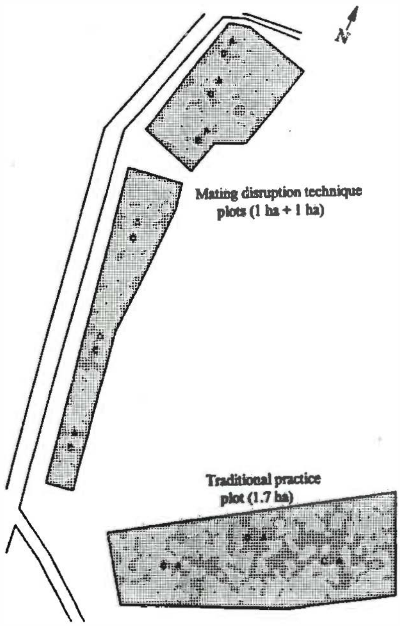

Fig. 1. Map of plots and distribution of pheromone traps in trials (1988-1991) for controlling OFM (C) and PTB (A) in peach orchards at Calvi Risorta (CE), Italy.

In 1989, in the MDT plot, 695 dispensers(including 195 along the borders) were used for both OFM and PTB, but the pheromone amount was respectively 486.5 g/ha and 347.5/ha. The OFM pheromone release was evaluated on a sample of 10 dispensers selected according to the main plot conditions, weekly weighed. In TPP 2 treatments with pesticides were applied.

In 1990 two trials were carried out only for OFM, respectively with 793 dispensers/ha (including 355 along the borders) and 330 (including 158 along the borders); the amount of pheromone/ha was respectively of 555.1 and 231.0 g/ha. In TPP 3 applications of pesticides were made.

The trials from 1988 to 1990 were carried out with dispensers provided by the Basf-Italia.

In 1991 one trial was carried out for OFM, but two placements of dispensers were made: the first with 268 (including 132 along the borders) corresponding to 48.24 g/ha and the second one with 272 dispensers (including 159 along the borders) corresponding to 48.96 g/ha. The total amount of pheromone g/ha was of 97.2. As in 1989 the weekly release of OFM pheromone was evaluated. In TPP 5 treatments with pesticides were applied.

In this year, dispensers made by Consep^{TM}, Membranes, inc. and supplied by the Intrachem Italia, were employed.

During the experiments the captures of the pheromone traps in all plots were noted. Samplings to evaluate the percentage of damaged twigs and fruits were carried out. For this purpose, respectively, 250 twigs and 250 fruits/week/50 trees were sampled, moreover damaged fruits were detected at harvest on 2000 fruits.

RESULTS

1988. The total captures of males were very low for both species (5 OFM, 30 PTB) in the MDT plots. The captures of PTB were in general higher than those of OFM, but the average was lower than 0.4 m/t/w. In no case m/t/w was above 4. The amount of OFM pheromone release from April 17 to October 25, was in general not uniforn and higher than the MDT threshold of 20-25 mg/ha/h as supposed by Audemard et al. (1989). The percentage of damaged twigs and fruits was respectively 2.0% and 0.4%. At harvest the damaged fruits were 0.1%

In the TPP the maximum peak of captures of OFM was 184 m/t/w; the average 36.3 m/t/w. The captures of PTB were lower than 2.6 m/t/w. The percentage of damaged twigs and fruits was respectively 0.4% and 2.4%. At harvest the damaged fruits was 0.9%.

1989. The male captures were very rare for both pest species (2 of OFM; 1 of PTB) in the MDT plot. The percentage of damaged twigs and fruits was less than 0.4%. At harvest the percentage of damaged fruits was less than 0.05%.

In TPP the average captures m/t/w of OFM was 36.9, with a maximum peak of 138. The captures of PTB were lower than 2.6 m/t/w. The damaged twigs and fruits were respectively 8.0% and 0.05%. At harvest fruits were damaged as in MDT plot.

In the TPP the PTB traps captured also a consistent number (147) of the ant *Formica cunicularia* Latr., but not in the MDT plot.

1990. In the plot with 793 dispensers the captures by pheromone traps were negligible for OFM (1) and sporadic for PTB (12), with the average captures lower than 0.2 m/t/w. In no case m/t/w was above 4. On the contrary, in the plot with 330 dispensers the captures of both species were rather constant and only in one case reached 11 m/t/w. The highest percentage of damaged twigs in the plot with 793 dispensers was 5.6%; no damaged fruit was detected. In the plot with 330 dispensers the percentage of damaged twigs and fruits was respectively, at maximum, 2.4% and 1.6%. At harvest damaged fruits were less than 0.1% in both plots.

In the TPP the maximum peak of OFM captures was 180 m/t/w and the average was 39.8. In the same plot the PTB traps captured also many males of *F. cunicularia* (26), but very rare individuals in MDT plots (2). The percentage of damaged twigs and fruits was respectively 4.8% and 0.4%. At harvest the percentage of damaged fruits was 0.1%.

1991.The total captures of the pheromone traps in the MTD were very low for the OFM (3 males), but rather high for the PTB (37 males) with the average m/t/w respectively of 0,2 and 0,6. In no case the captures m/t/w were above 4. The release of pheromone from dispensers was rather uniforn and generally higher than the MDT theshold. The percentage of damaged twigs and fruits was respectively 5.6% and 0.8%. At harvest the damaged fruits were 0.5%.

In the TPP the peak of OFM captures was 38 m/t/w and the average was 12.6 m/t/w. The percentage of damaged twigs and fruits was respectively 3.6% and 0.8%. At harvest the damaged fruits were 0.2%. In all plots (MDT and TPP) many males of *F. cunicularia* were captured.

CONCLUSIONS

Field trials with MDT against OFM and PTB have shown that it can successfully control both species and keep the damage to competitive levels with those of conventional insecticide programmes. However for PTB should be considered that the captures were very low as the infested twigs and fruits, even when the MDT was not applied for this species.

The pheromone release by Consep dispensers performed more uniform results than those of BASF ones, but two applications were needed. However, the total pheromone amount used was lower than that released by BASF dispensers and below the maximum rate suggested by EPA (Jutsum et al., 1989).

Satisfactory results were obtained applying the MDT on the same areas for several years.

The pheromone blend used for the MDT against PTB was found to be active also for the ant *F. cunicularia* Latr. These observations were confirmed indirectly by the captures of this ant in the pheromone traps used for PTB even in areas where the MDT was used in the preceding years.

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Topic 3: Experiments carried out in pome fruits protection.

Chairman: DR. LEO BLOMMERS

MATING DISRUPTION OF TORTRICIDS IN TOP FRUIT IPM: A QUESTION OF IMPLEMENTATION.

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ABSTRACT

Mating disruption is effective against both codling moth (*Cydia pomonella*) and a group of major leafroller pests, including *Adoxophyes orana*, *Pandemis heparana* and *Archips podana*, but unexplained failures have occurred in field tests against codling moth. Various weaknesses in current methods are indicated, and some aspects of the implementation of both methods in current integrated pest management systems are discussed. More accurate quantitative sampling is proposed as a means to improve practical recommendations.

INTRODUCTION

The mating disruption technique (MDT) has been tried on various top fruit pests during many years. The codling moth *Cydia pomonella* (L.) in particular has been subject to a multitude of experiments, and recently also commercial applications, both in Europe and elsewhere. Fewer trials were run initially against summer fruit tortrix moth *Adoxophyes orana* (F.v.R.), and, more recently, against a larger group of related leafrollers. As both codling moth and (some) leafrollers are perennial pests in all European top fruit regions, replacement of chemical control by mating disruption should affect various elements of Integrated Pest Management (IPM), the most important being the reduction of disruptive effects on the ecosystem, and the beneficial insects in particular.

Most field work so far has gone into efficacy testing, with generally promising results. This work, as well as similar trials against leafroller species in other crops, like vineyards, has shown that the use of MDT is subject to some topological and ecological restrictions like a sufficiently large and homogenous treatment area, and a low initial pest density (cf. Charmillot, 1990). Nevertheless, unexpected failures are reported now and then. Evidently, these should get an explanation, before MDT can be recommended to growers. Most of this discussion is about the inadequacies in experimental methods, or in reporting results, some of which can be pinpointed in almost any report on field tests with MDT and might explain part of these failures. In fact, this observation made me refrain from composing an overview of recent advances. I have mainly used as illustration some of our own experiences with field tests with BASF twin-dispensers during 1989 - 1991 (van Deventer et al., in prep.).

Also, fruit growers will need advice as to how MDT against one or more target Tortricidae fits into current orchard IPM systems. While this question has received rather limited attention so far, it will be discussed here in relation to past and future field work. For, as more definitive formulations for MDT are to be expected, implementation instead of efficacy should become the main interest in field tests.

MATING DISRUPTION OF CODLING MOTH

Experiments over many years have provided sufficient evidence that codlemone (E8,E10–12:OH) can be used to suppress outbreaks of codling moth. In temperate regions, where codling moth has only one or two annual generations, this technique alone should be sufficient to prevent damage. However, occasional failures occur, which are seemingly not explained by any neglect of the aforementioned general restrictions. Several weaknesses in field testing MDT against codling moth (MDT/CM) can, however, be noted that might explain the variability of results.

(1) Till now, more detailed appreciation of the efficacy of MDT/CM has been hindered by an almost continuous change of method; dispensers, and their dispensing qualities, have been changing over years, while precise data on the local emission of unaltered pheromone is often lacking. Testing of dispensers should not be mixed with large scale efficacy tests; the latter should be run with material of defined quality.

(2) Estimates of initial codling moth densities prior to MDT/CM tend to be inaccurate. Two sorts of samples are usually taken: larval fruit entries at previous harvest and densities of diapausing larvae in tree bands. For example, MDT/CM failed in Swiss orchards with more than 2000 fruit entries per hectare (Mani, 1987), while Charmillot (1990) suggests an upper limit for treatment of 2-3 diapausing larvae per tree. It should be clear that both sort of estimates are rather inaccurate, for both biological and statistical reasons.

While the fruit entries have to be scored at harvest, everyone seems to check the tree bands also in autumn, as an additional proof of earlier treatment. Evidently, such estimates do not take into account winter mortality previous to the next treatment, and, particularly, favourable winters, for the pest, may go unnoticed.

As population densities are low, the sample size may be critical, too. For example, a seemingly reasonable sample of 2000 apples taken from a quite moderate 200.000 fruits/ha, must contain fewer than 10 entries (or 0.5%), to show with 95% confidence that the actual density does not exceed 1% or 2000 entries/ha. Counts in 50 or more tree bands might be a bit more accurate, but it is likely that, in the same orchard, 50 tree bands will yield far fewer larvae; in our experience, easily 80% less than the number of scored entries.

In order to avoid the effects of winter mortality, predation and disease, one should take adequate samples in spring, right before the first flight starts. Of course, tree bands might be used, but the survival of larvae in these bands might have been different from those hibernating on bare trees, especially if these are small and have a smooth bark on trunk and branches.

(3) Good results of MDT/CM might be promoted, in particular by the use of some pesticides against other pests. Various insecticides — fenoxycarb, diflubenzuron, and phosalone — kill eggs or young larvae of codling moth. An application of one of these compounds once the flower cluster leaves are fully developed, should kill at least 50% of the eggs. The application of phosalone against mussel scale *Lepidosaphes ulmi* (L.) in our three MDT orchards in mid-May 1990, *i.e.*shortly after flowering, should therefore have been partly responsible for the excellent results in that year. The possibility of such side effects seems to be more or less neglected in most studies. When an application affecting hatching larvae can not be avoided, some untreated trees should be used in future field work to estimate the effect.

(4) Monitoring codling moth during treatment, in order to recognize failures, remains cumbersome.

Evidently, pheromone trap catches of male moths should remain extremely low. How low is less evident, even if there is a comparison with an untreated plantation. This problem might be solved if one, unchanged, formulation can be tested for several years. For it might be assumed that trap catch, though low, has some fixed relation with both treatment and population density.

(5) Immigration of fertilized female moths is an evident risk in MDT/CM. This appears to be associated mainly with "neglected" fruit trees in the proximity. Long range migration has not been reported, probably because these females are difficult to capture. It should not be ruled out as cause of some unexplained failures. Evidently, a means to monitor female codling moths would solve most of previous questions.

MATING DISRUPTION OF LEAFROLLERS

MDT against leafrollers (MDT/LR) appears to be successful with Z11-14 : Ac, the component common to the pheromone blend of most Tortricidae, Tortricini and Archipini (e.g. Ioriatti, 1992). Efficacy against the major pests *A. orana*, *Archips podana* (Scopoli), *A. rosana* (L.), and *Pandemis heparana* (D.& S.) is now more or less documented, but is likely also on various minor ones. For example, the usual fruit damage by *Syndemis musculana* (Hübner) in our orchard had disappeared completely after this treatment in 1989, while pheromone trap catches of *Clepsis spectrana* (Treischke) became virtually nil. Because this technique has been tested only for about three years, a critical appraisal is still difficult.

(1) As higher leafroller densities can be tolerated, monitoring efficacy should pose less problems than with codling moth. The estimate of initial densities might give some problems, because several species are involved. While leafrollers can be easily sampled in spring, on flower clusters, the time of sampling might be critical. Early pupating species, primarily *A. orana*, should be sampled before or during early bloom (in the Netherlands). At that time, many larvae of late species like *P. heparana* are still small and difficult to detect. Thus, more than one sample might be needed.

(2) The size of these samples should be rather large. For example, 300 flower clusters yielding 3 larvae is equal to a density of 6000 larvae/ha, when the tree density is 2000/ha and each tree has 300 of these clusters, a rather moderate estimate. But twice that number or more, might be easily present in this case , as the upper 95% confidence interval lays at 3.6%, or 22.600 larvae/ha, and additional numbers of larvae might be living on leaf clusters. From our trials, 4 larvae of *P. heparana*, including some *A. podana*, in 2 x 300 flower clusters would be a safe density; the 95% limit would be about 2%. In this cases, *A. orana* was hardly present.

(3) Evidently, some leafroller species remain unaffected, notably the bud moth *Spilonota ocellana* (D. & S.) appears most important so far (Ioriatti & Rizzi, 1992). Attempts are underway to check also this species with MDT (Minks & van Deventer, this meeting). Where this species still interferes in experiments, samples of long shoots or fruit clusters maybe taken in late summer to establish its relative abundance. Fortunately, the brown *S. ocellana* larvae are easily to distinguish from the green caterpillars of *A. orana*, *P. heparana* and *A. podana.*

(4) Very little is, however, known about the relative amount of fruit damage inflicted by these various leafroller species. Earlier attempts (cf. de Reede et al., 1985) were not very successful. A major problem is the determination of young caterpillars around harvest. Identification by allozyme gel electrophoresis is possible (cf. Menken, 1991), and our group assists in an attempt to devise a method for processing larger field samples. Differential effects of the MDT/LR on single species have to come forward yet, but evidently the most abundant species in any location would be the least

vulnerable.

IMPLEMENTATION

The observation by Vickers & Rothschild (1991) that "in many parts of the world codling moth is just one of a complex of pests attacking the crop, and pheromone-based control is less attractive in such situations" , certainly applies to Europe. In many situations, the control of codling moth and some other caterpillars overlap. Moreover, several insecticides are suitable for integrated pest management (IPM) including rather selective compounds like diflubenzuron, teflubenzuron and fenoxycarb, and the, still largely experimental, granulosis virus. Monitoring, for example with pheromone traps, is sometimes used to avoid redundant treatments. Thus, preventive MDT/CM alone should not have much chance to be implemented, a fact already recognized by both researchers and industry. Similarly, an isolated application of MDT/LR should have little future. As either postbloom or summer treatments of the leafrollers would be suspended, the number of treatments against codling moth should rise in most regions, reducing the economic and environmental appeal of the approach. In this case, the use of granulosis virus against codling moth might be considered, purely for reasons of environmental impact. Thus, the combined implementation of MDT against codling moth and leafrollers (MDT/2) appears to be the most sensible approach at present.

In order to discuss the implementation of MDT/2, current IPM schemes might be divided in two sorts, with respect to tortricid control. The first one is characterized by the application of fenoxycarb, mainly after bloom; this juvenile hormone mimic disturbs the pupation of the various leafrollers. The treatment has a side effect on the eggs laid by codling moth in the following weeks, often strong enough to make treatment of this pest redundant. As mentioned before, post-bloom treatment of noctuids, mussel scale, or sawfly, might have a similar side-effect. Otherwise, codling moth is preferably treated with diflubenzuron or teflubenzuron. Note that this is an essentially preventive scheme, as the first treatment (fenoxycarb) is directed against full grown caterpillars in order to prevent the "usual" population increase in the next generation(s). It is also the most selective one available at present. Beneficials, including parasitoids and other potential antagonists of the tortricids, become more or less abundant under this regime. While the leafroller fauna becomes more variable, more elevated natural mortalities help to prevent, or slow down, outbreaks of most species. After a few years, reduced dosages of, for example, fenoxycarb and diflubenzuron often suffice. Therefore, implementation of MDT/2 should pose little problems, when this sort of IPM scheme has been applied previously. The growers are already acquainted with the use of fairly selective control methods, and great or sudden changes in pest numbers are unlikely.

In the other IPM scheme no fenoxycarb is used, but, often older, broad-spectrum, pesticides, like chlorpyriphos and phosmet, to treat both leafrollers and codling moth at the time of egg emergence. This is mainly the approach in areas where fenoxycarb is not available, like in the U.K., but also in the U.S.A. and Canada. Replacing this scheme by MDT/2 constitutes a greater step. The previously curative approach is replaced by a preventive one, and because more broad-spectrum compounds have been used, the beneficial fauna is less developed and one leafroller species is more likely to dominate. Thus, replacement by MDT/2 constitutes in this case a greater improvement with regard to the natural control of pests like phytophagous mites (*Panonychus ulmi*), pear sucker (*Psylla* spp.) and probably other fruit pests, but the efficacy of the method will be more challenged initially.

The replacement of current chemical control by MTD/2 should not be overestimated in terms of quantity. Chemical control of tortricids in apple and pear IPM in Holland amounts often to only one application of a reduced dose of fenoxycarb, and an occasional correction of codling moth with diflubenzuron. Usually, the total amount does not need to exceed one full rate of each compound annually, including some control of noctuids and geometrids. Evidently, these amounts increase considerably towards the South, notably where codling moth and some leafrollers have more than two generations annually. In this case, a combination of MDT and selective chemical control might be most attractive. Early chemical control might provide the best initial conditions for MDT, and a crop without pesticide residues. While such considerations might have quite some influence on the acceptance by MTD/2 by growers in various regions, the efficacy of the method will be looked at first.

CONCLUDING REMARKS

Some results of field tests with MDT, whether positive or negative, are usually difficult to interpret. The previous remarks might help to remedy some of these weaknesses. It is suggested that once a more definite dispenser formulation is available, more accurate observations might lead to an explanation of most "unexplained failures". The most critical concern in chronological order:

(1) Leafroller densities, and species composition, in spring,
(2) and codling moth densities just before the (first) flight starts.
(3) Side effects from chemical control against other pests.
(4) Density of codling moth entries, separating 1st and following generation(s),
(5) and leafroller densities on fruit clusters, or shoots, in late summer.

Other observations, like the use of pheromone traps and estimates of leafroller damage, are less interesting, unless they can be quantitatively related to one of the above observations.

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MATING DISRUPTION OF CODLING MOTH AND FRUIT TREE LEAFROLLERS IN DUTCH APPLE ORCHARDS: TESTING OF COMMERCIAL PRODUCTS

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ABSTRACT

Mating disruption activity of three commercial products has been tested on the codling moth and four species of leafroller moths in apple orchards in the Netherlands. The products were: 1) the BASF twin-dispensers, 2) the Biocontrol twisted-ropes (only for codling moth) and 3) the TNO polymer matrix formulation. Preliminary results obtained by pheromone trap captures and counting of infestations in mid-season samples of apples and growing shoots indicated a satisfactory level of mating disruption in most of the treatments. A density of 300 BASF dispensers/ha looked a marginal dosage in particular for the eye-spotted budmoth *Spilonota ocellana*.

INTRODUCTION

From 1989-1991, we have tested mating disruption activity of a commercial pheromone formulation in three apple orchards in the Netherlands (van Deventer et al. 1992). It was the "twin-dispenser" formulation developed by BASF (Germany) for control of the codling moth, *Cydia pomonella* (dispenser 1), and of three leafroller species, *Adoxophyes orana, Archips podana* and *Pandemis heparana* (dispenser 2). The latter dispenser did not contain the three specific pheromone blends of each species, but only the common component for all three leafrollers: Z11:14Ac.

The results were positive during the whole testing period. In most cases fruit damage could be kept under the economically acceptable level of 1%. For the codling moth the results were encouraging even in 1991, when its population in two of the experimental orchards became so high, that a diflubenzuron treatment was necessary in the untreated plots. From pheromone trap captures and the number of larval fruit entries it could clearly be seen that it is not recommendable to apply mating disruption close to untreated orchards with high populations, to avoid the risk of moths migrating into the treated area.

In 1992, we started to refine our tests. Firstly, two dosages of pheromone were introduced: the usual 500 dispensers/ha and a lower density of 300 dispensers/ha, in order to find out whether with less pheromone sufficient mating disruption still can be achieved. Secondly, another leafroller species, *Spilonota ocellana*, was added in a third dispenser. Since 3-4 years this leafroller occurs in growing numbers in our "integrated" orchards and it might be responsible for an important part of the leafroller fruit damage which yet could be found at harvest time.

In addition to the further examination of the BASF twin-dispenser formulation, we have run trials in commercial apple orchards to evaluate under Dutch conditions the "twisted rope" formulation of Biocontrol Ltd. (USA) for codling moth only and the TNO polymer formulation (The Netherlands) for codling moth and three of the above-mentioned leafroller species (no *S. ocellana* included).

MATERIALS AND METHODS

Experimental orchards

Our tests were conducted in 5 apple orchards, four of which are located in the "Betuwe" region approx. 20 km southwest of Wageningen. Orchard 5 is situated at 3 km distance from the North Sea coast between Haarlem and Leyden. All orchards have been planted with 5-10 year-old spindle trees with an average height of 2 m. Major varieties were Elstar and Jonagold. Plot sizes varied between 3 and 1.5 ha. Buffer zones of at least 25 m were kept between treated and control plots. All orchards were under an IPM regime using biological control of spider mites and, if necessary, selective chemical control of other pests and diseases was applied. Fenoxycarb was sprayed once just after blossoming against leafrollers in the control plots.

Mating disruption formulations

a. The BASF twin-dispenser formulation had two ampullae, either containing approx. 300 mg *E,E*8,10-12:OH (codling moth) or the same amount of *Z*11-14:Ac (leafrollers). Twenty percent of 14:OH was added to the codling moth ampullae to keep the codlemone liquid. For the additional treatment of *S. ocellana*, we used a third dispenser loaded with approx. 300 mg *Z*8-14:Ac, the major pheromone component of this moth species. This means that at densities of 500, respectively 300 dispensers/ha approx. 150 respectively 90 g of each of the 3 pheromone compounds were administered per ha.
b. The TNO formulation consisted of a polymer matrix in which the pheromone compounds were homogeneously impregnated. The codling moth dispensers contained 210 mg codlemone and no further additives, and the leafroller dispenser 650 mg *Z*11-14:Ac. This means that at a density of 500 dispensers/ha a dosage of 105 g codlemone and 325 g of *Z*11-14:Ac was given per ha.
c. The Biocontrol twisted-ropes each contained approx. 160 mg codlemone with addition of approx. 40 mg dodecanol (12:OH) and 8 mg tetradecanol (14:OH). At the recommended density of 1000 dispensers/ha a total quantity of 160 g of codlemone is applied per ha.

All three types of dispensers were suspended in the trees at a height of approx. 1.5 m.

Assessment methods

Effects of mating disruption were measured by various methods:
1) pheromone trap catches,
2) counting of larval attacks and pupae during mid-summer on fruit (codling moth) and on fresh shoots (leafrollers),
3) damage assessment of fruit at harvest time (codling moth and leafrollers).

RESULTS AND DISCUSSION

Pheromone trap catches

Our tests started between 18 and 22 May 1992. Because of the warm weather in April and May we were probably too late to include the start of the *C. pomonella* flight in our treatment. This was illustrated by relatively high captures in the first two weeks of the test period, particularly in the plots treated with 300 BASF dispensers/ha: in orchard 1, plot A, 6 moths out of the total catch of 10 moths until 21 August (see Table 1) were caught in those first 2 weeks and in orchard 2, plot B it was 5 out of a total of 7 moths. When taking this initial effect into account, we can safely conclude that for the rest of the test period (-21 August) trap catch reduction of *C. pomonella* was very high in all treatments. This was also the case in orchards 4 and 5 (not included in Table 1), where the twisted-rope dispensers were tested. Captures until 21 August were in the treated versus the control plot (total in two pheromone traps) in orchard 4: one moth versus 23 moths and in orchard 5: 7 moths (all in the first two weeks!) versus 28 moths.

For the three leafroller species, *A. orana, P. heparana* and *A. podana* trap catch reduction was almost 100%. This cannot be said for the two treatments in which the *S. ocellana* pheromone was included: in orchard 1, plot A (300 dispensers/ha) captures were reduced by only 50% and in orchard 2, plot B, at a density of 500 dispensers/ha catch reduction was better, namely 85%.

Table 1. Pheromone trap captures (total of 2 traps per plot) of codling moth and 4 leafroller species in the pheromone treated and control plots in orchards 2 and 3. Season 1992.

Treatments were in orchard 1: Plot A: 300 BASF disp./ha, including *S. ocellana* pheromone; Plot B: not included; Plot C: fenoxycarb treated control. In orchard 2: Plot A: 300 BASF disp./ha; Plot B: 500 BASF disp./ha including *S. ocellana* pheromone; Plot C: fenoxycarb treated control. And in orchard 3: Plot A: 500 TNO disp./ha; Plot B: 500 BASF disp./ha; Plot C: fenoxycarb treated control.

Plot/ Moth species	Captures (until 21 August) Orchard 1	Orchard 2	Orchard 3
Plot A			
Cydia pomonella	10	7	0
Adoxophyes orana	0	7	1
Pandemis heparana	1	6	0
Archips podana	0	0	0
Spilonota ocellana	102*	426	52
Plot B			
Cydia pomonella	-	2	0
Adoxophyes orana	-	0	3
Pandemis heparana	-	2	1
Archips podana	-	0	0
Spilonota ocellana	-	27*	60
Plot C			
Cydia pomonella	74	8	7
Adoxophyes orana	145	269	132
Pandemis heparana	30	19	16
Archips podana	161	23	81
Spilonota ocellana	223	201	76

* = *S. ocellana* pheromone treatment included

Number of larval entries in mid-season fruit samples

In Table 2 it is shown that larval entries of codling moth were generally very low in all plots. No differences could be observed between treatments and their controls.

Table 2. Number of codling moth entries found in mid-season samples of 1000 apples per plot in pheromone treated and control plots in orchards 1-5. Premature fruit drop is included in the samples. Season 1992

Orchard/treatment	30 June phero.	30 June contr.	23 July phero.	23 July contr.
1. BASF (300 disp./ha)	0	-)	2	-)
2. BASF (300 " ")	2	3	0	4
2. BASF (500 " ")	2	3	2	4
3. TNO (500 " ")	0	0	0	0
4. Biocontrol (1000 disp./ha)	0	2	0	0
5. Biocontrol (1000 " ")	1	2	0	2

-) no control plot available

Number of *A. orana* larvae in growing shoots

Table 3 also shows a rather high level of infested shoots particularly in the control plot of orchard 2, probably reflecting the high flight activity of *A. orana* and *S. ocellana* as was recorded in the pheromone traps.

Table 3. Number of first-generation *A. orana* larvae found in samples of 800 growing shoots per plot in pheromone treated and control plots in orchards 1-3 on 9 July 1992

Orchard/treatment	phero.	contr.
1. BASF (300 disp./ha)	1	-)
2. BASF (300 " ")	6	16
2. BASF (500 " ")	4	16
3. TNO (500 " ")	4	2

-) no control plot available

Damage assessment of harvested fruit

Results of the damage rate of harvested apples, undoubtedly being the most essential information of the whole test, could not yet be collected at the time of writing of this report.

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RESULTS OF 12 YEARS EXPERIENCE TO CONTROL CODLING MOTH, *CYDIA POMONELLA* L. BY MATING DISRUPTION

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ABSTRACT

From 1979 to 1991, 50 trials were carried out to control codling moth by mating disruption in an area of about 160 ha totally. The size of the orchards was between 1 and 4,5 ha (in one case 17 ha). The pheromone quantity applied per ha varied from 25 to 140 g and the number of dispensers from 90 to 500. Rubber tubes, flakes (Hercon, Montedison), polyethylene tubes (Biocontrol) as well as plastic ampoules (BASF) were used.

The efficacy was satisfactory in 70% of the experiments. This means, that the fruit attack by codling moth could be kept under the threshold of 1 - 2% (windfall fruits included) for one or several years. The disruption method, however, failed to control codling moth sufficiently in 30% of the cases.

INTRODUCTION

Codling moth (*Cydia pomonella* L.) is one of the key pests in the apple orchards of our region. Insecticide sprays are regularly applied against this pest. In integrated plant protection programs we have to look for alternative methods to chemical treatments. Since Roelofs et al. (1971) could identify the sex pheromone of the codling moth, one of the possibilities of controlling the pest is the mating disruption by the evaporation of high quantities of this compound.

In the last years the mating disruption system has been studied in many regions of the world (Audemard et al.1979, Charmillot 1980; Charmillot and Bloesch 1987; Howell et al. 1991; Ioriatti and Rizzi 1989 Moffitt and Westigard 1984; Neumann et al. 1990; Vickers and Rothschild 1991).

In 1979 we started the first trial to control codling moth by mating disruption in the field (Mani et al. 1984). In the following years we increased the number of treated orchards as well as the treated area (Mani 1985, Mani et al. 1987). From 1979 - 1991 about 50 trials in an area of 160 ha have been carried out.

MATERIAL AND METHODS

The substance (E,E -8,10-dodecadien-l-01) used for evaporation in the orchard was synthesized in different laboratories. As dispensers were utilized:

- Rubber tubes impregnated with the pheromone (1979 - 1983)
- Hercon flakes (1984 - 87)
- Plastic ampoules from BASF (1988 - 91)
- Polyethylene dispensers from Biocontrol (1987 and 1992)
- Flakes from Montedison (1989 - 1991)

Rubber tubes were placed at a density of 90 dispensers per ha, Hercon flakes at a density of 140 per ha, Montedison flakes, plastic ampoules of BASF and polyethylene tubes from Biocontrol at a density of 500 per ha. In all trials additional dispensers were placed in the border lines and on the wire screen fence surrounding the orchard.

The dispensers were placed as soon as the first moths were captured in the traps. In our region this happened generally during the first days of May. In orchards where the tree size was higher than the usual 3 -3,5 m, the dispensers were fixed alternately at eye level and in the canopy of the trees.

Most experimental orchards were treated for 3 - 5 years, some for only one year and a single orchard at Uttwil for ten years. Until 1987 we had a check orchard in the neighbourhood of every pheromone treated orchard.

The size of the pheromone treated orchards was 1 - 4,5 ha and in one case 17 ha.

The efficacy of the method was examined by

- the inhibition of moth catches in pheromone baited traps
- the copulation rate of tethered virgin females
- the fruit attack

Traps (8-12 per experiment) were placed in the center, in the border lines and corners of the orchard. They were fixed at eye level as well as in the top of the trees.

Virgin females (10-15) were exposed 2-3 times per season in the pheromone treated and in a check orchard. They were tethered with a cotton thread and left for 2-3 nights.

In July and August 1'000 - 8'000 fruits were examined for attack weekly. One to three weeks before harvest wind fall fruits of at least 50 trees per variety were examined for attack. At the same time 10'000 - 20'000 fruits (2'000 - 3'000 per variety) were inspected for attack on the trees. The percentage of fruit attack combined with the estimated number of fruits in the orchard enabled us to calculate the number of full grown larvae per ha.

RESULTS

Fig. 1 shows the summary of the results we obtained in our trials. The efficacy was satisfactory in about 70% of the experiments, i. e. the fruit attack by codling moth could be kept under the threshold of 1-2% (windfall fruits included). On the other hand fruit attack in check plots or orchards in the neighbourhood often amounted to 10 percent or more.

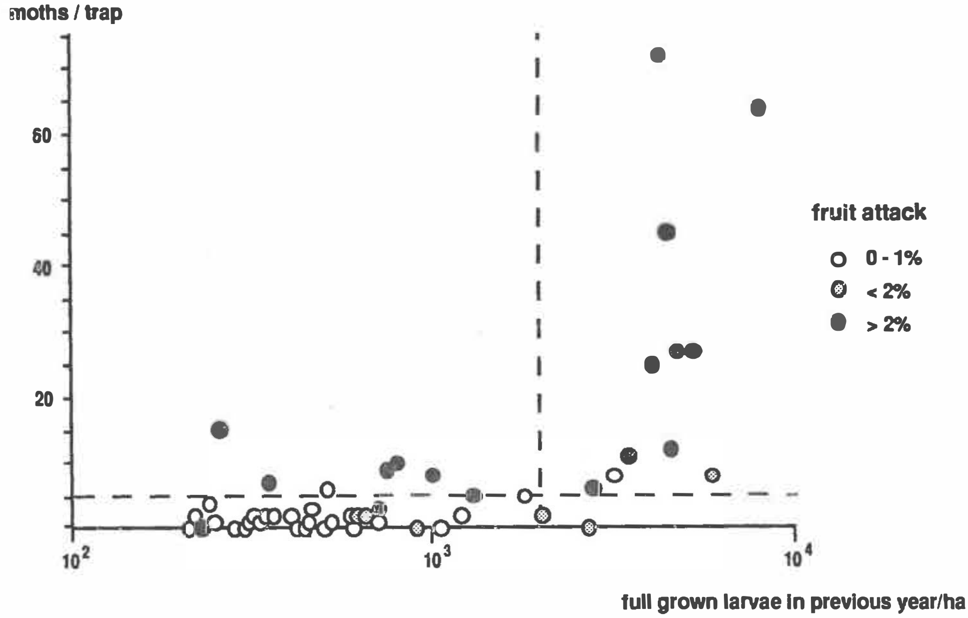
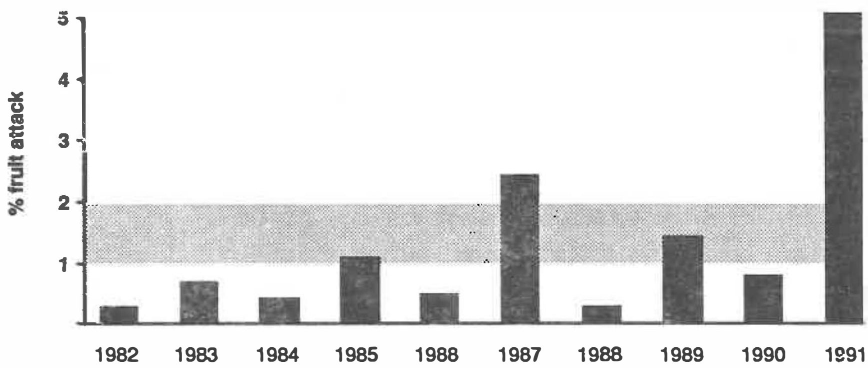


Fig. 1: Fruit attack in relation to moth catches and to larval population in the previous year

The disruption method, however, failed to control codling moth sufficiently in 30% of the trials. This was mostly the case, when the codling moth population had been high (more than 2000 full grown larvae per ha) in the previous year. But it also happened, when moth catches became important in traps at eye level in the center of the orchard (more than 5 moths per trap and season). Such catches were a first indication for an insufficient pheromone evaporation.

Fig. 2 shows the results we obtained in a 4.5 ha orchard at Uttwil during ten years. Although the number of dispensers and the quantity of the pheromone per ha were increased constantly over the years, the efficacy declined. The poor effect in 1987 and in 1991 seems to be connected with the quality of the dispensers (insufficient evaporation of the pheromone). A decline of the efficacy is also obvious in the copulation rate of tethered females.



Dispenser	rubber tubes		flakes (Hercon)				plastic ampules (BASF)			
Dispensers / ha	90	90	120/120	120/120	70/140	140/140	500	500	500	500
Pheromone / ha (g)	25	25	40	42	48	60	120	120	140	140

Fig. 2: Control of codling moth with mating disruption in the 4.5 ha apple orchard at Uttwil

In successful trials, where moth catches at eye level in the center of the orchard were zero or very low, we often caught distinct numbers of moths in traps placed at the border and in the top of the trees. The same situation could be found in view of the copulation rate of tethered females. This indicates distinct differences in the pheromone concentration within the orchard.

A further trial was carried out for 3 years in an orchard with organic production and with a high population pressure. A distinct reduction in the fruit attack could be achieved even under such conditions. But the level of 1-2% was not reached. Nevertheless the efficacy was good compared with a fruit attack of 20- 30% in an adjacent check plot.

Unusual results of moth catches and fruit attack were observed in the 3.7 ha orchard at Stegen. This orchard was well isolated on the W, N and S. In the east there were several untreated standard trees behind a hedge. However, the highest moth catches and the highest fruit attack occurred in the SW corner. In this corner we had placed many dispensers to balance the influence of the prevailing westwinds.

Contradictory results we obtained in two orchards separated by only 300 m at Uttwil in 1986. The orchards had about the same very low larval population in the previous year and the same isolation. In one orchard moth catch in the center was zero and fruit attack very low (0.4%). In the other orchard disruption failed. Traps in the center of the orchard caught many moths and fruit attack was too high (2.3%).

During the first week of the experiment we often captured some moths in the center of a pheromone treated orchard and no moth afterwards. This indicates, that the plants absorb the pheromone and act afterwards as additional dispensers. In special studies we could confirm this hypothesis. Leaves, fruits and branches taken from disruption orchards were placed in traps and proved to be attractive to codling moth.

DISCUSSION

Mating disruption as an ecologically safe and specific method has shown to be successful in most of our experiments. Such results have created much interest among growers and the fruit industry.

However, results were insufficient in too many cases and the numbers of failures became unacceptable. The registration given to a codlemone formulation in 1987 had to be cancelled in 1990.

Reasons for failures may be found in the characteristics of some orchards: Insufficient isolation, irregular shape of the orchard and the planting, high codling moth population (fig. 1).

Failures may also be due to the pheromone used. Over the years it has been synthesized in different laboratories. The purity and the content of secondary substances were in general not known sufficiently. Moreover, we do not know the ideal composition of the pheromone.

Formulations had been in a constant change during our studies (fig.2). Obviously the evaporation was not always sufficient. The degradation of the pheromone in the dispensers is far from being understood. Therefore progress in the production of dispensers is decisive. We need reliable formulations, whose characteristics remain unchanged over the years. This is a prerequisite to judge field trials and to introduce the method in the practice.

Introducing a new method for codling moth control is not easy. The growers are used today to very efficient insecticides, which are selective for many natural enemies. The accepted threshold for fruit damage is low. Moreover, the growers overestimate in general the economic importance of codling moth attack. Fruit damage due to other causes such as scab are accepted with less complaints.

Ecological advantages of mating disruption are obvious. The method is specific and not only selective. Such a quality may have disadvantages. Other fruit insects normally controlled by insecticides may become a problem. In most of our trials attack by other fruit insects (e.g. *Adoxophyes orana*) was negligible. In a few cases, however, *Grapholita lobarzewskii* occurred in too high numbers. In such orchards mating disruption for other fruit attacking tortricids would become necessary.

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EXPERIENCE WITH MATING DISRUPTION FOR CONTROL OF THE CODLING MOTH AND LEAFROLLERS AT THE LAIMBURG EXPERIMENT STATION (South Tirol - Bolzano)

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Introduction

Mating disruption with pheromones for control of Codling moth *(Cydia pomonella L.)* and various leafrollers *(Archips podana Scop., Pandemis heparana Denis & Schiff* and *Capua reticulana Hb.)* on apple at the Experiment Station Laimburg (South Tirol, Bolzano) has intensively been studied since 1988. Earlier test results with Codlemone against the codling moth have not been encouraging because of small treatment areas and high initial population density.

Test areas

This control method was first tested in a 5 ha orchard at the Datumhof near Siebeneich (Bolzano). This test was later expanded to 16 ha and is still on-going. Based on this experience, a 10 ha test was initiated in 1990 at the Laimburg Experiment Station, which was expanded in 1992 to 20 ha.

Varieties

Data are only shown for the following apple varieties: Golden Delicious, Granny Smith, Jonagold. Other varieties which were represented in the test orchards were: Red Delicious, Stayman Winesap, Gloster, Summerred, Jonathan and a few others.

Dispensers

The pheromone dispensers used in all tests were provided by the German Company BASF. The dispensers were applied once per season. The pheromones for the codling moth and leafrollers were held in two separate compartments. The dispensers consisted of transparent brown plastic (since 1989) which allowed the fruit grower and the researcher to observe the amount of pheromone remaining in each dispenser compartment.
The number of dispensers per ha was 500 (about 1 dispenser per 20 m²). More dispensers were placed along the borders than inside the test area. In 1992 the dispensers differed in terms of the type of plastic used, their colors (brown and black), formulation and dosage of pheromone (Table 1).
Additional investigations are needed to determine the minimum pheromone release necessary to achieve seasonal control and make this control method more economical. At this time it is too expensive and cannot compete economically with insecticidal control. The commercial dosage

today is 360 mg for each compartment. The dosages tested at the Datumhof and also at the Laimburg were 200 mg in 1992 in order to determine a reduced optimum dosage.
In 1991 the pheromone dosage for leafrollers was 270 mg/dispenser. This dosage was not sufficient for full seasonal control because of a very dry and hot summer.

Catches of codling moth and leafrollers in mating disruption blocks.

The lack of response to pheromone traps can be taken as one indication that males cannot locate females and that mating is disrupted. However, as Table 8 shows, high numbers of codling moth males responded to pheromone traps in all tests. On most of the treated area catches were higher during the first weeks after the dispensers were placed in the field. Possibly these early catches were due to insufficient distribution of the pheromone shortly after placement of the dispensers. Another reason for the high catches in early 1990 was the influx of moths from a nearby packing house which caused the population to increase and the mating disruption block to fail. The population was treated in 1991 with insecticide sprays.

Results

Datumhof 1988 - 1989

In 1988 a chemical barrier was maintained to separate the mating disruption block from the rest of the orchard and prevent influx of moths. In view of favourable results in 1988 no chemical barrier was used the following year. As can be seen in Table 2 and 3 control was satisfactory in the pheromone-treated blocks in both years when the infestation levels are compared to the chemical treatments. Codling moth damage in the mating disruption plots reached 0,2 - 0,7 % in 1988 and 0,1 - 0,7 % in 1989 while the chemically treated areas experienced damage between 0,0 - 0,2 % during both years. Fruit damage caused by leafrollers was 0,2 - 3,8 % in 1988 and 0,5 - 1,7 % in 1989 in the pheromone-treated plots. The chemically treated areas had between 1,3 and 4,4 % damage in 1988 and from 0,5 - 1,5 % damage in 1989. The results of both years were comparable.

Datumhof 1990

After two years of positive results barrier treatments were partially omitted in 1990. Omission of a chemical barrier is believed to be the principle cause for the failure of the confusion method during that year. Table 4 shows that the damage in the pheromone-treated areas with Golden Delicious and Granny Smith rose to 7,4 % and 12,4 %.
Areas far away from the packing house had lower damage than the pheromone-treated areas with the insecticide barriers with Diflubenzuron and Formothion. Damage reached 0,6 % on the Jonagold variety.
In the comparison areas treated with insecticides (4 treatments) damage was 3,8 % on Golden Delicious and 0,6 % on Granny Smith. In this case the differences were caused by the different age of apple trees, by the different growth forms and by the difference in timing of the chemical treatments. For instance, the first important treatment immediately after flowering was not applied to Golden Delicious.
One must stress the importance of chemically-treated barriers, when an infestation from outside is possible.

Datumhof 1991

During that year it became necessary to reduce populations of codling moth and leafrollers inside the pheromone-treated areas with insecticide sprays. Codling moth and leafroller damage was reduced by different chemical treatments. The results of the treatments in the infested areas are presented in Table 5.

Mating disruption was limited to an area of 2 ha far away from possible sources of infestation. The results obtained in this situation were better than those obtained exclusively by chemical treatment.

Datumhof 1992

After chemical treatments in 1991 mating disruption was again tested in this orchard. The barriers were chemically treated with Fenoxycarb, Teflubenzuron and Diflubenzuron. The results of the treatments are reported in Table 6.

By 05.08. it became evident that the original barriers were insufficient and that they had to be enlarged on two sides (Golden Delicious and Jonagold), because of the danger of a growing codling moth infestation in the last month. It was observed that the apples were also damaged by *Pammene rhediella Cl.* since this species was not affected by the pheromone treatments. Frequent visual inspection is necessary because various insect pests normally controlled by insecticides can develop in mating disruption blocks. The variety mostly damaged by *Pammene rhediella Cl.* was Granny Smith. This block was treated with the Enicham dispenser and showed fruit damage of 3,4 % in mid-July. Half of that damage (1,7 %) was caused by *P. rhediella*, the other half by codling moth. The comparison area treated with three sprays of Teflubenzuron had higher codling moth damage than the mating disruption blocks (Golden Delicious/Seedling 5,7 %; Table 6). However the Jonagold cultivar was better protected with three sprays of Fenoxycarb and Teflubenzorn (the observed damage was 1,3 %).

Laimburg tests

The results of the three years of experiments are reported in Table 7. Results show that the pheromone application was effective and limited codling moth damage. These results suggest that the mating disruption method could be adopted at the Laimburg site for seasonal control of codling moth (Table 1). The experimental area was relatively isolated and was bordered on three sides by roads and ditches. A chemical barrier was established on the remaining side of the experimental orchard. The point of infestation was eliminated in the first year of the experiment. At the Laimburg site a few blocks were older than 20 years. Historically these older blocks have higher codling moth infestation.

Special problems

A major problem at the Datumhof site was a packing house with fruit bins nearby which were the source of a large number of codling moth adults. Maintaining chemically treated barriers is critical to the success of the mating disruption method. Barriers should be 40 - 50 m wide to prevent the immigration of moths from outside sources.

Other problems are the differences among orchards in terms of training systems, age and size of trees, rootstocks and vigor. These factors may affect the effectiveness of the mating disruption method in various and still largely unknown ways.

Large trees (more than 20 years old) are often more heavily attacked by codling moth and leafrollers than small trees. Mating disruption as well as insecticides have more difficulty maintaining control in orchards with large trees. Visual inspection of the orchard is very important and should be conducted at frequent intervals. Since mating disruption specifically controlled codling moth and leafrollers, other insect pests appeared in the test plots, for example: leafhoppers, pear lace bug *(Stephanitis pyri pyri F.)*, European corn borer *(Ostrinia nubilalis)*, fruitlet mining tortrix *(Pammene rhediella Cl.)* and leafminers.

These pests can create difficult problems and need to be controlled separately.

Conclusions

Mating disruption with the sex pheromone appears to be a promising control technology when certain conditions are met:

- Low population density of the target pest
- Establishment of chemically treated barriers to prevent influx of pest individuals from outside sources (e.g. from packing houses, bin storage areas, unsprayed hosts). Migration can also be caused by favourable climatic conditions.
- The barrier areas should be frequently inspected to detect movement of pests. Visual inspection is also necessary to determine the need for control of pests not controlled by mating disruption.
- The areas treated with pheromone should be large. This also reduces the per hectar costs of mating disruption.
- The treated orchards should be uniform in terms of the vigor, planting distances, age and size of trees. Dispensers can be more easily distributed in orchards where trees are of uniform age and size. Visual inspection is also more easily performed in such orchards.
- Pheromone traps inside the treated area should not catch males. If males are caught in pheromone traps the pheromone concentration may be too low due to a low rate of evaporation (in early season at low temperature) or the pheromone is exhausted. In any case, if males are caught, the reasons for the captures should be investigated and corrective actions should be taken.
- The costs of this control method are still too high and need to be lowered to be competitive. Good results can be obtained with 200 mg of pheromone/dispenser instead of 360 mg. Determining the minimum effective dosage will lower the cost of this control method.
- Mating disruption should not completely exclude the chemical control option with conventional insecticides. Chemical control should also be considered, especially when the population density gets too high. Also, both control methods can be used simultaneously, one to maintain control in larger areas, the other to create barriers and protect pheromone-treated blocks.

TABLE 1: MATING DISRUPTION EXPERIMENTS CONDUCTED AT THE LAIMBURG EXPERIMENT STATION WITH DIFFERENT PHEROMONE DISPENSERS

YEAR	DISPENSER TYPE	PHEROMONE CONTENT PER DISPENSER IN mg		LOCATION AND DATE
		Codling Moth	Leafrollers	
1988	Black Basf	500	?	Datumhof 06.05.
	Brown Hercon	18g/ha	-	Datumhof 05.08.
1989	Brown Basf	340	340	Datumhof 03.05.
1990	Brown Basf Type H	530 - 50% Codl.. 50% other	430	Datumhof 03.05.
	Brown Basf Type B and E	430	430	Laimburg 02.05
1991	Brown Basf	370	270	Datumhof 07.05
		430	430	Datumhof 07.05
		370	270	Laimburg 08-09.05
1992	Brown Basf	200	200	Datumhof 04.05.
		360	360	Datumhof 11.05
		200	200	Laimburg 07-08.05

Table 2: MATING DISRUPTION - LAIMBURG 1988
LOCATION DATUMHOF - TOTAL DAMAGE OF CODLING MOTH AND LEAFROLLERS

TREATMENTS ACTIVE INGREDIENTS AND DATE	VARIETY/ROOTSTOCK	PERCENT FRUIT DAMAGE	
		Codling Moth	Leafrollers
Confusion Method	1) Golden Del/M9 Granny Smith/M9	0,7 0,2	3,8 0,2
Insecticide Barrier Confusion Method Diflubenzuron (0,1%) 07.05 -22.07	2) Golden Del/M9	0,3	1,3
Confusion Method + Diflubenzuron (0,1%) 07.05	3) Golden Del/M9	0	1
Insecticidal Control Fenoxycarb (0.03 %) 06.05 Diflubenzuron (0,1%) 15.07 Chlorpyriphos-Methyl (0.2%) 09.08	Golden Del/Seedling Granny Smith/M9	0,1 0	4,4 1,3

1) Distance from Packing House "Obsi" 100-300 m
2) Distance from Packing House "Obsi" 40 - 120 m
3) Distance from Packing House "Obsi" 250-350 m

Table 3: MATING DISRUPTION LAIMBURG 1989
LOCATION DATUMHOF - TOTAL DAMAGE OF CODLING MOTH AND LEAFROLLERS

TREATMENTS Active ingredients and date	VARIETY/ROOTSTOCK	PERCENT FRUIT DAMAGE	
		Codling Moth	Leafrollers
Confusion Methode Without Insecticide Barrier	1) Golden Del/M9	0,2	1,2
	2) Golden Del/M9	0,7	1,7
	3) Golden Del/M9	0,1	0,9
	2) Granny Smith/M9	0,3	0,5
Insecticidal Control	Golden Del/Seedling	0,2	1,5
Fenoxycarb (0,02%) 09.05	Granny Smith/M9 Schn.	0,1	0,5

1) Distance from Packing House 'Obsi' 100-300 m
2) Distance from Packing House 'Obsi' 40 - 120 m
3) Distance from Packing House 'Obsi' 250-350 m

Table 4: MATING DISRUPTION - LAIMBURG 1990 - LOCATION DATUMHOF
TOTAL DAMAGE OF LODLING MOTH AND LEAFROLLERS

TREATMENTS ACTIVE INGREDIENTS	DATE	VARIETY/ROOTSTOCK	PERCENT FRUIT DAMAGE	
			Codling Moth	Leafrollers
Confusion Method without Insecticide Barrier		1) Golden Del/M9	4,4	2,3
		2) Golden Del./M9	7,4	2,5
		3) Golden Del/M9	1,6	0,9
		2) Granny Smith/M9	12,4	0,5
		3) Granny Smith/M9	2,9	1,4
Confusion Method with Insecticide Barrier				
Diflubenzuron (0,08%)	25.06.-28.07.	2) Jonagold/M9	0,6	0,9
* Formothion (0,1%)	25.06.-28.07.			
Insecticidal Control				
° Diflubenzuron (0,08%)	06.07.	Golden Del/Seedling	3,8	5,5
° Diflubenzuron (0,06%)	20.07.			
° Diflubenzuron (0,066)	15.05.	Ganny Smith/M9	0,6	2,5
° Diflubenzuron (0,08%)	06.07.-19.07.			
° Diflubenzuron (0,1%)	05.07.	Jonagold/M9	0,7	3
°Diflubenzuron (0,08%)	20.07.			
* Formothion (0,1%)	20.06.-27.07.			

1) Distance from Packing/House "Obsi" 100 - 300 m
2) Distance from Packing/House "Obsi" 40 - 120 m
3) Distance from Packing/House "Obsi" 250 - 300 m

* Primarily applied against Leafhoppers
° Three Different Timings and Control programs

Table 5: MATING DISRUPTION - LAIMBURG 1991
LOCATION DATUMHOF - TOTAL DAMAGE OF CODLING MOTH AND LEAFROLLERS

TREATMENTS ACTIVE INGREDIENTS	DATE	VARIETY/ROOTSTOCK	PERCENT FRUIT DAMAGE	
			Codling Moth	Leafrollers
1) Confusion Method Dispenser Basf		Granny Smith/M9	0,4	0,3
2) Confusion Method		Golden Del/M9	0,2	0,5
Dispenser Basf 370 mg/Amp CM		Granny Smith/M9	0,3	0,5
Dispenser Basf 270 mg/Ampl.R and				
Fenoxycarb 0,015%	13.05.+23.05.			
Teflubenzuron 0,04%	07.06.			
3) Insecticidal Control		Jonagold/M9	1	2,1
Fenoxycarb 0,017%	15.05.			
Teflubenzuron 0,033%	11.06.			
Teflubenzuron 0,03%	03.07.			
Diflubenzuron 0,1%	23.07.			

Table 6: MATING DISRUPTION - LAIMBURG 1992 - LOCATION DATUMHOF PRELIMINARY RESULTS - DAMAGE OF CODLING MOTH

TREATMENTS ACTIVE INGREDIENTS	DATE	VARIETY/ROOTSTOCK	PERCENT FRUIT DAMAGE Codling Moth 2.6.92	16.6.92	14.7.92	5.8.92	Leafrollers 5.8.92
Confusion Method Dispenser Basf	04.05.	1) Golden Del/M9	0,2	0,7	0,4	1,0	0,3
		3) Golden Del/M9	0,2	1,4	2,9*	2,9*	0,0
		Jonagold/M9	0,5	0,7	1,8*	1,6*	0,0
Dispenser Enichem	09.05.	Granny Smith	2,3	2,8	3,4**	1,9	0,3
Confusion Method Disp. Basf and Insecticide Barrier with		1) Golden Del/M9	0,0	0,1	0,4	1,0	0,6
		2) Golden Del/M9	0,0	0,2	0,4	0,8	0,1
Teflubenzuron 0,03%	13.05.,29.07.	Jonagold/M9	0,2	0,3	0,7	2,3	
or							
Diflubenzuron 0.1% Teflubenzuron 0,03%	13.05. 09.06.,15.07.	3) Golden Del/M9	0,5	0,5	1,2	2,1	0,3
Insecticidal control with Teflubenzuron 0,03%	20.06.-20.07. 31.07.	Golden Del/Seedling	0,3	3,5	6,0	5,7	0,3
or							
Fenoxycarb 0,03% Teflubenzuron 0,03%	13.05. 20.06.-15.07.	Jonagold/M9	0,4	1,1	0,6	1,3	0,6

* Treatment to 15.07.92 with Teflubenzuron 0,03%
** 50% Damage of Pammene rhediella Cl.

1) Distance from Packing House "Obsi" 100 - 300 m
2) Distance from Packing House "Obsi" 40 - 120. m
3) Distance from Packing House "Obsi" 250 - 300 m

Table 7
MATING DISRUPTION - LAIMBURG 1990 - 1992
LOCATION LAIMBURG - SUMMARY OF RESULTS FOR 3 YEARS

TREATMENTS ACTIVE INGREDIENTS AND DATE	VARIETY/ROOTSTOCK	PERCENT FRUIT DAMAGE Codling Moth 1990	1991	1992	Leafrollers 1990	1991
Confusion Method Dispenser Basf	73 Golden Del/M9	0	0	0,5*	0,5	1
	65 Granny Smith/M9	0,1	0,1	0	0,3	0,1
Insecticidal Control	45 Golden Del/M9	-	1,6	0,3	-	2,4
	61 Granny Smith/M9	-	0,2		-	0,3
	63 Morgenduft/M106	-	1,6		-	1,2
	111 Morgenduft/M7	1,7	4,8		1,9	2,8
Organic Program	1 Golden Del/M7	0,2	0,9	1,6	5,8	6,5

* Probable damage of Pammene rhediella Cl.

Tab. 8: Catch of Codling Moth and Leafrollers - Laimburg 1988-92
Location Datumhof

YEAR	TOTAL NUMBER CAUGHT: CODLING MOTH CONFUSION	CODLING MOTH INSECTICIDE	LEAFROLLERS: ARCHIPS PODANA Confusion	ARCHIPS PODANA Insecticide	PANDEMIS HEPARANA Confusion	PANDEMIS HEPARANA Insecticide	CAPUA RETICULANA Confusion	CAPUA RETICULANA Insecticide
1988	19	-	0	410	0	75	0	520
1989	17	88	0	159	0	2	0	425
1990	161	255	0	69	14	3	0	39
1991	151	252	0	0	0	50	0	68
1992	38	449	0	0	1	24	2	8

FIVE-YEAR EXPERIENCE WITH MATING DISRUPTION AS A CONTROL METHOD AGAINST CODLING MOTH AND LEAFROLLER SPECIES IN APPLE ORCHARDS OF TRENTINO

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ABSTRACT

In order to evaluate the efficacy of mating disruption against codling moth (Cydia pomonella) and the leafrollers tortrix moth, trials using Donegani dispensers have been carried on in three apple orchards (8.6 ha, 3.8 ha, 11.2 ha) located in different climatc areas of Trentino. These trials in the three sites started respectively in 1987, 1988 and 1991.

Donegani dispensers (now colled ISAGRO) consist in platelets of resin-treated filter paper impregnated with pheromone. The diffusion rate of pheromone was evaluated through weighing and gaschromatographic analysis.

The effects of mating disruption were evaluated by taking into consideration the inhibition of pheromone trap catches, the damage on fruits and the number of hibernating larvae in tree bands.

From the ground of this observations we modified some factors as the quantity of attractant/ha, the quantity of attractant/dispenser and the number of applications/year. Two applications of 300 dispensers impregnated with 300-350 mg both of codlemone and of leafrollers attractant are what we finally suggest to apply.

The results were in general positive both for codling moth and leafrollers; the initial problems in some of the blocks, which required sometime a chemical control in the first year, decreased gradually in the following years.

The consequences of either the reduction or suspension of pheromone application in the orchards where the tortrix moth population appear to be low are discussed.

INTRODUCTION

Since 1987 the Istituto Agrario of S.Michele a/A has been conducting a series of trials to determine the feasibility of mating disruption as a control method against codling moth (*Cydia pomonella* L.) and the leafroller species, which are the main pests requiring curative treatments in the fruit growing areas of the region.

In the particular conditions of our region, the codling moth has two overlapping generations, the adult flight starts in May and continues without interruptions until September.

The three main leafroller species (*Adoxophyes orana* F.v.R., *Archips podanus* Sc., *Pandemis heparana* D. et S.) also have two generations. These species, together with the less common *Argyrotaenia pulchellana* (Hw.), contain the same compound, although in different proportions, in their natural pheromone. It is therefore possible to control all these species by diffusing the one component they are in common. In some hilly areas these species are associated with another one, *Spilonota ocellana* (D. et S.), with a different pheromone blend.

MATERIAL AND METHODS

Dispensers. ISAGRO's cellulose flakes (2.5x5 cm and 2 mm thick), impregnated with the attractant mixed with stabilizers, are used as dispensers. The attractant used for the codling moth is E8,E10-12:OH while for the leafrollers is Z11-14:Ac, either pure or mixed with a certain percentage of Z9-14:Ac. In the trials carried out until 1990, the two attractants for codling moth and leafrollers, were impregnated separately, while in the last two years dispensers have been tested where the two attractants are present at once. The diffusion rate of the attractant has been measured by weighing the dispensers and by gas chromatographic (GC) analysis. In order to adapt the emission rate to the specific requirements of the environment and the pest, in the different trials we modified the amount of attractant used for unit of surface (47-228 g/ha for codling moth and 116-192 g/ha for leafrollers), the number of applications per season (1-2) and of dispensers per hectare (300-500), the amount of attractant per dispenser (175-600 mg for the codling moth and 300-600 mg for leafrollers) and some characteristics of the dispenser.

Methods and Procedures. During the first year of experimentation, 1987 the mating disruption technique was used only to control the codling moth, while from the second year onwards, trials were started to control also the leafroller complex. In the growing areas where all these pests coexisted the two different pheromones were distributed at the same time. The trials have been carried out in three different orchards (Sporminore, Sarche, Marco) which are representative of the different climatic and cultural conditions typical of our region.

Placement of the dispensers in the orchard. The dispensers are uniformly distributed inside the orchards by hanging them on the branches at a height of about 1.5-2 m. Where trees are particularly high the dispensers are placed on more levels (2-3). Along the borders of the plot the number of dispensers has been increased to compensate the dilution of the attractant in the atmosphere surrounding the growing area.

Efficacy assesement. The effectiveness of the method has been assessed according to the inhibition of captures in pheromone traps, by checking the fruit damage during the season and at harvest and, for the codling moth, according to the number of diapausing larvae captured in corrugated paperband traps.

RESULTS

Before examining the individual trials it should be underlined that in all cases the mating disruption technique has achieved an almost complete inhibition of catches in pheromone traps.

At Sarche (3.8 ha) in 1988, pheromones were used only against the codling moth, and during the summer two applications of insecticides (Chlorpyriphos-etil) was necessary to control the population of leafrollers which had exceeded the threshold level. At the beginning of the 1989 season, before starting the disruption programme, an application of fenoxycarb plus acephate was used to reduce the population of leafroller overwintering larvae. In 1990 no insecticide treatment was needed. In 1991 and 1992 the mating disruption programme was discontinued and the damage caused by both groups of pests gradually increased. During the present season an application of diflubenzuron has been necessary to control the codling moth population.

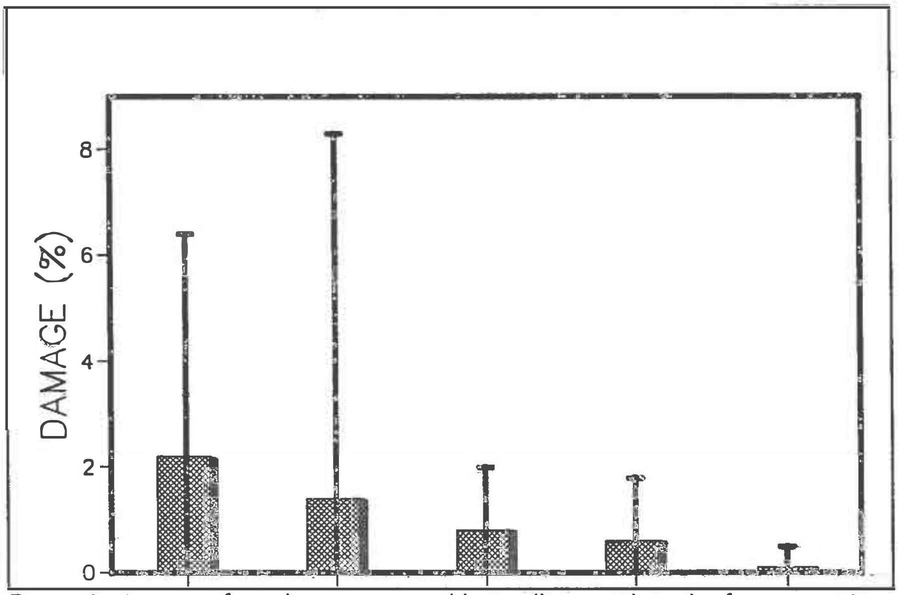

Figure 1. Average fruit damage caused by codling moth in the five years. Line bars show the highest value reached.

The orchard located at Marco (11.2 ha) has been treated with mating disruption method against codling moth and leafrollers only since 1991 and the results obtained in the first year can be considered encouraging. A single insecticide treatment on less than 30% of the entire area was sufficient to control the codling moth. During this second year the problem seems even more limited and only a few rows along the borders of the area have been treated with an insecticide when, towards the end of August, the threshold was exceeded.

The orchard at Sporminore cover 8.6 ha and has been run using biological methods since 1986. The introduction of mating disruption against the codling moth has resulted in a gradual reduction in damage at harvest. Figure 1 show the average fruit damage in the different years and also the highest level of damage reached, the figure also clearly indicates that, although the average damage was reasonably close to the tolerance threshold, during the first two years of experimentation in some areas the damage level was considerably high; in particular, in one of the six plots in which the orchard is subdivided, the damage level reached 7% in 1987 and 8.7% in the following year. In order to limit the damage it was therefore decided to treat part of the plot with granulosis virus.

In the following years the average damage at harvest gradually declined to such a level that in 1992 the pheromone treatment has been reduced to a single application. Such a treatment, however, has not been sufficient to keep the codling moth population under control for the entire season; therefore, when in August the damage threshold was exceeded, an application of ryania was made on a 10% of the orchard.

Another interesting aspect that should be underlined is the gradual decline of the codling moth overwintering population showed by corrugated paperband traps (tab.1); the number of larvae per trap decreased from 1.15 in 1987, to less than 0.2 in the following years.

YEAR	PEST DAMAGE				
	CODLING MOTH	LEAFROLLERS	APPLE FRUIT WEEVIL	NOCTUIDAE and GEOMETRIDAE	FRUTLET MINING TORTRIX
1987	2.2	3.0	0.8	7.1	1.0
1988	1.4	7.0	1.5	2.7	2.3
1989	0.8	8.7	2.9	3.5	3.9
1990	0.4	3.1	0.5	0.8	1.2
1991	0.1	1.4	1.0	2.3	1.4

Tab.1 - Fruit-damage of the main pests found out at the harvest.

Inspection at harvest in 1989 showed a 8.7% damage caused by the first and the second generation of leafrollers, as a consequence, in 1990 the pheromone programme was extended also to the leafrollers. The attack level rapidly decreased in the following years (tab.2) probably even thanks to the action of all the beneficial insects which managed to develop in these years of selective pest control.

	YEAR				
	87	88	89	90	91
LARVAE/ CARDBOARD BAND	1.15	0.04	0.02	0.23	0.05

Tab.2 - Average number of codling moth overwintering larvae caught in the cardboard bands at Sporminore in the five years.

It often happens that the use of selective control methods against key pests allows the development of otherwise secondary pests; this was also the case of this particular growing area where , since 1989, the damage caused by *Pammene rhediella* has dramatically increased (13.8% in June, 3.9% at harvest). Being this species responsive to codlemone, the dispensers for codling moth were placed in the orchards one month in advance so that they could cover also the flight of *Pammene rhediella*. The results achieved in the first two years of experiments were encouraging, while in the last year the method has been completely unsatisfactory. However, it should be underlined that, as a consequence of a delay in delivery, the dispensers were placed in the orchards when the flight of the pest had already started.

As far as other pests are concerned (tab.1), the damage never increased to a level which would require curative treatment.

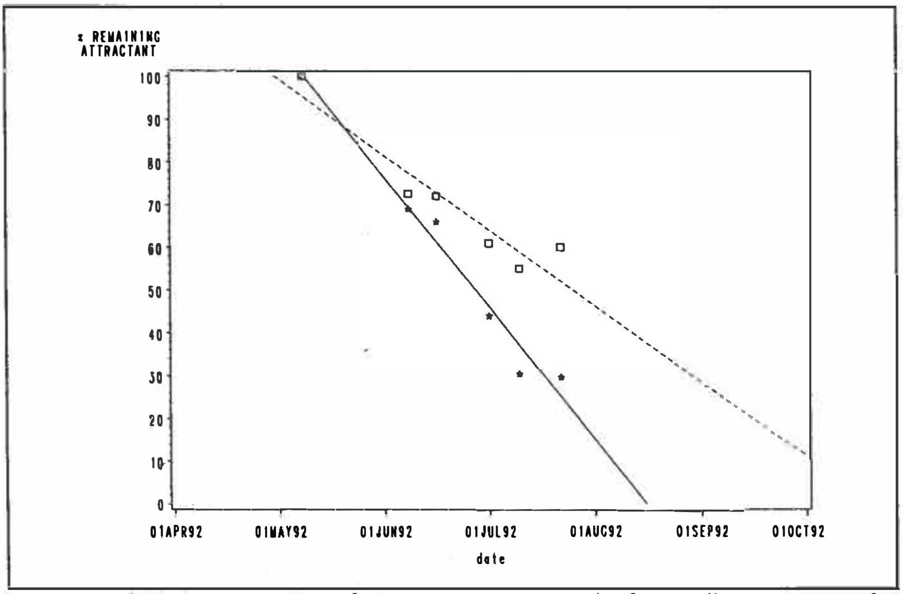

Figure 2. The emission rate of the two attractants (★ for codling moth, □ for leafrollers) assessed by GC analysis in 1992.

CONCLUSIONS

Weighing the dispensers is not a reliable method for assessing the diffusion rates of this particular type of dispenser because in the field the attractant undergoes a different process of oxidation or, more simply, it accumulates impurities, dust and moisture differently from the control dispensers used to correct the weight. It is therefore necessary to refer to data obtained from GC analysis which show a more constant emission rate.

At present we apply twice a year 300 dispensers/ha; these are loaded with 300-350 mg of attractant, that means about 190 g/ha of pheromone per season. The modification of the characteristics of the dispenser, and of the attractant contained in it, has also modified the half diffusion-life. The GC analysis shown that the dispensers have an half diffusion-life of about 35 days for codlemone (57mg/ha per hour) and about 45 days for the leafrollers attractant (44 mg/ha per hour). The presence of the two attractants in the same dispenser reduces the emission rate. Codlemone has an half diffusion-life of more than 50 days (40 mg/ha per hour) while the blend of Z11-14Ac + Z9-14 Ac has an half diffusion-life of about 100 days (20 mg/ha per hour) (fig.2). The attractant emission rate of dispenser distributed in summer is always higher than that of dispensers placed in the field in spring, although the difference is not always noticeable. Increasing the lure/ha does not necessarily mean that a higher quantity of attractant is diffused in the atmosphere but it rather produces a more homogeneous emission rate during the season.

From what has been said no far, it is clear that in the climatic conditions of our region, the performances of the dispensers available at the moment require two applications per season. The higher distribution cost is compensated by a better use of the pheromone which can therefore lead to a reduction in the amount of attractant needed and, finally, in the cost of dispensers.

ESSAIS DE LUTTE PAR CONFUSION SEXUELLE CONTRE LES LEPIDOPTERES NUISIBLES AUX VERGERS DE POMMIERS DANS LA BASSE VALLEE DU RHONE

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Les essais de lutte par confusion sexuelle réalisés en verger de pommiers de la basse vallée du Rhône de 1983 à 1991 concernent plusieurs espèces de Lépidoptères nuisibles. Il s'agit des xylophages Zeuzère *Zeuzera pyrina* L. (1er essai en 1991) et Sésie *Synanthedon myopaeformis* Borkh. (9 années d'essai), des tordeuses de la pelure surtout *Pandemis heparana* Den. et Schiff. (5 années) et du Carpocapse *Cydia pomonella* L. (4 années).

ZEUZERE

Les diffuseurs utilisés sont du modèle ampoule Rak 8^R de BASF, chargés avec le composé principal de la phéromone E2Z13-18:Ac. Une seule mise en place de 1000 ampoules/ha est effectuée le 29 mai 1991, la dose étant de 234 g/ha d'attractif. Deux vergers sont utilisés : Montfavet I.N.R.A., 1 ha de pommiers et de poiriers, assez isolé et Cavaillon, 1,2 ha de pommiers au sein d'une grande exploitation arboricole. Dans cette situation, un barrage de diffuseurs est placé dans les parcelles avoisinantes sur une superficie de 2,2 ha.

La diffusion, estimée par gravimétrie, est assez bien corrélée avec les degrés-jours cumulés des températures moyennes journalières. Elle est supérieure à 20 mg/ha/heure jusqu'à 1 mois après la fin du vol de la Zeuzère. Il reste alors plus de 50 % de l'attractif dans les diffuseurs. La proportion d'arbres attaqués, établie par contrôle visuel des attaques secondaires dans les branches et les troncs, montre une réduction des attaques par rapport à l'année précédente de 76 et 82 % pour les 2 vergers. Cela est équivalent à ce que l'on aurait obtenu avec une lutte chimique. Ces résultats sont donc très encourageants.

SESIE

1 - Conditions expérimentales

L'attractif sexuel utilisé est du Z3Z13-18:Ac. Deux modèles de diffuseurs sont expérimentés : les rubans polystratifiés Hercon^{R} chargés théoriquement de 37 mg/inch^{2} d'attractif et à partir de 1989 les diffuseurs Rak 7^{R} de BASF. On place en général 1750 diffuseurs Hercon de 30 à 50 cm de long/ha, 2 fois par saison et 3 en 1984. La dose hectare/saison est de 127 à 141 g et 228 en 1984, car les analyses ont révélé des charges inférieures à la charge théorique. Une seule mise en place de 500 diffuseurs Rak 7/ha/saison est réalisée à la mi-mai, ce qui représente 122 à 132 g d'attractif.

Cinq vergers sont utilisés pour les essais. Quatre sont situés à Cavaillon et forment un ensemble de 3,7 ha de pommiers entourés d'un barrage de diffuseurs sur 2,4 ha. L'un d'entre eux est protégé dès sa plantation. L'autre verger assez isolé est localisé à Montfavet I.N.R.A., il comprend 1 ha de jeunes pommiers et poiriers. A Cavaillon, un verger de 0,6 ha est utilisé comme témoin.

2 - Résultats

La diffusion est correctement estimée par gravimétrie pour les diffuseurs Rak 7, alors que pour les diffuseurs Hercon seule l'analyse est utilisable. Pour les 2 modèles, la diffusion est assez bien corrélée avec les degrés-jours cumulés des températures moyennes journalières jusqu'à une diffusion de 50-60 % de la charge initiale. A ce point correspond 1250 degrés-jours pour le Hercon qui dure 7-8 semaines et 3000 pour le Rak 7 qui couvre plus de 20 semaines, soit plus que la durée du vol.

Les quantités diffusées ne sont pas inférieures à 10-15 mg/ha/heure, ce qui parait suffisant pour un insecte à activité diurne. Les diffuseurs Hercon, dont la fiabilité est mauvaise en 1984, n'ont jamais pu être placés avant le début du vol.

L'inhibition des captures aux pièges appâtés avec l'attractif sexuel est de 98-100 % pour le Hercon et totale pour le Rak 7. Dans les 5 pièges alimentaires par verger on capture plusieurs milliers d'adultes par saison et quelques centaines dans le verger protégé dès sa plantation et à Montfavet. La proportion de mâles capturés dans les vergers soumis à la confusion (55-60 %) est inférieure à celle du témoin (70 %), ce qui indique leur nette perturbation. La réduction de la proportion des femelles accouplées est très faible dans le cas des essais avec les diffuseurs Hercon et marque un net progrès avec le Rak 7 atteignant moins de 50 %. Il faut souligner que l'on capture dans les pièges alimentaires des insectes physiologiquement âgés pour lesquels la probabilité d'accouplement est alors importante.

La population est estimée par le comptage des dépouilles nymphales, ce qui représente une information sur l'effet de la confusion différée de 2 ans comptetenu de la durée du cycle évolutif. La population du verger protégé dès sa plantation est maintenue à un niveau faible à nul de 1985 à 1991 : 0 ; 0,1 ; 0 ; 0 ; 0,05 ; 0,05 ; 0 nymphes/arbre. Il en est de même dans le verger de Montfavet. Il ne semble pas possible d'obtenir une réduction significative ou un maintien de la population lorsqu'il y a plus de 5 nymphes/arbre.

TORDEUSES DE LA PELURE

Les diffuseurs ampoule Rak 4^R de BASF expérimentés sont chargés avec le Z11-14:Ac de 1988 à 1991, plus un antioxydant, qui est le composé soit majoritaire, soit minoritaire des phéromones des 4 principales espèces de tordeuses de la pelure : *Adoxophyes orana* F.v.R., *Archips podana* Scop., *Argyrotaenia pulchellana* Haw et *Pandemis heparana* Den. et Schiff. En 1987, l'attractif est composé d'un mélange de Z9-14:Ac et Z11-14:Ac. Une seule mise en place de 500 diffuseurs/ha dans la 2ème quinzaine d'avril est effectuée, ce qui représente une dose de 130 à 327 g/ha. Une ceinture de diffuseurs est disposée sur les haies et arbres entourant les parcelles d'essai.

Les essais sont conduits dans 3 vergers localisés respectivement à : Avignon, 0,6 ha de pommiers entourés de poiriers, Montfavet I.N.R.A. 1 ha de jeunes pommiers et poiriers, Cavaillon 1,4 ha de pommiers situés dans un ensemble de vergers bien protégés par la lutte chimique. Deux vergers de référence, traités chimiquement sont surveillés à Avignon, 2 ha et Cavaillon 1,2 ha. Les espèces dominantes sont *P. heparana* et *A. pulchellana*.

La diffusion, bien estimée par gravimétrie, est assez régulière en 1989, 1990 et 1991 et corrélée avec les degrés-jours cumulés des températures moyennes journalières. Il reste un peu plus de 30 % de la charge initiale à 3500 degrés-jours. Cela correspond à une durée de 24-25 semaines, durant laquelle on a diffusé toujours plus de 20 mg/ha/heure.

En 1988, on relève 96,8 % d'inhibition des captures de *P. heparana* au piège sexuel, avec 547 captures dan le verger de référence, ce qui est attribué à une durée de diffusion insuffisante. L'attaque atteint 1,4 % des fruits en août nécessitant un traitement chimique. Les 3 autres années, l'inhibition des captures des 4 espèces est quasi totale et les attaques sur fruits, dans un contexte d'assez basse population, limitées à 0,1 - 2 %. Le diffuseur parait donc au point.

CARPOCAPSE

Les essais conduits de 1988 à 1991 ont pour objet principal la mise au point du matériel de diffusion : les ampoules doubles Rak 3 + 4^R de BASF, permettant une lutte conjointe contre les tordeuses de la pelure (cf. supra). L'attractif utilisé est du E8E10-12:OH/12:Ac jusqu'en 1990, remplacé par le 14:Ac en 1991 (ratio 80/20). On place 500 diffuseurs/ha, avec 2 mises en place mi-avril et fin juillet en 1988 et 1989 et des doses/ha/saison de 127 à 280. Une seule mise en place apporte 421 g en 1990 et

240 en 1991. Une ceinture de diffuseurs est disposée sur les haies et arbres entourant les parcelles d'essai.

Les essais sont réalisés dans les 3 vergers utilisés pour les tordeuses de la pelure. Dans un des vergers de référence, le Carpocapse est combattu avec une préparation de virus de la granulose, la Carpovirusine.

En 1988 et 1989, la diffusion, estimée par analyse n'est pas satisfaisante. Les 2 années suivantes, elle est assez bien corrélée avec les degrés-jours cumulés des températures moyennes journalières. Les résultats des pesées des diffuseurs demandent à être corrigés par ceux des analyses. Il reste environ 50 % de la charge initiale après 3500 degrés-jours, ce qui est beaucoup trop. De plus, celà correspond à une durée de diffusion de 25 semaines, ce qui excède de 2 semaines la durée du vol. La quantité diffusée est supérieure à 20 mg/ha/heure en 1990 et 1991, cette valeur n'est atteinte en 1991 qu'à partir de la mi-mai.

L'inhibition des captures aux pièges avec l'attractif sexuel est quasi totale, sauf à Montfavet où le faible développement de la végétation du jeune verger et l'impossibilité de boucler la ceinture de diffuseurs, a entraîné des attaques croissantes et une population trop forte pour la lutte par confusion.

Dans le verger de Cavaillon en 1989, l'adjonction de 2 traitements dont 1 à la Carpovirusine permet de pallier l'insuffisance du matériel et d'obtenir une bonne protection de la récolte. En 1990, la confusion donne de bons résultats avec cependant une augmentation de la population hivernante. En 1991, la situation s'est dégradée en août consécutivement à l'arrachage d'un grand verger d'une ferme voisine et l'arrivée massive de papillons. Les attaques sont supérieures au seuil malgré un traitement à la Carpovirusine, la parcelle de référence avec cette préparation subissant les mêmes attaques. Dans le verger de référence lutte chimique d'Avignon, l'insuffisance du diflubenzuron à 10 g matière active/hl, employé depuis 15 ans est à signaler. Les taux d'attaque sur fruits à la récolte sont de 16,5 % en 1990 et 50,7 en 1991.

Ces essais illustrent bien les conditions nécessaires à la réussite de la lutte par confusion contre le Carpocapse : faible population, dimension, âge et isolation des vergers, barrière de diffuseurs, fiabilité du matériel.

REMERCIEMENTS : Nous exprimons notre gratitude à tous ceux qui ont participé à ce programme et plus particulièrement à : Drs. BUSCHMAN A. et NEUMANN U. (BASF), DAURES V. et FREMOND J.C. (INRA), MANGUIN J.P. et MESTRE R. (Arboriculteurs).

MATING DISRUPTION OF CODLING MOTH AND LEAFROLLERS

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Various studies are in progress at our laboraotry concerning the development of mating disruption for codling moth and several species of leafrollers. These studies have been organized with a 'systems approach' which attempts first to understand the behavior of the insect and pheromone in the orchard and then to optimize various operational factors associated with the use of specific pheromone dispenser systems. This paper provides a brief summary of the effectiveness of Pacific Biocontrol's Shin-etsu rope dispenser for codling moth in apple orchards in Washington during 1991 and a number of experiments which we have conducted to address the optimal release rate, blend, and placement of these dispensers. Ongoing research on the behavior of codling moth is also provided. Finally, this paper summarizes our recent research comparing two dispenser systems loaded with two blends for disruption of a number of leafroller species.

In 1991, the codling moth dispenser was used in ca. 1,000 ha in North America. We monitored 10 pairs of pheromone-treated and insecticide-treated orchards (ca. 100 ha of each type). The pheromone was applied once per season at 1,000 dispensers per hectare. Dispensers were placed in the upper third of the canopy. In all but one pair of orchards the amount of fruit injury in the pheromone treatment was comparable to the standard insecticide program. In the one failure ca. 10% injury occurred. This lack of effectiveness was likely due to a high overwintering population, a very irregular canopy structure (i.e. missing trees and trees of various sizes), a 6% slope, and an uneven application of dispensers. The majority of the injury occurred along the uphill edge (ca. 30% injury) of the orchard. In the case of a pair of certified-organic orchards the use of pheromone maintained injury at less than 1% versus 38% in the block treated with ryania and codling moth granulosis virus.

Research at our laboratory has characterized the release rate of the rope dispenser as a function of accumulated degree hours and the instantaneous temperature. Thus we are able to predict the mean release rate at dusk (the period of codling moth sexual activity). Using the predictions of this model we conducted a number of studies in 1991 to evaluate the amount of pheromone released in the orchard per hectare per hour versus the percentage of female-baited traps shut down. The first experiment was conducted in 8 orchards at 7 time periods during the season. Thirty female-baited traps were placed in each 0.1 ha plot and 60-90 marked male moths were released. The predicted mean release rate over a 7 day period at dusk during these tests varied from 2.0 to 5.5 mg/ha/h. No statistical difference was seen in the percentage of trap shutdown (ranged from 96-100%) among release rates. In the second type of experiment, small 0.1 ha plots were established in an abandoned orchard with dispensers of various ages. Each plot was ca. 50 m apart. Again female baited traps and released marked males were used. The study was replicated four times. There was no significant difference in female-baited trap shut-down for predicted mean release rates at dusk of 1-18 mg/ha/h (range of 93-100%).

In summary, these data from 1991 suggested that we do not know how little pheromone is needed to disrupt codling moth. Obviously the amount of pheromone needed will be determined by the population density of this insect. In our tests very high densities of codling moths were used and disruption of female-baited traps still exceeded 90%. For these studies and the analysis of the release rate of the rope dispensers during an entire season we suggest that the optimal use of 1000 dispensers per hectare would be to make two applications of 650 and 350 in April and June, resepectively, to maintain at least 2 mg/ha/h for the entire season. Future research and evaluation of field trials will address the reliability of this threshold.

A study was conducted in 1992 to address the amount of pheromone which is needed for disruption of codling moth and to evaluate whether the three component blend used in the rope dispenser improves disruption versus a single component. Dispensers were provided by Scentry Inc. and consisted of black celcon fibers. Dispensers were formulate to approximate a release rate of 0.5, 2.0, and 10.0 mg/ha/h at 20°C. Seven 0.1 ha plots were established and treatments were applied to each plot once during the season. Dispensers were applied at a rate of 1,000 per hectare. Ten female-baited traps were used and 300 male moths were released into each plot. Trap catch was reduced >90% in all treatments. No significant differences were found between release rates or between the one and three component blend.

Studies addressing the behavior of male and female codling moth are still in progress this summer. Preliminary data has shown that in orchards (trees were 4.5 m in height) where the rope dispenser was placed at 2 m, significant increases in mating of tethered females occurred at 2, 3, and 4 m. In contrast, when dispensers were placed at 4 m only females at 4 m were mated and at a significantly lower level than in the 2 m treatment.

In the laboratory, an actinograph has been developed to measure the activity of male and female codling moth in the presence and absence of pheromone. This device uses ultrasound to detect moth movement. Preliminary data has shown that the periodicity of male codling moths in this device is identical to catches of males in a pheromone-baited trap. Later studies will attempt to examine whether the presence of high levels of pheromone will affect the timing and magnitude of moth activity.

In 1991, studies conducted in pheromone-treated orchards found that in 4 out of 6 trials oviposition by codling moth females was reduced ca. 50% compared with an untreated orchard. However, results were contradictroy in the other two tests and no significant difference was found across all these tests. In 1992-93 we will again examine the effect of high levels of pheromone on female oviposition. These studies will be conducted in the laboratory with an apparatus which allows better control of pheromone concentration and length of exposure.

A technique has been developed using clear plexiglass sheets (0.3 x 0.3 m) covered with STP, a commercial petroleum product, to monitor adult codling moths. Preliminary tests showed that a significant increase in marked-released males were caught in pheromone-treated plots versus untreated plots. Also, recapture of virgin females was significantly lower in the pheromone plot, but no difference was found in the recapture of mated females. Current experiments are exploring a number of hypotheses which may explain these data. Studies in progress are also looking at the movement of males into pheromone-treated plots and the movement of females out of pheromone plots using this technique.

A number of species of leafrollers are of concern to apple growers in the western United States. In 1992, we conducted small-plot trials with three species, *Pandemis pyrusana*, *Choristoneura rosaceana*, and *Argyrotaenia citrana*. Studies were conducted with Pacific Biocontrol's Hamiki-con dispenser which is loaded with Z11-14 acetate, and another rope dispenser loaded with a blend of Z11-14 acetate and Z11-14 aldehyde. Spiral dispensers were obtained from Scentry Inc. and were loaded with two amounts of Z11-14 acetate and a single rate of the two component blend. In all studies, 0.1 plots were established and replicated five times, ten female-baited traps were placed in each plot, and a single trap baited with a synthetic dispenser was placed in each plot for ca. 7 days either alone or concurrently with the female traps.

Results from our leafroller studies found no significant difference between the one and two component blend for either company's dispenser. Also no difference was found between the Hamiki-con and the spirals. Our data suggested that the sprial loaded at the high rate (ca. equal to the Hamiki-con load rate) was more effective than the lower load rate, however, this difference was not significant. Data from a field trial in California on pears also showed that the Hamiki-con dispenser completely shut down traps baited with a synthetic lure for the leafroller, *Platynota sultana*.

These data for mating disruption of leafrollers suggest that it may be possible to manage a number of species with a single blend. Studies are planned in our laboratory which will utilize a flight tunnel and field cages to examine this multi-species approach more carefully.

PHEROMONE IN NEW ZEALAND APPLE ORCHARDS

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NZ apple orchards require protection from a complex of four endemic leafrollers, *Ctenopseustis obliquana, C. herana, Planotortrix excessana, P. octo* an Australian immigrant *Epiphyas postvittana* and the cosmopolitan codling, *Cydia pomonella.*

A great deal of basic research was required with the native leafrollers, to identify the chemical components of the pheromone and to delineate the relationship of each of pair of sibling species. A high degree of commonality of chemical components allows some degree of commonality of pheromone dispenser. Limited field testing has given promising results.

The first large scale field experiments were undertaken in order to provide a distinctive input for control of Nelson population of insecticide resistant *E. postvittana*. A similar reason, concern over a Central Otago population of *P. octo* lead to successful small scale trial of mating disruption for this species.

Initial attempts on mating disruption used the Connel fibre and achieved poor results. A later three year long attempt to control a large population of codling with the Isomate C ropes produced results satisfactory for the gate sales that made up the market for this orchard. A years application of Isomate C to a export orchard with a lower initial codling population produced an excellent result and New Zealands first export consignment of insecticide free apples.

DEVELOPMENT OF DISPENSERS AND FIELD TRIALS IN MATING DISRUPTION OF THE CODLING MOTH

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ABSTRACT

Mating disruption trials for the control of the codling moth, *Cydia pomonella*, have been carried out with five different types of dispensers for hand application. The main aim of our effort was the development of a satisfactory formulation, the problem of which seems to be still one of the limiting factors of the mating disruption method. The data from the laboratory tests and five years trials are given and problems of economic and registrational character are discussed.

INTRODUCTION

Problems associated with the use of insecticides such as resistence, outbreak of secondary pests, reduction of predators and parasites, toxicity to pollinators or wildlife and general environmental and health hazard might be solved by the development of selective biorational means for insect pest control.

Pheromones, as one group of selective biorational compounds, seem to be suitable for use in IPM programmes and have potential for development in agricultural pest management. Use of pheromones for direct control of insects by mating disruption techniques was first proposed well over 25 years ago. The mechanisms involved in achieving this effect have not been really known yet (Bartell, 1982; Cardé, 1990). Nevertheless, some commercial formulations are already available, and acceptable levels of control have been demonstrated in a limited number of pest species (Ridgway et al., 1990).

EARLY FIELD TRIALS

Our first attempts to utilize pheromones for mating disruption in Czechoslovakia were carried out with two forest pests. Different formulations such as liquid polymers, porous granules and microcapsules loaded with different doses of pheromones were sprayed using conventional applicators. Rubber tubing were used for hand applications. The results were encouraging, but only at low or medium population densities as one might expect. In later field trials with orchard pests such as the codling moth, *Cydia pomonella*, the plum fruit moth, *C. funebrana* and the Oriental fruit moth, *C. molesta*, only dispensers for hand application were deemed acceptable. The dispensers requiring adhesives or those leaving particles on fruit were rejected, mainly for hygienic or "cosmetic" reasons.

DEVELOPMENT OF DISPENSERS AND COMPOSITION OF THE DISRUPTANT

The success of mating disruption techniques depends on many factors. From a chemical point of view there exist two major problems - the cost of synthetic pheromones and the imperfection of controlled release formulations.

In our mating disruption trials for the control of *C. pomonella* we have therefore focused on:

a) development of dispensers with a reasonable release rate, longevity of action, good protection of the active components and minimal pheromone residues in the dispensers after the end of the flight period;

b) determination of the optimal quantity of pheromones per ha and per season to achieve pest control;

c) reduction of the present cost of mating disruption to level comparable with that of conventional pest control.

(E8,E10)-8,10-Dodecadien-1-ol (E8,E10-12:OH) was identified as the main pheromone component of the codling moth *C. pomonella* (Roelofs et al., 1971). Additional components were identified later (Einhorn et al., 1984 and Arn et al., 1985). Some of these components were reported to be synergists of the sexual response level (Bartell et al., 1988).

Most of our experiments were carried out using the main component only, some of them using incomplete pheromone blends - different combinations of E8,E10-12:OH and saturated 12:OH and 14:OH. We also tested the possibility of using an unpurified technical product containing a nearly equilibrium mixture of all four geometric isomers.

All chemical analyses were performed on dispensers exposed either in the laboratory at room temperature or exposed in orchards. The pheromone released was quantitatively analysed by GC using the relative static method according to Baker et al., 1980.

Release rates from the individual types of dispensers loaded with 20 mg of disruptant are summarized in Figs. 1- 4.

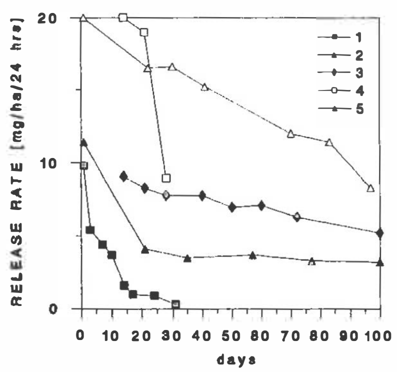

Fig. 1

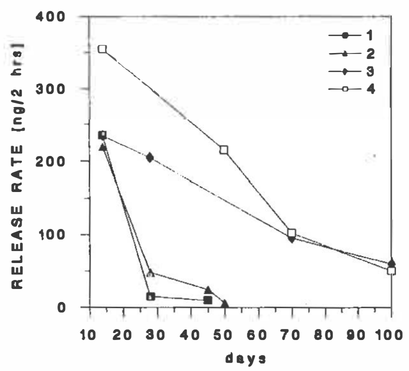

Fig. 2

Fig.1: (1) rubber tubing; (2) rubber bands; (3) PE microvials with porous fillings; (4) porous rope with PE cocer; (5) tubular PE bags with nonporous fibers.

Fig. 2: (1) PE microvials, wall thickness 0.5 mm; (2) PE microvials, wall thickness 1.0 mm; (3) PE microvials with porous fillings, wall thickness 1.0 mm; (4) PE microvials with porous fillings, wall thickness 0.5 mm;

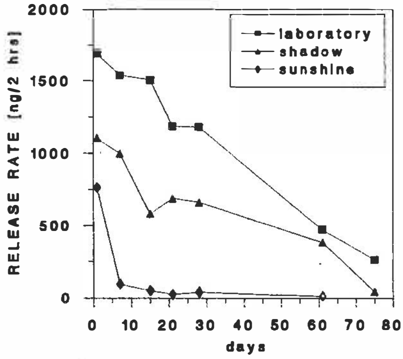

Fig. 3

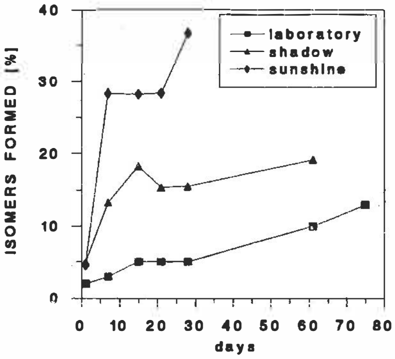

Fig. 4

Fig. 3: The dynamics of codlemone release from tubular PE bags with nonporous fibers in the laboratory and in different field conditions.

Fig. 4: Influence of the laboratory and of different field conditions on isomeration of codlemone.

DESIGN OF FIELD TRIALS

Screening of single compounds or of different blends as well as optimization of dispensers were carried out in small scale trials for the sake of convenience. Tested pheromone dispensers - one to each tree - were attached to the canopies of the border trees in 10 x 10 m plots (9 trees, 15 year old, 2 m high). The pheromone traps with the type of dispensers used for monitoring were placed in the centre of plots in each experiment. There are certainly limitations to such trials but our results were consistent across many repetitions, including those with nonhomogenous populations.

Large scale trials with the most promising dispensers were performed in 1 to 5 ha square shaped plots. Pheromone dispensers - 1 or 2 per tree according to the dose used - were attached to the upper part of canopy.

The effect of the disruption of males and the efficacy of the mating disruption method was calculated:

a) from the decrease in moth caught in pheromone traps on treated plots as compared with those on untreated ones;

b) from the counting of larvae and pupae in tree bands, and

c) from the sampling of fruit damage.

TAB. 1. MATING DISRUPTION TRIALS ON PLOT WITH LOW INFESTATION (Chelčice 1986-1988)*

Year	average males / trap		average larvae / tree band		fruit damage [%]	
	C	D	C	D	C	D
1986	64.2	6.8	9.2	3.5	4.4	1.3
1987	19.6	11.3	0.7	0.9	1.0	0.3
1988	14.8	4.8	0.1	0.2	0.1	0.0

Orchard size 5 ha; control (1 ha) separated by 250 m; formulation 3; E8,E10-12:OH; 40 g/ha/season, (2 x 20 g); C = untreated area, D = treated area; * trial depreciated by unexpected decrease of population even in control;

TAB. 2. MATING DISRUPTION TRIAL ON PLOT WITH MEDIUM INFESTATION (Rodina 1988)

average males / trap			average larvae / tree band			fruit damage [%]		
C	D	E	C	D	E	C	D	E
32.8	0.3	36.5	26.9	1.7	2.9	23.1	0.3	0.8

All trial plots 1 ha; formulation E8,E10-12:OH, 40 g/ha/season, (2 x 20 g);C = untreated area, control; D = area treated by pheromone; E = area treated by 2 insecticide sprays according to monitoring by traps.

Small scale trials with different blends of E8,E10-12:OH and saturated 12:OH and/or 14:OH did not demonstrated any advantage. In contrast the unpurified equilibrium mixture of all isomers was demonstrated to be effective in disrupting the mating of the codling moth.

CONCLUSIONS

Our field trials of mating disruption techniques for the control of the codling moth in Czechoslovakia have progressed satisfactorily. Even though all problems have not been solved, the practical applications may be considered. The design of the pheromone dispensers and the disruptant system are, however, far from perfection. Available dispensers still need significant improvements. The main problem is the protection of the active components from heat and in some cases also from solar radiation and atmospheric oxygen. Another very important and as yet unsolved problem is how to avoid loss from evaporation throughout the day or over the course of the hot season when the insects are not active. The imperfection of the controlled release formulations, the high price of the active compound and the general registration requirements (similar to those required for conventional pesticides) are factors which not only influence the use but can even endanger the application of the mating disruption strategy in Czechoslovakia.

Combinations of juvenile hormone analogs with ovicidal activity to control the first generation of codling moths and some secondary lepidopteran pests, and mating disruption to control the codling moth during the rest of season could be promising, however. The advantages of such combination are not only economical but also in the fact that neither method damages the natural biological means of control.

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MATING DISRUPTION OF CODLING MOTH AND LEAFROLLERS SPECIES IN APPLE ORCHARDS OF TRENTINO - FIRST YEAR RESULTS

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In 1991 ESAT, in collaboration with Plant Protection Service and Istituto agrario of S.Michele, began a control programmme against codling moth (*Cydia pomonella*) and apple leafroller (*Archips podana, Pandemis heparana, Adoxophyes orana, Argyrotaenia pulchellana*) by applying the mating disruption method.
The experiences had been carried out in 5 orchards using the BASF-dispenser.
This method aims to control these pests by the distribution in field of permeable plastic dispenser that during the season leave pheromon substances belongig to insects to prevent their maiting.
The lack of mating tends to lower the pest population to a density level that does not require the application of chemical products.
Instead of treating the plant this innovative method treats the atmosphere thus creating an environment unfavorable to pest reproduction.
Because correct evaluation of its efficiency cannot be limited to the results obtained after only one year's application, several years more experimentation have been programmed to facilitate evaluation of containment of the pest population and damage over an extended period.
The following information is the result of the first year of study. In 1991 the method was applied to an area of about 23 hectars.
In our experiences we have decided to avoid any preventive treatments.

Some farms did not have the best condition as fare as surface and planting system uniformity, however they were chosen to verify the method under non optimal conditions.
The dispenser distribution had place during may. Then we began the checks each ten days.

RESULTS

The experience was made in the following areas:
ARCO .... surface 6.5 ha
CEMBRA .... surface 5.0 ha
VIGOLO VATTARO ... surface 5.0 ha
MARTIGNANO .... surface 2.8 ha
VALSORDA .... surface 4.0 ha
For the global results see table 1.

ARCO In this area control of codling moth gave good results keeping the pest population below the damage threshold (2% damaged fruit).
Appreciable damages caused by the codling moth was found in only one plot of 5,000 sq. In this area the pest population was very high. The source of infection was found in two walnut trees situated near the plot. This area was treated twice thus limiting damages to the harvest.

CEMBRA The experimental surface contained 95% appletrees on rootstock M26 and M111. The other 5% contained a vineyard. The results of control were good although we had a few problems along the edges probably caused by insufficient saturation of the atmosphere due to high wind dispersion. In this case we have intervened the borders.

VIGOLO VATTARO The area is surrounded by wood on three sides. The results were positive on 90% of the surface. Prior to harvest we noticed increased leafrollers damage in parts of the orchard, especially near the woods. We were able to exert sufficient control of codling moth population with the exception of two small areas where damage was above the accepted threshold. One application of Chlorpiriphos metil was made at the end of August on these plots.

VALSORDA This is an isolated area surrounded by woods on three sides and a field on the fourth. The plantig system is regular. At the beginning of August a great increase in codling moth damages was found in the elevated part of the orchard. It was necessary to apply a diflubenzuron treatment on the entire surface. It is believed that the progressive increase in damage is due to a high pest population. Unfortunately we could not forsee the level.

MARTIGNANO We felt that this area did not offer the best condition when the methode was applied, because it is not isolated from other orchards and the area is very windy. The results of the experiment confirmed our initial doubts. Serious damages occured especially in one particular plot in the area.
There was an increase in damage from leafrollers prior to harvest and therfore the entire surface was treated twice. At harvest time and particularly in the areas where the treatment had been made twice we found more extensive damage.

CONCLUSION

This first experiences permitted us to focus on certain problems regarding the mating disruption method. It was possible to verify the importance of the optimal application conditions regarding the relation between edges and internal surface. As far as possible the surfaces should be wide enough the perimeter of the area is less percentagewise that the inside area.
It also important that the planting system be regular. Homogenious planting systems are preferable to weak rootstock.
The presence of plots with high size plants necessitates the use of a dispenser on two levels, this make checking more difficult. With reference to pest population evaluation, the importance of low level was emphasized although unfortunately there is no consolidated criteria of evaluation. When in doubt it is peraphs preferable to apply drastic insecticide treatment before using the dispenser. For a first estimate and evaluation of the pest population it is without doubt useful to distribute roll bands in the orchard a year before the first application.

table 1

mating disruption appletree 1991
first year results

areas	ha	no dispenser	Variety/ rootstock	harvest ceck data	% harvest damage coodling m. average	leaf roll.	no treatm. 1991	active ingredient	treated surface ha	root band n.	n. larvae coodling m.	leaf roll.	no historical treatments active ingredients '89	'90
ARCO	6,5	3590	Golden M26	18-set	0,44	0,049	2	Chlorpyrifos	0,5	42	16	9	Fenoxycarb	Fenoxycarb
			Golden M7					Phosalone	0,5				Azinphos	Diflubenzuron
			Red chief M9											Diflubenzuron
CEMBRA	5	3050	Golden M26	16-ott	2,16	0,73	1	Chlorpyrifos	0,05	31	113	26	Fenoxycarb	Diflubenzuron
			Golden M111										Azinphos	Diflubenzuron
			Starking M26										Diflubenzuron	
VIGOLO V.	5	2710	Golden M9	14-ott	0,92	2,41	1	Chlorpyrifos	0,7	34	5	2	Fenoxycarb	Fenoxycarb
			Jonagold M9										Fenoxycarb	Diflubenzuron
													Diflubenzuron	
VALSORDA	4	2268	Golden M9	10-ott	3,41	2,17	1		4	36	77	3	Diflubenzuron	Diflubenzuron
			Starking M9										Azinphos	Azinphos
													Chlorpyrifos	Chlorpyrifos
													Chlorpyrifos	Chlorpyrifos
MARTIGNANO	2,8	1512	Golden M9	17-set	2,87	2,35	2		2,8	56	210	35	Diflubenzuron	Diflubenzuron
			Golden Franco					Chlorpyrifos	0,8				Diflubenzuron	Diflubenzuron
			HyEarly M9										Chlorpyrifos	

Topic 4: Experiments carried out in viticulture.

Chairman: Dr. Pierre Joseph Charmillot

MATING DISRUPTION TECHNIQUE TO CONTROL GRAPE AND WINE MOTHS : GENERAL CONSIDERATIONS

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ABSTRACT

The success of mating disruption technique requires the development of reliable dispensers to protect attractants and to insure a regular emission during the whole duration of pest flight. Physical factors affecting emission as temperature, wind, rain, light, are meteorological constraints, varying during the season, from year to year and with the location. Biological factors as flight duration, rhythm of sexual activity, mobility of adults are others constraints depending on the species, that we cannot modify. Population density of the pests is the single biological factor that can be manipulated by control measures in the purpose to reduce it for contributing to the success of mating disruption.

The most important evaluation means of mating disruption are sex and bait trapping, copulation rate of tethered females and sample of damage. With both grape moths species, it is relatively easy to estimate population density for the first generation but very difficult to do it for the second generation and overwintering population.

INTRODUCTION

In Europe, grape berry moth *Eupoecilia ambiguella* and wine moth *Lobesia botrana*, each alone or both together, are the most important pests of vineyards. *E. ambiguella* is more frequent in northern, wet and coldest regions whereas *L. botrana* prefers the dry meridional countries. Both species cohabite in intermediate climates. Introduction of biological or biotechnical control measures against these both species allows the giving up most insecticide and miticide treatments in vineyards. Other insect pests are scarce with local economic significance and *Typhlodromus* species can very efficiently control phytophagous mites. Mating disruption technique is a potential tool to reach this aim.

SEX ATTRACTANTS

The main component of sex pheromone of grape berry moth is Z9-12:Ac. It is available for experimentation and mating disruption technique. It is commercialized at reasonable price. The main component of wine moth is E7,Z9-12:Ac. It is available, but mating disruption technique is not registrated against that pest because synthesis of that product is more difficult and expensive so that experimentation was delayed.

DISPENSERS AND EMISSION

The purpose of dispensers is to release slowly and regularly the attractant, protecting it for degradation and avoiding waste, during the whole flight length of the pest. Until now, only two formulations have been registrated in Europe to control *E. ambiguella*. They are HERCON flakes which have been distributed for a few years ago by BASF and BASF double ampulla. HERCON flakes dispense quickly and have to be renewed for each flight period whereas BASF dispensers release slowlier throughout the season. The most important physical factors influencing the quantity and quality of the emission are temperature, wind, rain and light. Those constraints vary with time and depend on the region but cannot be modified.

The dispenser is the primary emitter but the plant acts as a secondary emitter by catching attractant and releasing it later. In the case of wineyard, the buffer effect of vegetation (the secondary emitter) varies tremendously during the season: grape plants have almost no leaves at the beginning of first flight but there are walls of vegetation during the second flight period slowing down the evacuation of molecules. The concentration of attractant in the atmosphere depends also on the size and shape of the vineyard. Concentration is not homogenous: it theoretically increases from the border at wind to the opposite border, as the moving air increases progressively the attractant concentration by the different encountered dispensers. Concentration also varies vertically as air evacuation changes with the strate, vegetation acting as buffer for wind.

BIOLOGICAL FACTORS

Flight length. To be successful, mating disruption technique requires a sufficient emission, of attractant during the whole flight duration. In the case of grape moths, there are two flight periods of about 4 weeks each in the north of the distribution area of grapes but three generations, sometimes overlapping in meridional regions. Thus, depending on the location, the required emission duration varies from two periods of 30 days in the north to about 150 consecutive days in the south.

Rhythm of sexual activity. *L. botrana* has sexual activity in dusk, *E. ambiguella* during the night whereas the maximum emission rate of the dispensers occurs during day-time at the highest temperature. This waste of attractant can of course not be avoided.

Mobility of the adults. It is necessary to apply mating disruption in the whole vineyard space where adults may copulate and are susceptible to lay eggs. Females are less mobile than males but may however reach about hundred meters depending on the climatic and environmental conditions. Mobility seems to be less important during the second flight period, vegetation constituing a fence.

In the presence of very high population density in a whole region, female moths previously mated should be able to move at higher altitude over bigger distance. That exceptional behaviour could contribute to explain some failure in mating disruption experimentation encountered with codling moth and grape moth where other plausible explanations could not be found (*NEUMANN*, pers. comm.).

Population density. With grape and wine moth, the economic threshold is very high for the first generation but very low for the second one due to the risk of rot induced by damage berries. So, in principle, we could avoid the control in first generation. But it is known that the efficiency of mating disruption is strongly affected by high population densities. So it is necessary to start with mating disruption already in first generation in order to reduce the population to insure the successful control in second generation. However, this strategy is not always sufficient. When initial population density is too high, it is recommended to reduce it previously or simultaneously by insecticide treatment.

Among this biological factors only population density can be manipulated by treatments, the others being constraints on which we have to adapt.

EVALUATION MEANS FOR MATING DISRUPTION TECHNIQUE

Sex trapping. When an attractant is dispensed in the atmosphere, the most simple test is to calculate the reduction of catches provocated in sex traps in comparision with control traps of the same region. However this test is not sufficient. A lot of examples are known where even very small attractant emission inhibites completely the catches without conducting to a corresponding reduction of damage.

Tethered females. Determining reduction of mating by the tethered females is a more laborious test which is also more reliable. It has however some limits as tethered females have not the same movement possibility and the same behaviour as those of natural population.

Bait traps. Bait trapping is laborious; it requires a lot of work for sorting because it attracts a huge amount of insects which has to be collected frequently. This efficacy varies with temperature and it is not objective while it mainly attracts old copulated females which need to feed.

Sampling of damage. Sampling of damage is easy in first generation because it can be done later on when all attaks are well recognisable. However, damage distribution of grape moth are scarcely homogeneous: it is strongly influenced by location, relief, exposition and borders of the vineyard. We have to take into account all those elements in the interpretation of the efficacy. Moreover in the same location, damage may strongly fluctuate from year to year, even from generation to generation. In second more difficult and because it is necessary to treat quickly if the tolerance level is reached, before larvae enter too deep in the berries. In mating disruption experimentation, it is essentially in first generation, on the base of damage that decision will be taken whether to continue the trial or to treat preventively in second generation.

Estimation of population density. Estimation of population density is feasible in June on the basis of grape sampling, when the whole attaks of first generation are visible. In the Swiss conditions, we know that at this period the number of grapes varies between 80-160'000 per ha depending on the variety, way of cultivation and pruning. A lot of grapes will be cut later in July to adapt the load to the limitation prescribed by the law. On the other hand, estimation of the populationdensity is difficult in second generation because tolerance level is so low that control is normally necessary with varying efficacy and because some larvae are carried out with the harvest. Our knowledge on winter mortality is so poor that it is practically impossible to estimate surviving populations in spring.

CONCLUSION

In the opposite of chemical treatments which consist of a protection of the plant with toxic residues, mating disruption technique do not protect the grapes but aims to insure permanently a sufficient concentration of attractant in the atmosphere of the whole space where moth are susceptible to copulate. Meteorological factors as temperature, wind, rain, light are constraints imposed by the nature onto we have to adapt.

Biological factors as flight duration, rhythm of sexual activity and mobility of the moths are also imposed by the species and there is no way to modify them. The single biological factor we can manipulate is the population density of the pest. As efficacy of mating disruption is strongly correlated with population density, we shall reduce it at the lowest possible level before or simultaneously by beginning the experimentation. Then, the most important factor we can play with to improve the disruption technique is the control of attractant emission from the dispensers. It is undoubtely in that field that the most important progress have to be realized to insure more fiability in mating disruption technique. That is the role of chemists and physicists of the firms involved in development of dispensers.

THREE YEARS EXPERIENCE IN THE CONTROL OF THE GRAPE MOTH *LOBESIA BOTRANA* USING MATING DISRUPTION IN A BORDEAUX VINEYARD

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ABSTRACT

The study, in collaboration with the BASF company, started in 1989 in a 8 ha vineyard and continued in 1990 and 1991 on a 12 ha area in the "Sauternais" vineyard. A variable reference plot was used. Pheromone dispensers were installed in the whole vineyard at beginning of the 1st generation except a 2 ha area, where they were administred at the beginning of the 2nd generation. Observations of the natural population of the insect during the 1st generation in this area were used to appreciate the value of an other reference plot, an untreated area 500m further, which was used itself to evaluate the final efficiency of the method. Thus, the efficiency of mating disruption is comparable to a correct insecticide control. Finally, with 500 dispensers/ha, releasing pheromone at a constant rate: 50mg/ha/hour, we confirm:
1) 10 ha is the minimum surface, inside a vineyard area for mating disruption use; 2) The method exhibits a cumulative effect in the course of year; 3) The biocoenotic balance achieved by use of the method involves the cancelling of a specific control against other pests: leafhopper, *Empoasca vitis*, and red mite, *Panonychus ulmi*. A new strategy to control *L. botrana* is suggested.

1. INTRODUCTION

L'Eudémis, *Lobesia botrana*, est le principal ravageur du vignoble bordelais. Trois à quatre traitements insecticides sont souvent effectués sur les 2ème et 3ème générations pour en diminuer le niveau de population. De 1989 à 1991, on a réalisé, à l'aide de diffuseurs BASF, des essais de confusion sexuelle sur une douzaine d'ha en Sauternais (STOCKEL et al 1992).

2. MATERIEL ET METHODE

2.1 Dispositif expérimental

- En 1989, la confusion fut appliquée contre les 2ème et 3ème générations sur la zone 2 (6ha) (fig.1). On utilisa la zone 1 (2ha), comme référence en vue d'évaluer l'efficacité du procédé par rapport à un traitement sur chaque génération (G1: Téflubenzuron; G2 et G3: Thiodicarbe), sur les 2 dernières seulement (Thiodicarbe), ou aucun traitement.
- En 1990, la zone 3 (4ha) fut associée au dispositif. La confusion fut alors appliquée contre les 3 générations sur les zones 2 et 3, et contre les 2 dernières sur la zone 1. La zone 4 (3,5ha), distante d'environ 500m devenant alors zone de référence comme précédemment.
- Les diffuseurs BASF, remplis d'environ 500mg de phéromone (E7Z9-12AC), sont répartis à raison de 500 unités/ha, (250 g /ha). Les bordures des parcelles, bois vignes et vergers sont également pourvus de diffuseurs sur une largeur de 50m environ. La pose des diffuseurs a lieu dés les 1éres captures prévues par sommation thermique (ROEHRICH et al 1989) pour la 1ère génération, et selon le modéle Eudémis "météopro" (ACTA) initialisé à partir des 1éres captures du 1er vol pour la seconde.

2.2. Suivi de l'essai - Les vols sont contrôlés de manière tri-hebdomadaire par 2 piéges sexuels, type INRA, appâtés de 1 et 1000µg de phéromone disposés dans chacune des zones 1,2,3,et 4 à 30m l'un de l'autre. Chaque ensemble de ces 2 piéges dont les captures sont additionnées constitue l'unité de piégeage sexuel.

- L'état sexuel des femelles est contrôlé par 2 piéges alimentaires disposés dans chaque zone dés le début du 2ème vol. En 1989, on a utilisé en plus, la technique des femelles attachées. Ces dernières ainsi que les femelles capturées sont disséquées au laboratoire pour la recherche des spermatophores.
- Le contrôle des attaques est effectué *in situ* aprés des sondages réguliers lors de chaque génération sur 100 grappes/parcelle. En 3ème génération les grappes sont prélevées en vue d'une extraction des chenilles par la méthode de la saumure pour les dénombrer.
- Le suivi de la diffusion est assuré par la pesée hebdomadaire de 10 diffuseurs marqués placés dans le vignoble.
- Le suivi des autres populations de ravageurs: l'Araignée rouge *Panonychus ulmi* et la Cicadelle des grillures, *Empoasca vitis* ont lieu réguliérement dans toutes les parcelles en vue de les limiter en cas de dépassement des seuils à l'aide de pesticides sans action sur l'Eudémis (Benzoximat/*P.ulmi*, et Vamidothion/*E.vitis*)

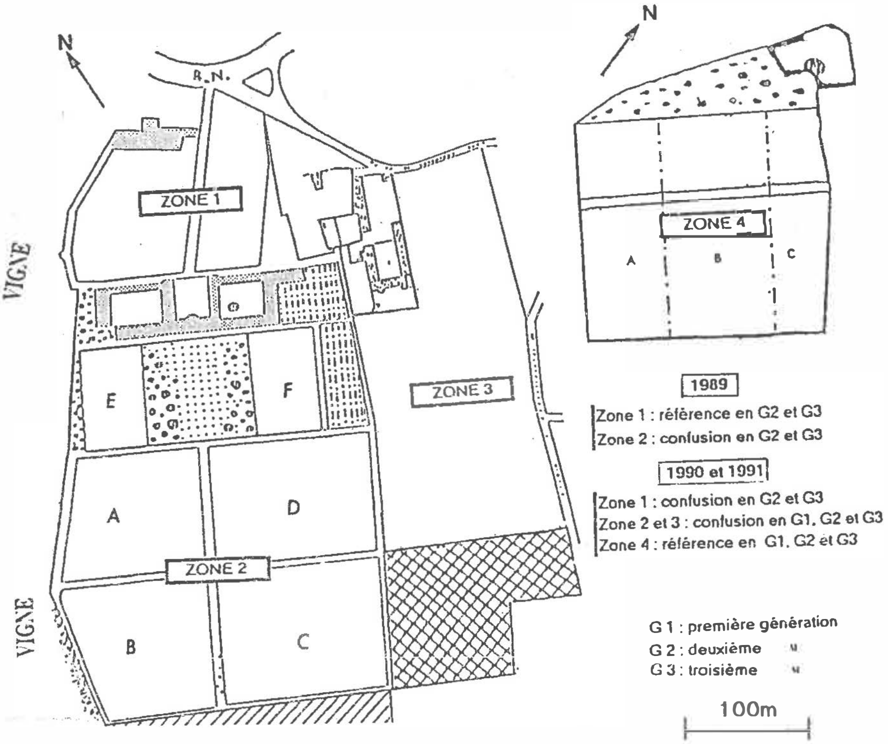

Figure 1 – Implantation des zones d'essais en 1989, 1990, et 1991

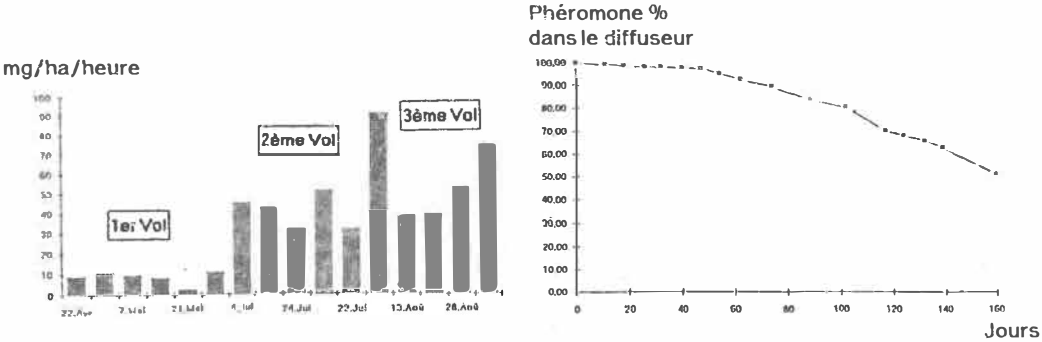

Figure 2 – Evolution de la diffusion en 1991 déterminée par la perte pondérale des diffuseurs

3. RESULTATS

- En 1989, une diffusion trop rapide avait nécessité un renouvellement des diffuseurs dés la fin du 2éme mois. En 1990 et 1991 les nouveaux diffuseurs ont permis de couvrir aisément les 3 générations. Si la diffusion est trés lente pendant le 1er vol: avril-mai, et se situe entre 10 et 15 mg/ha/heure elle est plus élevée ensuite (50-70 mg/ha/h) mais on contate qu'il reste encore prés de 50% de phéromone fin septembre (fig.2).
- Les captures au piége sexuel sont bien inhibées en zone 2, c'est-à-dire au centre du dispositif de confusion. En revanche, dans la partie Est de la zone 3, en bordure du dispositif, non protégée par une barriére de diffuseurs, quelques prises permettent d'identifier les vols. Si dans la zone 4 les 3 vols sont bien caractérisés avec des effectifs capturés aussi importants en 1990 qu'en 1991, on constate que dans la zone 1 (référence évolutive), le niveau des captures en 1er vol (hors confusion) baisse réguliérement entre 1989 et 1991.
- En zone de confusion, si aucune femelle vierge attachée n'a été inséminée (1989) les femelles capturées au piége alimentaires présentent un taux d'insémination variable, compris entre 30 et 50%, toujours inférieur à ce qu'on observe en zone de référence (95 à 100%)
- La population larvaire de 1ére génération (% de grappes attaquées: au moins 1 glomérule/grappe) dépassant le seuil initialement fixé à 10%, entraîna en 1989 une intervention curative générale (Téflubenzuron) avant la pose des diffuseurs.
-En 1990 et 1991 l'efficacité de la confusion, en 1ére génération, est convenable, seulement dans les parcelles centrales de la zone 2, ce qui implique de traiter partout ailleurs comme dans les zones de référence.
- Le pourcentage d'attaques en 2éme génération ne dépasse pas 10%, en 1990, dans toutes les zones sous confusion. Ce seuil est largement dépassé en 1991 (environ 20%); toutefois, en raison de la gelée printaniére qui a éliminé plus de la moitié des grappes aucun traitement insecticide ne s'avére nécessaire.(tableau 1)
- En 3éme génération,(tableau 2) l'efficacité de la confusion, appréciée par le nombre de chenilles, est dix fois supérieure à la lutte insecticide en 1889(année où les traitements chimiques ont été particuliérement inefficaces), deux fois en 1990 et identique en 1991. Comparée enfin à l'absence totale de lutte, l'efficacité de la confusion dépasse 90% au cours des 3 années d'expérimentations.

Tableau I - Pourcentages d'attaques en 2éme génération (G2) selon la protection dans chaque zone

	parcelle	Zone 1			Zone 2
1989	traitement G1	0	Tellu.	0	Tellu.
	traitement G2	0	Methi.	Methi	Conf.
	% grappes attaquées	39	16	21,5	4

Conf. : Confusion
Methi. : Méthidathion (ULTRACIDE)
Tellu. : Téllubenzuron (DART)
Thio.. : Thiodicarbe (LARVIN)

	parcelle	Zone 4			Zone 1	Zone 3	Zone 2ABE	Zone 2CDF
1990	traitement G1	0	0	Tellu.	Tellu.	Conf.+Tellu.	Conf.+Tellu.	Conf
	traitement G2	0	Thio.	Thio.	Conf.	Conf.	Conf.	Conf.
	% grappes attaquées	26	27	15,0	3	15	1	0.66
1991	traitement G1	0	0	Tellu.	Tellu.	Conf.+Tellu.	Conf.+Tellu.	Conf
	traitement G2	0	Thio.	Thio.	Conf.	Conf.	Conf.	Conf.
	% grappes attaquées	40	28	17,0	11,5	13,4	9,0	10,7

4 DISCUSSION-CONCLUSION

- Sur l'ensemble des 3 années, lorsqu'elle est appliquée dés le début du 1er vol, la confusion assure une bonne protection du vignoble, au moins équivalente à une lutte chimique bien conduite mais dont l'efficacité est liée aux dates d'application parfois difficilement contrôlables.

Tableau II– Pourcentages d'attaques ou nombre de chenilles pour 100 grappes en 3éme génération (G3) selon la protection dans chaque zone

	parcelle	Zone 1			Zone 2
1989	traitement G1	0	Teflu.	0	Teflu.
	traitement G2	0	Methi.	Methi	Conf.
	traitement G3	0	Methi.	methi.	Conf.
	% grappes attaquées	55.9	54.8	54.6	5
	nombre de chen./100 gr.		100		7

Conf. : Confusion
Methi. : Méthidathion (ULTRACIDE)
Teflu. : Téflubenzuron (DART)
Thio. : Thiodicarbe(LARVIN)

	parcelle	Zone 4			Zone 1	Zone 3	Zone 2ABE	Zone 2CDF
1990	traitement G1	0	0	Teflu.	Teflu.	Conf.+Teflu.	Conf +Teflu.	Conf.
	traitement G2	0	Thio.	Thio.	Conf.	Conf.	Conf.	Conf.
	traitement G3	0	Thio.	Thio.	Conf.	Conf.	Conf.	Conf.
	% grappes attaquées	68	35	22.8	15.6	7.7	6.7	21.1
	nombre de chen./100 gr.	255	50	26	16	23	7.	23
1991	traitement G1	0	0	Teflu.	Teflu.	Conf.+Teflu.	Conf +Teflu.	Conf.
	traitement G2	0	Thio.	Thio.	Conf.	Conf.	Conf.	Conf.
	traitement G3	0	Thio.	Thio.	Conf.	Conf.	Conf.	Conf.
	% grappes attaquées	?	?	?	?	?	?	?
	nombre de chen./100 gr.	300	16	12	8	16	15.	9

– Parmi les méthodes de contrôle, seul le piégeage sexuel semble facilement utilisable: l'inhibition des captures est aisément obtenue mais elle doit être totale pour confirmer l'efficacité de la confusion.
– L'efficacité de la méthode est relativement faible en 1ére génération et dépend du niveau de population initiale. Il est donc important de distinguer le seuil économique de dégâts du seuil préventif correspondant à la densité de population à ne pas dépasser pour que la confusion puisse s'exercer. Ces seuils peuvent être différents et ne devraient pas être exprimés dans la même unité: Grappes attaquées% (seuil économique) et Grappes attaquées/ha (Densité de population)
– Le choix des parcelles de référence pour évaluer l'efficacité est délicat: Trop proches de la zone sous confusion, elles peuvent subir l'action de la phéromone ou constituer des sources de réinfestation par les femelles inséminées. Si elles en sont trop éloignées, en revanche, les taux de multiplication d'une génération à la suivante, liés aux conditions agroclimatiques peuvent varier et rendre la comparaison impossible (ROEHRICH et CARLES 1987). Les zones 1 et 4 utilisées ici conviennent parfaitement.
– En conclusion, avec 550 diffuseurs/ha fournissant une diffusion régulière de l'ordre de 50 à 60 mg/ha/h de phéromone pendant toute la période d'activité de l'insecte (6 mois en bordelais),il est établi que la méthode, en zone de vignoble, est applicable sur une surface minimale de 10 ha. Une stratégie nouvelle serait, lors de la la 1ére année, d'effectuer une intervention curative sur les larves de 1ére génération, et une lutte préventive par confusion sur les adultes des 2éme et 3éme vols. Cette stratégie devrait évoluer vers l'emploi de la confusion contre les 3 générations dés l'année suivante.

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MATING DISRUPTION OF LOBESIA BOTRANA IN TRENTINO (ITALY): ORGANIZATION OF THE GROWERS AND FIRST RESULTS.

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ABSTRACT

The high number of small size vineyards is one of the major obstacle to the application of mating disruption method for the control *Lobesia botrana* in Trentino. A trial with mating disruption has been carried out for two years in a viticulture area of 22.7 hectares with 55 vine-growers. Both the years 500 dispensers per hectare provided by BASF have been applied. Dispensers with different pheromone content have been used during the two years: 360 mg/dispenser in 1991 and 240 mg/dispenser in 1992. The dispensers have been applied by the vine-growers themselves once a year at the beginning of the first flight of *Lobesia botrana* (end of April).

The efficacy of the method has been evaluated by: observation of the damage caused by the first generation larvae, counting of the eggs laid by the second generation moth, observation of the damage caused by the second generation larvae.

The organization of the vine-growers involved in the experience and the first results are discussed.

INTRODUCTION

For two years (1991-1992) a trial to assess the feasibility of mating disruption against the grape vine moth (Lobesia botrana) has been carried out in the area of Mezzocorona (Trento). In our region this pest has two complete generation and sometimes a partial third one, which is never dangerous. In practice, control measures are restricted to the second generation (first half of July), since the first generation never causes damage. Trials have been carried out by the Istituto Agrario of S.Michele all'Adige, with the cooperation of a local advisor from ESAT (Regional Association for the Development of Agriculture) and of the vine-growers association "Cantine Mezzacorona"

MATERIALS AND METHODS

Vineyards site. The area selected for the trial (Sottodossi) is located within the build-up area of Mezzocorona. In this vineyard Teroldego vines are used, trained on a kind of trellis called Trentinian pergola. Those characteristics have added interest to the experimentation of the mating disruption technique, in order to establish whether it could be used as a reliable alternative to traditional control strategies in sites neighbouring urban area and with high-value varieties. The trials has been carried out on an area of 22.7 ha, 13.8 ha which are the actual disruption area and 8.9 are protective barriers (tab.1)

Dispensers. The dispensers used are produced by BASF. Each dispenser contained

360 mg of attractant for the grape vine moth and 400 mg for the European grape berry moth (*Eupoecilia ambiguella*) in 1991, and 240 mg and 350 mg respectively in 1992. The dispensers were all placed at once (500 per hectare) by the 55 vine-growers, owners of the selected plots, at the beginning of the first generation flight (end of April). The release rate of the attractant was calculated by regularly weighing 4 dispensers; at the end of the season the remaining attractant and the weight of the dispensers were calculated and the data corrected.

AREA	SURFACE (ha)	N° DISPENSER	DENSITY
mating disruption	13.7518	7121	1/19 sq.m
surrouding areas (vineyards)	4.0157	2006	1/20 sq.m
surrouding areas (houses, gardens)	4.5	933	1/48 sq.m
TOTAL	22.2675	10060	1/22 sq.m

Table 1. Distribution of the dispensers in the different treated areas.

AREA	SURFACE	CHECKED BUNCHES	N° OF LARVAS/ 100 BUNCHES
EDGE 1 row width	1.45 ha 10.5 %	900	4.8
2nd BELT 20-30 meter width	4.35 ha 31.6 %	1200	1
CENTER	7.95 ha 57.9 %	700	0.1
AVERAGE DAMAGE (WEIGHTED MEAN)			0.9

Table 2. Second generation damage assessed in the different sites of the maiting disruption area in 1991.

Inspections. The efficiency of the method was assessed by a regular inspection of the pheromone traps placed in 7 different sites inside the pheromone-treated area, and by visual inspections for attack by the first generation, for the oviposition of the second generation and for final damage.

RESULTS

Year 1991. No catch was ever made in the traps placed inside the disruption area. For the first generation the average population was of 0.8 larvae per 100 bunches. For the second generation, an inspection for the oviposition indicated the presence of small number of grape moth in the rows closer to houses, roads and gardens, and the absence of eggs in the centre of the pheromone-treated area.

The following final inspection indicated an average of 0.9 larvae per bunches. The inspections, however, showed an interesting distribution of population which is summarized in table 2. In the surrounding areas, not treated with pheromones, the attack rate was of 5.4 larvae per 100 bunches and of 11 larvae per 100 bunches for the first and second generation respectively.

Year 1992. There were no catches in the traps in the disruption area starting from the exposure of the dispènsers (end of April). It should be noted, however, that the dispensers were delivered with a certain delay; by that time the flight had already started and two traps placed in the disruption area had already captured a total of 34 individuals.

AREA	SURFACE	CHECKED BUNCHES	N° OF LARVAE/ 100 BUNCHES
EDGE 1 row width	1.45 ha 10.5 %	600	10.2
2nd BELT 20-30 meter width	4.35 ha 31.6 %	1000	5.1
CENTER	7.95 ha 57.9 %	1100	1.4
AVERAGE DAMAGE (WEIGHTED MEAN)			3.5

Table 3. Second generation damage assessed in the different sites of the maiting disruption area in 1992.

For the first generation the average population was of 4 larvae per 100 bunches. For the second generation, as in the previous year, the inspection for eggs confirmed the presence of grape vine moth mainly along the borders and the following final inspection showed an average of 3.5 larvae per 100 bunches, mainly restricted to the rows closer to houses gardens and roads (tab.3). In the surrounding areas, not interested by mating disruption, the attack rate for the first generation was of about 7.5 larvae per 100 bunches, while for the second generation the average was of 25 larvae per 100 bunches.

Diffusion of the attractant. The two different dispensers used in 1991 and in 1992, although loaded with different quantities of attractant, gave similar emission rates. The half-emission time was 108 days and 72 days respectively, with an average emission rate, during this period, of 34.7 mg/ha per hour (fig.1). The dispensers used in 1992 are loaded with a smaller quantity of attractant, and yet they cover the entire period of activity of adults of the two generations and diffuses the same quantity of attractant, per hour using 1/3 less of attractant.

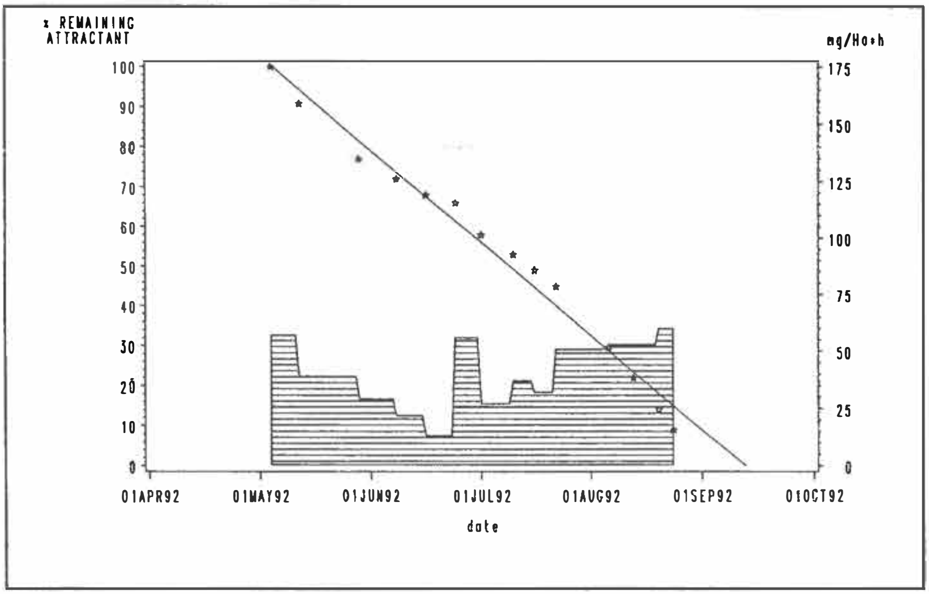

Figure 1. Diffusion rate of grape vine moth attractant assessed by weighing in 1992.

CONCLUSIONS

The following elements make this experiment particularly interesting:

- the mating disruption technique has proved to be reasonably effective against the grape vine-moth and for two years it allowed the avoidance of 1 or 2 treatments with organophosphate insecticides with otherwise should have been applied in the month of July inside an urban area.
- vine-growers took an active part in the trial and this is particularly important since it allowed a more rapid diffusion of the knowledge on the subject and, in the case of mating disruption, offered a significant example of responsible and autonomous work.
- several authors have stated the importance of using the mating disruption technique on large areas in our region, however, where growing areas are very small (in the case of Sottodossi the average area is about 3000 sq.m.), this requirement would make the application of this method impossible. Cooperation is therefore very important in order to coordinate the efforts of advisors and researchers on one side and associations of growers on the other. In this specific case the coordinating role was played by the vine-growers association "Cantine Mezzacorona", which organized the group of growers and provided them with direct information by means of regular updating reports on the ongoing trials.

EVALUATION OF MATING DISRUPTION FOR CONTROLLING THE GRAPE BERRY MOTH, *ENDOPIZA VITEANA* (CLEMENS), IN THE NIAGARA PENINSULA, ONTARIO, CANADA

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The efficacy of mating disruption for controlling the grape berry moth, *Endopiza viteana* (Clemens) (Lepidoptera: Tortricidae), was evaluated from 1987 to 1989 in the Niagara Peninsula, Ontario, Canada (Trimble, R.M. *et al.* 1991). Mating disruption was tested in commercial vineyards with high-, moderate-, and low-density grape berry moth populations using the Pacific Biocontrol Ltd. tape-type and wire-type pheromone dispensers. Pheromone-baited trap catches were reduced by 92 % or greater in plots treated with pheromone. Treatment with pheromone significantly reduced damage (i.e. percentage infested clusters) compared with an untreated control in each of two tests, and provided control as good as or better than an insecticide control programme in two of four tests. Damage was greater on the borders of some plots treated with pheromone or insecticide, and increased from 1.3- to 12.8-fold between each of the three generations in plots treated with pheromone. Mating disruption was used at two Niagara Peninsula farms during three consecutive growing seasons, 1989-1991, to determine if between-generation increases in the percentage of infested grape clusters continued between growing seasons (Trimble, R.M. in press). Pheromone-baited trap catches were reduced by more than 99 % during the three-year-study. At one farm, insecticides provided better control than pheromone during 1989, but during 1990 and 1991, no difference was observed between methods. At the other farm, mating disruption provided control as good as or better than insecticides during three years of study. The percentage of infested clusters increased from 1.7- to 56.6-fold between successive generations. However, there was no indication that the level of infestation at harvest affected the level of infestion the following spring.

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Topic 5: Mechanisms, side effects and quality control.

Chairman: PROF. PIERO CRAVEDI

TARGET INSECTS BEHAVIOR IN PRESENCE OF HIGH PHEROMONES CONCENTRATION AND MATING DISRUPTION SIDE EFFECTS

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ABSTRACT

The application of the confusion method with sexual pheromones gives good results in the fight against several Lepidoptera species.

These successes are the result of basic research into the sexual pheromone emission of the females, the dispersion in the air of odour molecules and the response of the males to chemical messages.

Insects' behaviour in presence of high pheromone concentration is not yet completely clear.

Numerous experimental results make up a continuously evolving picture that enables the formation of more and more reliable interpretation models.

INTRODUCTION

The high calling power, that the sexual pheromones have towards the males of a lot of harmful species, has facilitated their use for monitoring. Very early it was understood that it was also possible to use synthetic sexual attractants to prevent mating (Wright, 1984). Their application for the pest control has been delayed by the difficulties in preparing proper apparatus for their distribution.

In the last few years important progress has been made precisely in this sector (Jutsum e Gordon, 1989). From a recent report of mating disruption method it emerges that in Western Europe researches have been done into 13 Lepidoptera species and good results have been obtained in 6 of them (Audemard, 1988).

Despite these positive results in crop defence, the physiological and behavioural phenomena which caused by the continuous presence of high pheromone concentration are not yet completely clear (Cardé, 1990).

From the seventies the progress in the research tehcniques has allowed us to gain important information about the chemical messages of the insects.

The identification of the components, present in the blends of pheromones and of the behavioral responses evoked by them have offered the chance to undertake an examination of the syntactic structure of the chemical communication through pheromones (Tumlinson and Teal, 1987).

The study of the elements that constitute the message has continued with the interpretation of what the sender codifies in the signal and the meaning that is given to it by the receiver.

One important result has been to ascertain the necessity to follow rigorous methodological procedures to avoid simplistic interpretations of behavioural phenomena which are experimentally induced and void of real meaning.

SEXUAL PHEROMONES EMISSION BY FEMALES

Female sexual pheromone biosynthesis is activated by a neurohormone that is produced in the suboesophageal ganglion. It is continuously produced and transferred via the neurosecretory axons into the corpora cardiaca where it is stored. It is released into the hemolymph with a periodicity regulated by the daily variations of temperature and light. The neurohormone activates enzymes specifically for pheromone production, which takes place in specific glands, starting from precursors (Raina and Menn, 1987).

Biosynthesis of several pheromones are well known, as are the modifications of the genetic resource which are responsible for variations in the pheromone composition.

For example, in *Ostrinia nubilalis* the gene that leads to the production of (E)-11-

tetradecenyl-acetate has been identified. In a strain of *O. nubilalis* the ratio between the (E) and (Z)-11-tetradecenyl-acetates was 97:3; in another the ratio was inverted (Klun and Maini, 1979).

Therefore the pheromone composition proves responsible for processes of reproductive isolation and speciation, it is under genic control and can undergo the effects of selection due to various causes.

The discovery of the activator neurohormone and of the biosynthesis pathways enable us to predict great adaptive possibilities of the sexual pheromone production system by species exposed to environmental variations artificially created.

Sexual pheromone emission has a direct influence on reproduction and it is possible to predict that the distribution into the environment of high levels of synthetic attractants exerts a selective pressure on the populations of target Lepidoptera.

MESSAGE RECEPTION

Antennal dimorphism in Lepidoptera is ascribable to different sensory functions. The males of some species, for example, have very large bicombed antennae and as a result a notable increase in their potential to capture the odorous molecules in the air (Steinbrecht, 1987).

Pheromone concentration in the air, under normal conditions, is always very low and selection has privileged the high sensibility of the males.

The shape of antenna, the number and the type of sensilla on it are important features for the pheromone perception.

The olfactory sensilla of male antennae often have a hair as external apparatus. Inside the peripheric sense organs the dendrites of the sensory cells are surrounded by an extracellular medium called *sensillum lymph*.

Specific receptor cells for the different components of the pheromone has been shown in the sensilla. The cuticular wall of the olfactory sensilla is characterized by great number of pores that probably allow the passage of odorous molecules, reducing to a minimum the loss of water from the receptor lymph.

Pore diameter varies in different species and according to the sensilla considered, from 10 to 40 nm.

Some tubules start from the pore and cross the wall of the sensillum. The poretubule are produced together with the cuticule of the sensory hair by the trichogen cell and later they take contact with the dendrites.

It is still a subject of discussion how the molecules of the different pheromone components pass from the outside into the stimulus receptive cells. In the literature there are some reports based on transmission electron microscopy researches which attest that the pore-tubules and the dendrites are physically in contact. Some researchers think this situation comes about normally and can be more fully documented using appropriate fixative and preparation procedures on the material. These structural connections would explain how hydrophobic molecules, like the pheromones, can reach the dendrites of the nervous cells without having to cross the space occupied by the sensory liquid.

Biochemical studies give a different explanation of pheromone perception by the nervous system based on the properties of some proteins.

In 1970 Riddiford showed evidence of existence of a sexual dimorphism between the antenna soluble proteins in the Saturnidae. He showed also the reaction of the *Antheraea penyi* pheromone to a male specific protein (Riddiford, 1970).

Another protein, found only in the extracellular lymph surrounding the sensory dendrites, is the sensillar esterase (SE). This protein, present in very low concentration, is very active in degrading the pheromone.

Vogt, working on *Antheraea polyphemus*, showed the presence in the receptor sensillum lymph of a pheromone-binding protein (PBP) and of pheromone degrading enzymes which are believed to set off the transport and the inactivation of the pheromone molecules (Vogt and Riddiford, 1981).

The kinetic parameters of the sensillar esterase fit the physiological parameters and the behavioural responses found in experiment.

Both the enzyme and the physiological response of the sensillum to the pheromone stimulus are saturated at the same pheromone concentration, which corresponds to 10^6 molecules per hair (Vogt, 1987). The enzyme remove that amount of pheromone from a sensory hair in 0,5 seconds; this time is enough for the male to assume behavioral mode once again. In the absence of quick degrading, we can expect an accumulation of active pheromone molecules inside the hair and the blockage of the capacity to register the external fluctuations.

The Kinetic Equilibrium Model, proposed by Vogt and Riddiford, describes the result of biochemical pheromone reception and gives an interpretation of the molecular mechanisms involved (Vogt et al., 1985).

PBPs have multifunctional properties of solubilizer, carrier and protector of pheromone.

Pheromone molecules would thus have the opportunity to activate receptor protein molecules before being degraded by sensillar esterase. The possibility of repeated pheromone - receptor protein interaction can be the cause of an increase in sensitivity to low pheromone concentrations.

Dendrites simulations are transduced into action potentials which present themselves to the central nervous system with a frequency proportional to the scent intensity.

Most receptors display, in the presence of high quantities of odorous molecules, a succession of high frequent action potentials followed by a period of reduced frequency that continues for the duration of the stimulus. The receptor cells, specific for the different pheromone components, have different responses. Thus odour plumes determine the different stimuli on the various receptors.

The central nervous system has proved able to register the stimuli produced by odour plumes with a discontinuous structure. In natural conditions the presence of pheromone concentrations and appropriate visual stimuli enable the identification of the female and the beginnig of the courtship.

According to Vogt the transduction involves a pheromone binding to a membrane-bound receptor protein. The receptor protein would be directly coupled to one or more ion channels, whose conductance state would be altered by pheromone binding (Vogt, 1987).

These events presumably take place in the dendritic region of sensory neurons.

ODOUR MOLECULES IN THE AIR

There are still many doubts about the diffusion of odour molecules in the air and about the way insects are reached by chemical messages.

The determining of the concentration of pheromone in the air and of its propagation in the environment presents great difficulties in mating disruption application areas.

Recently an electroantonnogram method able to measure the pheromone concentration in the field, has been perfected.

A portable electroantennogram system has been used to measure the concentration of the pheromone components of *Lobesia botrana* and *C. pomonella* present in the air.

An analogous research made into *C. molesta* (Baker and Haynes, 1989) shows how the increase in the concentration near the pheromone-emitting source stops the upwind flight.

This behaviour has been attributed to a reduced sensitivity of the central nervous system of the insect which moves within the odour plume.

The information about the diffusion mechanisms of the molecules in the environment, although incomplete, allow us to imagine how the pheromones emitted by the females stimulate the males (Murlis et al., 1992).

The study of the structures of the odour plumes is very useful also to more clearly understand the kind of distribution of pheromone which depends on the characteristics of the dispensers, their density and distance from the ground.

Odour molecules, released by the females into the environment with a discontinuous rhythm, form filaments that spread slowly until they reach the size of the smallest eddies. The size of these small movements are in the range of few centimetres. Next faster processes of dispersion by air turbulence take over. The diffusion is initially connected with the characteristics of the molecules, the size of the emitting source and the speed of the wind.

After a first stage, which some authors reckon at a few metres while others estimate it at around one centimetre, the odour plume takes on the typical shape of a smoke plume.

Air turbulence is connected with atmospheric conditions and is affected from one point to another and from daytime to night-time.

Odour plumes structure is characterised by fluctuations in concentration which are able to act on the central nervous system of the insect, inducing instant responses. The shape and the average concentration of the large-scale pheromone plume, on the other hand, are important to determine the orientation of the insect.

The variation in time of the plume structure determines the probability that the insects located downwind can intercept it.

It has been noticed that insects do not respond to mean pheromone concentration, but to instantaneous ones, which are much higher.

The turbulence of the air flows and the size of the emitting source provoke the succession of instants in which at a given moment the signal is absent and at others there is a high concentration. However, the fluctuations in concentration decrease when the distance from the emission point increases. Further from the odour source the mean concentrations is consequently more representative.

INSECT BEHAVIOUR WITH DIFFERENT CONCENTRATIONS OF PHEROMONE

It still remains to be clarified how a complex of chemical interactions, induced by the pheromone molecules captured from the air by specific external sexual apparatuses, provokes a functional state in the individual.

It also has to be seen how the males modify their behaviour after extended exposure to high levels of pheromone.

Traditional explanations of sensory adaptation at the peripherical receptor level and central nervous system habituation are backed up by partial confirmation in experiments (Bartell, 1982).

The sensory system of the antennae must be stimulated by a physical signal to keep flight directed towards the attracting source. This mechanism has been verified in experiment only in the case of some Tortricids. The species used in this research proved in a wind tunnel to be able to follow a pheromone plume overlaid on an air flow containing a lesser concentration of pheromone (Murlis et al., 1992).

So it is necessary to keep the quantity of pheromone high and uniform to prevent the identification of the females present.

What are less well known are the phenomena attributed to the modification on the central nervous system, which is certainly involved. One can obtain confirmation of the importance of the central nervous system in pheromonal attraction by artificially damaging its funtioning (Vogt, 1987). It has been reported that insecticides with neurotoxic action cause the driving responses of the males to change by acting on the reception of pheromone precisely at the level of the central nervous system.

Adaptation and disadaptation phenomena are complex and little known and they only concern a restricted number of species of Lepidoptera.

Our knowledge of this subject has improved significantly over the last few years, but all the same the certainties are few and far between, and the answer to the question how insects behave in the presence of high pheromone concentrations can only be understood by analogy with the situations that have been examined in experiment.

Our vision of the processes involved remains therefore like a mass of results of specialised pieces of research. Our problem is to deal with higher levels of complexity where the whole organism is involved, not just biochemical processes, structural particulars or behavioural responses in ready-fixed conditions.

The analysis of the basic conditions for a good working of the mating disruption method helps us to foresee its limits, possible improvements and the probable causes of ineffectiveness.

All the authors who have dealt with this subject emphasize the necessity of involving large areas to obtain good results (Audemard, 1988; Molinari and Cravedi, 1991; Neuman e Cravedi 1989; Charmillot and Bloesch, 1987), and various trials have been carried out on a wide scale using surfaces of a few hundred hectares of peach orchards and vineyards (Cravedi et al., 1991).

A consequence which must not be underestimated in these cases is a pressure of selection that could favour variations in the behaviours of calling and identifying the partner.

The phenomena that could be involved in the females are the hormonal regulation of the pheromone production and of its rhythm of release into the environment, and the biochemical nature of the synthesis of the different components of the mixture. The males heve a complex system, possible changes to which could influence their sensitivity to odours and their behavioural responses.

It is also very important to keep in mind that often the used mixture does not contain all the components of natural pheromone.

It is generally recognised that the method works in the presence of a low population density of the pest and as long as a sufficient amount of pheromone is assured in the environment. Unfortunately, in most cases it is not actually possible reliably to estimate the population density of the target insects, nor to measure the amount of pheromone present in the volume of air in which we wish to carry out the disruption of the males.

This double uncertainty leads to the use of absolutely huge quantities of pheromone for situations where the populations are really very small.

Trials carried out for several years on the same peach orchards, even though they were not completely isolated, have confirmed that the repeated use of sexual confusion brings about the decrease of the population density of *C. molesta*. The quantity of pheromone necessary to assure the disorientation of the males reduces drastically as the years pass.

Through food traps, it has been noted that, even on the inside of large peach orchards where mating disruption is applied, mated females, albeit in small numbers, may be present (Molinari and Cravedi, 1989). This situation does not generally cause any risks for the crops, but it makes us suspect that mechanisms other than pheromonal calling may allow mating.

CONCLUSIONS

The results reached so far in the application of the confusion method against certain species are stimulating research which is, however, mainly directed towards improving the pheromone distribution apparatus.

Therefore it is important to stress the need to fill in the gaps in our knowledge that still exist on basic aspects (Pelosi and Maida, 1990). Great importance must be given to studies of the ultrastructural, physiological, biochemical and ethological aspects of insects and to those connected with the diffusion of odours in the air and the effects of various causes on selection among the species involved.

The necessity better to understand the reason for certain results constitutes the indispensable premise for the further progress which is to be hoped for in the application of pheromones according to the confusion method, which allows a considerable reduction in the levels of toxic substances used to protect cultures.

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MATING DISRUPTION OF *LOBESIA BOTRANA* AND SIDE EFFECTS OF PHEROMONES ON BENEFICIAL ARTHROPODS IN VINEYARDS OF THE "RHEINPFALZ" (GERMANY)

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In order to disrupt mating of *Lobesia botrana* (Lepidoptera, Tortricidae), the use of pheromones (ampulla-type BASF) has been investigated during trials beginning in 1989. In vineyards of 1, 5 and 10 hectares, disorientation rates between 98.2% and 99.8% have been achieved. The effectiveness was determined by the degree of infestation of larvae and ranged from 46% to 95% concerning the investigation sites of 5 and 10 hectares. In 1991, a result noticeable was the investation rate of a mean of 19.2% for the second generation within the area of the 10 hectares biotechnically treated in spite of the high degree of effectiveness during the first generation (infestation rate: 0.44%). A possible explanation might be the fact, that fertilized females flew into the investigation site.

The subject of a further research project was to determine the effects of a long-term pheromone application (non-insecticide treatment) on beneficial arthropods and insect pests during investigations in vineyards. The results provedthat pheromone treated sites had a wider spectrum of beneficial arthropods being present in higher abundances in comparison to the sites treated with common insecticides. Within the foliage, the order of Araneida and the superfamily of Chalcidoidea (Hymenoptera) was predominant among the beneficial arthropods. In the pheromone treated sites, much higher populations of the predatory mite *Typhlodromus pyri* (Acarina, Phytoseiidae) were found as well. In the foliage, the species *Sparganothis pilleriana* (Lepidoptera, Tortricidae) was found as a representative of insect pests. Its abundance was higher in the pheromone variants compared to the insecticide variants, nevertheless the infestation rates never exceeded the economic threshold. Concerning a minor percentage of *S. pilleriana* larvae, parasitism took place by Ichneumonidae (Hymenoptera) and Tachinidae (Diptera) in the pheromone treated variants. As far as the vine trunk is concerned, the spiders were again predominant among the beneficial arthropods. For the epigeal fauna no significant effects were observed for the differently treated variants. This can be explained by the fact, that in contrast to the treated foliage, soil and green cover were less contaminated by the insecticide.

In general the investigations proved, that the application of biotechnical methods do respect the fauna of beneficial arthropods. It can be assumed, that the latter lead to positive effects in control of insect pests.

Pheromone induced modifications of behaviour in the moth *Lobesia botrana*.

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From other presentations (e.g. Neumann, this volume) it may be concluded that, although the confusion method seems to work, it gives widely varying degrees of control. In order to improve this situation and to optimize this method in a rational way, better insight into its mode(s) of action is required. In crop protection, the mode of action of a chemical agent is often deduced from its known biological function. Thus the conclusion has been drawn that the application of pheromone in some way hampers orientation towards conspecific females. It is for this reason that much attention in confusion research has been concentrated on attraction and orientation.

However, the assumption that trap shutdown or reduced reproduction is simply a result of hampering orientation of the animals may be premature. This becomes clear when the amount of pheromone required for disruption is analysed somewhat more critically. An acceptable level of mating disruption is only reached when the equivalent of 1 to 10 million females per ha is released into the atmosphere. That is the equivalent of 100 to 1000 females per square meter, the females being only 3-10 cm apart. This is somehow excluding a false trail following mechanism.

It is because of such considerations that, in our opinion, more basic research into the mode of action of pheromones is required.

In the last few years the work in our lab was concentrated around the following working hypotheses:

1. Adaptation or habituation desensitizes males.
2. False trail following.
3. The combination of artificial pheromone components superimposed on female fragrance is less attractive to males.
4. The diurnal activity patterns of males and females are desynchronized.
5. The high pheromone concentration switches on unique types of behaviour, or reduces the willingness for reproduction.

Putting up hypotheses for possible mechanisms of mating disruption is rather simple. Testing these hypotheses, however, should involve some proof that observed effects are responsible for disruption. Adaptation, that is the effect that large pheromone reduce the responsiveness of the sensory organs to subsequent (small) stimuli, is quite easy demonstrate, especially when high concentrations of pheromone are used. However, a demonstration that such adaptation has a profound behavioural impact and is responsible for the overall mating disruption effect remains very difficult.

It is for such reasons, that our research is focussed around the study of the modifications in behaviour of Lobesia when stimulated with disruption-like pheromone concentrations.

In order to perform such studies in the laboratory, it is of course necessary to have some knowledge of pheromone concentration and pheromone distribution in the field. Such data were obtained in cooperative projects with Uwe Koch and coworkers and Roland Milli. Results may be presented elswhere in this volume.

In our lab, insect flight is investigated using a flight simulator. Here, the orientation towards pheromone sources can be studied under quite well controlled conditions.

Orientation is also studied in a wind tunnel. Results of these experiments are, to date, somewhat disappointing because the attractiveness of wine traps, as used in the field, could not be demonstrated. At present we are investigating whether the introduction of turbulence into a wind tunnel would enhance the attractiveness of such traps. However, turbulence is not an all or none effect, and the type of turbulence introduced into the wind tunnel should be related to the turbulence found in the field. Together with Uwe Koch we have therefore started an investigation of turbulence. For this purpose, the wind in many vineyards was measured using a newly developed vectorial anemometer. At present, we are trying to interprete these results as follows.

Individual wind sensors in the anemometer supply information about the air speed in one dimension. The compete anemometer consists of three orthogonally arranged sensors. Using Pythagoras, the data from these sensors can be transformed into wind speed and wind direction data, from which histograms can be made, where the probability of specific wind speeds or wind direction are displayed. A drawback of such a data reduction is the loss of temporal information. This may be overcome if we somehow reverse the problem, and interprete the anemometer as a source of smoke. This smoke now drifts away with subsequent, measured wind vectors. After a certain time the resulting smoke-field can be plotted. Although such a plot does give some insight into structures of odor plumes, it does not allow a quantitative interpretation of wind as yet. Such information may be derived if the net or average wind vector is divided by the average wind speed, which may be displayed as a function of the time of averaging. Using this algorithm, laminar wind gets a value of 1, and stationary turbulence a value of 0. At one single instant the wind is always laminar and with increasing averaging time it decreases to a stable value. At present we are trying to establish relationships between these values and climate, topography, texture or training in orchards. This also may provide some physical basis for the applicability of the mating disruption technique.

The (diurnal) behaviour of our animals is investigated using a specially developed radar-actograph. During observation, ten males are kept in a disposable box inside a faraday cage under an artificial light regime. Speed or repetition rate of movements can be derived from the spectrum of the radar-signal. For this presentation, two spectral bands of activity were analized, measured before pheromone was administered. One trace with the slow movements and the other with faster movements, with speeds of

0.5 mm/s and 10 mm/s respectively. In both traces a major activity peak occured during the sunset phase whereas some lesser activity during the sunrise period could also be observed.

If the light was suddenly switched on or off rather than gradually dimmed, only narrow activity peaks, which did not differ significantly in amplitude, coincided with the light changes. Compared to the behaviour with gradual modifications in light intensity, light transients caused the evening activity to appear later, whereas the morning activity appeared earlier. Some activity occured before the light was switched off, suggesting an internal clock.

Application of pheromone had a larger effect on the slow movements than on the faster ones. The bursts of slow activity at sunset and at dawn exceeded those in the untreated control, both in amplitude and duration. The usual activity at dawn was masked or replaced by a clear nocturnal activity.

In Cydia pomonella, the codling moth, a slightly different pattern of activity was found. The major activity peak at sunset was followed by a regular nocturnal activity which ended at dawn. After the application of codlemone, the slow nocturnal movements increased considerable.

These observations may be summarized as follows:

time of day	sunset		dawn	
type of activity	slow	fast	slow	fast
Lobesia, untreated	short	short	short	short
Lobesia, treated	all night	longer	longer	absent
Cydia, untreated	long	short	small	small
Cydia, treated	all night	all night	large	large

Apart from some influence on the duration of the evening flight activity, the main effect of pheromone appears, both in Lobesia and Cydia, in the band of very slow behaviours, where the velocity of movements is in the order of 0.5 mm/s (the lower limit of our detector) or less.

In females, the circadian pattern of activity is rather similar to those of conspecific, untreated males. Here, effects of pheromone could not yet be established.

The extent to which the observed modifications in behaviour form a basis for succesful mating disruption is not yet known. The effects however, were only observed with the application of disruption-like pheromone concentrations. In our view, it is astonishing that the most pronounced behavioural effect is in the band of slow activity which does not coincide with flight orientation. Such results tend to favour effects on diurnal activity patterns and unique types of behaviour as possible explanations for the mating disruption effect rather than other hypotheses.

A PROGRAM TO IDENTIFY MECHANISMS OF DISRUPTION IN THE ORIENTAL FRUIT MOTH

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The Oriental Fruit moth, *Grapholitha molesta*, is a pest of stone fruit which in Australia is now largely controlled by mating disruption with sex pheromones. The complete control system involving dispenser types, density and disposition was developed empirically and, even though a commercial product, Isomate-M, is now sold worldwide, the mechanisms which bring about disruption of mating have not been precisely identified. In spite of this, the idea that disruption operates through the males following false trails of pheromone has gained considerable currency and has featured repeatedly in popular accounts of control of this insect. There is however little direct evidence for this mechanism, but neither is there much for any other. In trying to develop pheromone mating systems for other insects this deficiency in our knowledge has proved a serious stumbling block. To try and correct this the CSIRO Division of Entomology instituted a program of research to identify the disruption mechanisms operative in this moth.

Experiments have concentrated on the behaviour of the males and have involved observations in orchards and wind-tunnels and electrophysiological (EAG) experiments. Although all possibilities have not yet been excluded, one distinct mode of action involving adaptation processes has been identified as operating with this insect. This presentation will detail the experiments which have been carried out, the difficulties encountered in trying to differentiate between mechanisms, the results obtained up to now and projected experiments. On the basis of the information collected for the Oriental Fruit moth similar experiments are about to commence with Codling moth and Lightbrown Apple moth. It is also intended to extend behavioural observations to females of these species, especially to study the effects of pheromone on calling and dispersal.

DISTRIBUTION OF PHEROMONES IN APPLE ORCHARDS WHERE CODLING MOTH IS CONTROLLED BY MATING DISRUPTION

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INTRODUCTION

Mating disruption is becoming increasingly popular in orchards and vineyards because it offers a method of controlling insect pests without the use of toxic compounds whose environmental impact is questionable. However, the limiting conditions for successful applications of this technique are, so far, not well understood. Dispenser types, distribution and loading have therefore been the subject of a great deal of investigation. Almost nothing is known of why the application of pheromones leads to reduced infestation and very little information exists on which molecules of the blend are most effective. The research partly described here was carried out to achieve a better understanding of questions concerning how pheromones are distributed in an orchard and what influence temperature, wind, foliage, dispenser distribution, orchard size and limiting treatments have.

Happily, the moths themselves may help us to answer the above mentioned questions. Moths bear antenna on their heads which are extremely sensitive to pheromone. Moreover, using electrophysiological recording techniques, they can provide us with information about how much pheromone they encounter.

MATERIAL AND METHODS
EAG-TECHNIQUE

In **Figure 1**, a calibration curve of the antenna of *Cydia pomonella* to codlemone is shown. Using this calibration curve, the response of an antenna to an unknown concentration of pheromone may be quantified.

In order to exploit this system, a portable EAG-set up was developed which allows experiments to be performed (see contribution of Uwe T. Koch, elsewhere in this volume). The equipment described here is a special light-weight, easily transportable "one man band" adaptation of this apparatus. It was developed to get information about treatment and vegetation depending variations in pheromone distribution. In this modificated set-up the antenna can be moved through a distinct experimental field which e.g. is a treated plot with at the edge an untreated plot or a field. Measurements in different altitudes and above the trees may also improve our knowledge and understanding of pheromone distribution in this part of the orchard. These measurements are performed using a specially developed lift-mast. Using this equipment the pheromone level throughout the orchard may be recorded, using the electrophysiological reaction of the antenna.

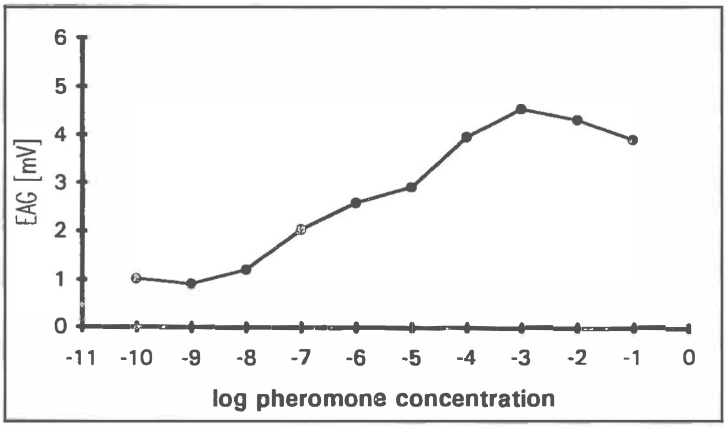

Figure 1: EAG-responses of an antenna from a male codling moth to pheromone dilutions (E8,E10-12:OH in paraffin highly liquid).

EXPERIMENTAL PLOT

An apple orchard (5 cultivars on rootstock M9, "dwarf tree", planted with 1 m distance) in the palatinate region (Rödersheim-Gronau/Pfalz) with the dimensions of 43 to 250 m (12 tree rows, alleyway distance 3,8 m, orientation NS) was divided in four uniform plots (Fig.2) which were treated for mating disruption in June 1991 with double-ampoule dispensers called RAK (BASF AG) and filled with E8,E10-12:OH.

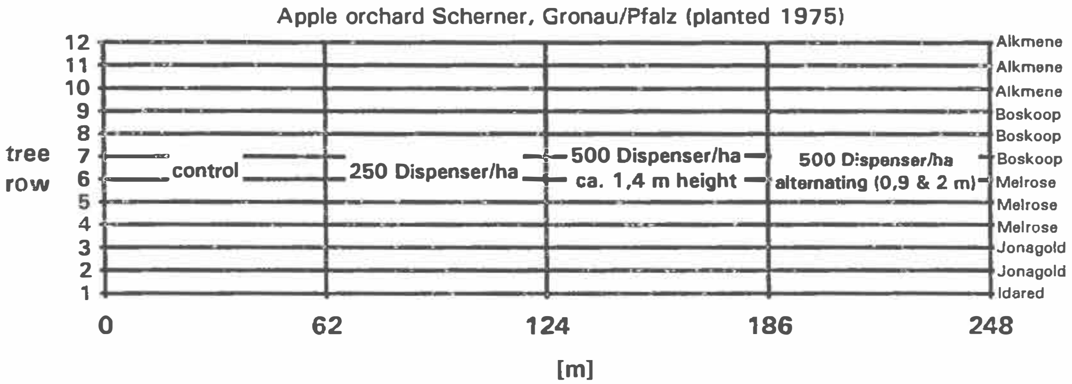

Figure 2: Experimental plot with different treatment areas

RESULTS

With the above described EAG-method it is possible to detect changes in pheromone concentration that are related to the type of treatment and the distance from the edge. As **Figure 3** illustrates, the highest pheromone concentrations were detected in the centre of the plots (20 m to the edges) and increased with the number of applied dispensers/ha. **Figure 4** shows that a uniform pheromone concentration was found independent of the treatment when the detector was placed between the first and second tree row of the plot.

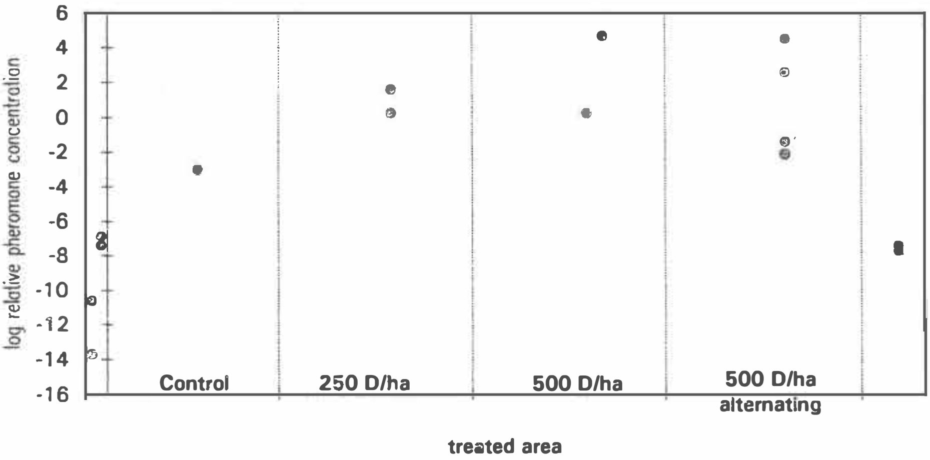

Figure 3: Pheromone distribution in plots with different dispenser application mode and density 20:53-21:11 CEST, 07.08.91

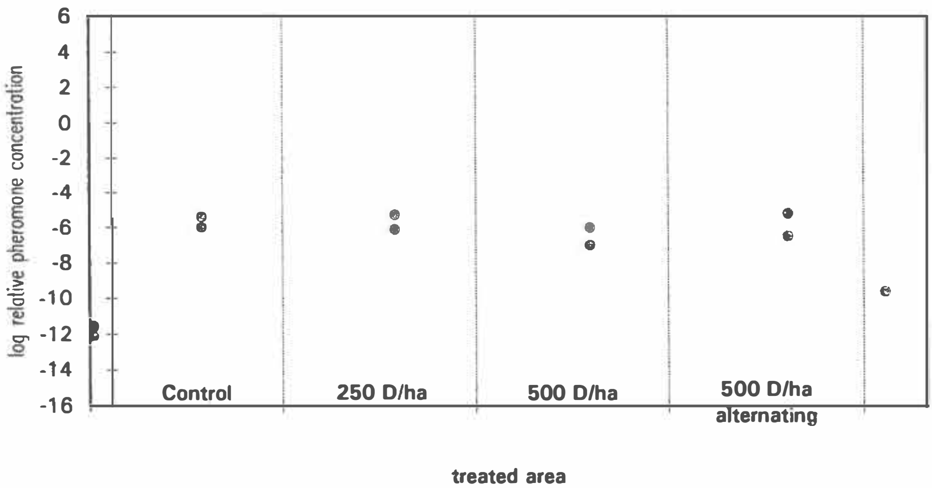

Figure 4: Pheromone distribution, measured in the edge row! 21:12-21:33 CEST, 07.08.91

As illustrated in Figures 5&6, the following vertical pheromone concentration profile was found: in the control plot no vertical profile could be detected, the concentration range in the half density-plot (250 D/ha) decreased over about 6 orders of magnitude between 1,4 to 6,5 m. As in the normal treated plot (500 D/ha, Fig. 6) the detected pheromone concentration at 1,4 m was higher as in the half density-plot, the decrease of pheromone concentration within 4 m altitude was much bigger.

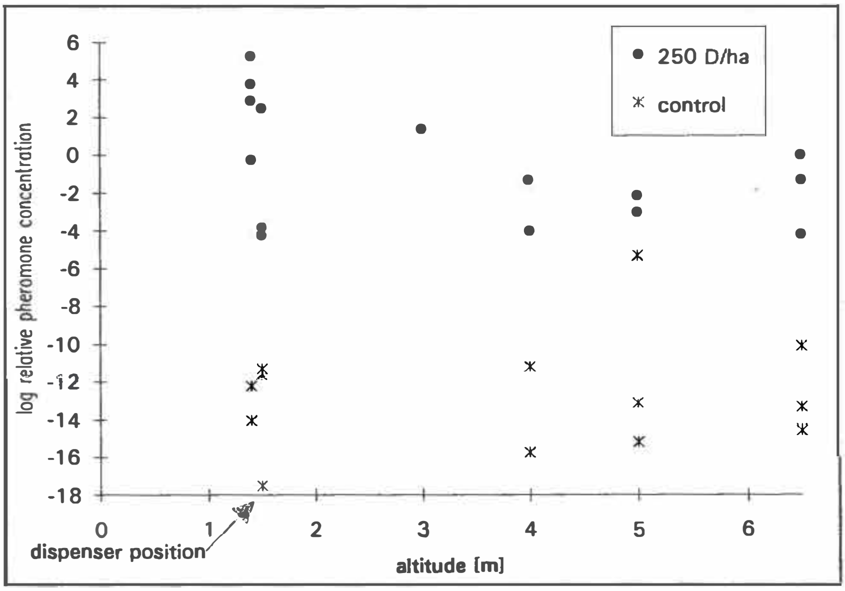

Figure 5: Vertical pheromone distribution in the control and 250 D/ha-plot

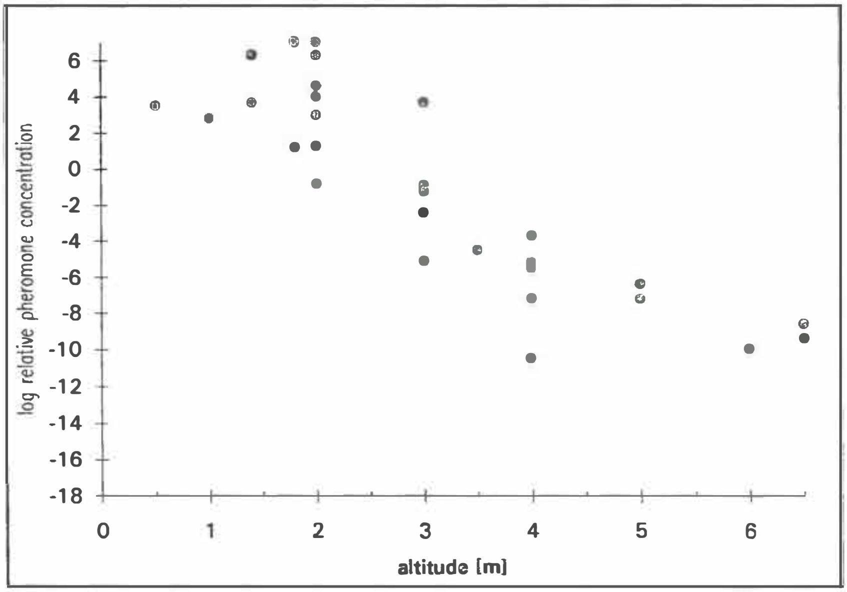

Figure 6: Vertical pheromone distribution in the 500 D/ha-plot

DISCUSSION

In **Figures 3 to 6** y-axes are not calibrated in universal units but in reproducible relative values. It appears that effects of treatment and/or foliage can be detected by an isolated antenna if it is used with the EAG-technique.

Figure 3 & 4 illustrate that there is a dramatic drop in pheromone concentration between the centre and the edge of the orchard. Successful mating disruption has to cover an orchard-surrounding belt of min. 20 m for establishing an effective pheromone concentration both in the edge row and in the centre of the orchard. **Figure 5 & 6** show decreasing pheromone concentrations with increasing altitude. Absence of pheromone is not detected yet.

Relationships with temperature, time of day and time of year will give more information about the efficacy of dispensers and may lead to a better use of pheromones in orchards.

With the application of the EAG-technique for the support of mating disruption in orchards and vineyards, the absence, appearance and concentration values of substances can be detected in a real time mode.

Knowledge about pheromone
- concentration,
- formulation and
- distribution

in orchards and vineyards will be helpful in developing a reliable bio(techno)logical tool for integrated pest management.

ACKNOWLEDGEMENTS

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PHEROMONE DENSITY MEASUREMENTS BY EAG METHOD IN VINEYARDS

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Measurements of pheromone density in fields treated for mating disruption are intended to serve a dual purpose:

1. To investigate influences of temperature, wind, type of plantation and other parameters on the actual pheromone density with the aim of maximizing the density with a given dispenser system.
2. To collect data about absolute values of the pheromone density and its variability in conjunction with wind measurements as reference values for realistic laboratory experiments investigating insect orientation in an odour plume and other mechanisms of mating disruption.

In the past 4 years, we have developed a highly sensitive pheromone density measurement system using the insect's antenna as a sensor element and a multichannel calibration system which permits to eliminate the effects of individual antennogram sensitivity [1) 3)].
With this system, it was established that the amount of foilage is an important factor in the final pheromone density that can be reached in a given field. As measured in wineyards treated for mating disruption of *Lobesia botrana*, the presence of the wine leaves (summer) increases pheromone density by a factor of 20 or more over the situation without leaves (Spring) [2)]. In addition, the structure of the pheromone clouds is affected by the foilage. In the summer, the pheromone distribution is very homogenous ("fog-like") while in spring, strong fluctuations of the pheromon density occur [2)]. Recently, we have added a device measuring the three components of the wind vector with high time resolution [3)]. We are currently investigating ways to evaluate the wind vector data to yield a compact description of the turbulences in the wind field. In addition, we search for possible correlations between wind activity and pheromone density to establish a database for realistic laboratory experiments in mating disruption.

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