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# Biological control in pear orchards under seasonal pest management programs with and without organophosphate insecticides

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**Abstract:** Although there is considerable potential for biological control in pears, there has only been limited success in taking advantage of it in the past because of the intensive use of broad-spectrum insecticides, in particular organophosphates (OPs) for control of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), and other pests. In recent years, resistance development and regulatory actions because of worker safety and environmental concerns have led to a reduction in OP insecticide use in pome fruits. New control tactics such as mating disruption, microbials and new insecticide chemistries such as insect growth regulators (IGRs) and neonicotinyls have now become available to take the place of OPs and other broad-spectrum insecticides. Although several of these new control tactics, such as mating disruption and microbials, have little impact on natural enemies, little is known about the selectivity of the newer insecticide chemistries which have begun to replace OP insecticides. Between 2001 and 2005, we had an opportunity to assess biological control in pear orchards under pest management programs which either included or excluded OP insecticides. This study was conducted as part of a federally funded collaborative project to promote the use of mating disruption and other selective control tactics on tree fruits in the western United States, to enhance opportunities for biological control and to demonstrate the feasibility and effectiveness of pest management programs on pears which excluded the use of OP insecticides. These field studies showed consistently higher numbers of natural enemies in pear orchards where OP insecticides were not used. Laboratory studies complemented the field studies and provided direct evidence of the acute toxicity and sublethal, i.e. reproductive effects of newer insecticide chemistries.

# **Beneficial effects of hedgerow plants for insect predators in adjacent orchards – the value of pollen and nectar to *Anthocoris nemorum* (L.)**

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**Abstract:** This paper reports a) on a field study comparing the spring predator community in hedgerows and in apple orchards (*Malus domestica*) as a measure of the potential value of different hedgerow types for conservation biological control; and b) on a laboratory study of the diet-dependent development of the predator *Anthocoris nemorum* (L.) (Heteroptera: Anthocoridae) on common prey types (lepidopteran eggs, aphids, collembola, pollen and nectar, and mixed diets), aiming to identify among others the value of pollen and nectar. Arthropod communities in alder hedgerows (*Alnus incana*, *A. glutinosa*), in elderberry shrubs (*Sambucus nigra*) in mixed hedgerows, and in the herbaceous layer under these two hedgerow types were more similar to apple orchards than insect communities in hedgerows dominated by hawthorn (*Crataegus monogyna*) and hazel (*Corylus avellana*). Total numbers of predators were highest in hazel and hawthorn followed by apple. Alder, hawthorn and herbaceous layers with stinging nettle (*Urtica dioica*) held the highest number of *A. nemorum*. At the time of the field survey, apple, elderberry and hawthorn were flowering. Though pollen and sucrose was inferior to arthropod diets for *A. nemorum* nymphs, they could survive on this diet in some cases over a month, showing that flowering plants can be valuable for *A. nemorum* survival in orchards when prey is temporarily scarce. Thus populations of *A. nemorum* in hedgerows may not only use this habitat as shelter or source of prey but also for collecting pollen and nectar.

## Adapting orchard management to re-establish earwigs in Belgian pome fruit orchards

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**Abstract:** Earwigs are key generalist predators to a variety of pome fruit pests, though aimed chemical control to prevent suspected fruit damage of earwigs considerably reduced populations in Belgian orchards. In recent years, integrated and organic fruit growers have tried to re-establish earwig populations, thus far with little success. We started a study linking various components of orchard management and the earwig life history to identify potential factors hazardous to earwigs. We investigate effects in both short term (e.g. knock down of pesticide use) and long term (e.g. introduction of populations). The goal of this study is to adapt management to allow optimal development of the earwig population.

Studying side-effects of orchard management on this univoltine organism, especially at the population level, revealed some intrinsic problems. First of all there is a strong variation within orchards, even at the tree level at a given site within the orchard, suggesting that large sample sizes are required for valid tests. Second, there appears to be a considerable effect of niche occupation (tree and soil) during larval stages, the most sensitive life stages. Third, spatial distribution patterns seem to change during life history, from clumped nests to patchy larval distribution and continuous adult presence. Finally, there is an unprecedented persistency in effect even when we apply fast degrading products on small plot sizes (6 trees). Contrary to our expectations, we observed no re-colonisation from adjacent untreated plots. In addition to this, transplants of large earwig populations to previously unoccupied orchards are seldom successful, limiting clear-cut experimental designs. These issues need to be properly addressed to limit their impact on the outcome of side-effect testing in field tests.

## Abundance and seasonal distribution of natural enemies in treated vs untreated pear orchards in Lleida (NE Spain)

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**Abstract:** The diversity of beneficial arthropods and the seasonal distribution of natural enemies associated with *Cacopsylla pyri* (L.) (Hemiptera: Psyllidae) was studied in two pear orchards (c.v. Blanquilla), one untreated and one treated with insecticides in Lleida (NE, Spain). Orchards were sampled weekly or fortnightly, using beating funnels, from March 2003 to December 2004 (except in July due to fruit maturity).

In both orchards, *C. pyri* was the most abundant phytophagous. The three most important groups of predaceous arthropods in orchards were Coleoptera, Heteroptera and Aranea. Among heteropterans *Anthocoris nemoralis*, was the most abundant in both orchards. Miridae and Dermaptera appeared at the same time at the early spring. Anthocoridae were the most important pear psylla predators, showing a strong response to the psylla outbreaks in both orchards. The insecticide applications affected the diversity and density of predaceous species. *Pilophorus perplexus*, *Hemerobius* sp. and the parasitoid *Trechmites psyllae* were only found in the untreated orchard.

## Pressure of predation in treated vs untreated pear orchards in Gimenells (Lleida, Spain) during spring and summer 2004

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**Abstract:** *Cacopsylla pyri* (L.) (Hemiptera: Psyllidae) is a key pest in pear orchards in Lleida (Spain). This pest is difficult to control because of its ability to develop resistance to pesticides and the few available and effective products that can be used. Biological control by conservation and increase of predators can contribute to its control it must be included in the integrated pest management of pear psylla.

Our objective was to estimate the level of activity of the predators during the spring and summer generations of *C. pyri*, with and without chemical control.

We offered as prey eggs of *Ephestia kuehniella* Z (Lepidoptera: Pyralidae) in two orchards of *Pyrus communis* cv. Blanquilla, one orchard under chemical control (**TO**) and the other orchard untreated against insects and mites since plantation (**UO**).

From January until the first insecticide treatment (April, 14<sup>th</sup>), we observed in the **TO** a slightly higher predation activity than in the **UO**, significant in some weeks. The psylla population in the previous autumn was higher in the **TO** and this favoured that the predators remained during winter, the anthocorids were present in **TO** already in January. From May onwards the level of predation was higher in the **UO**, mainly due to the predators with chewing activity. These predators were mainly earwigs, not detected in **TO**. During this year the activity of the predators with sucking activity was low in both orchards because the population of the psylla did not increase enough to attract *Anthocoris nemoralis* (F.) (Heteroptera: Anthocoridae). However in the **UO** the sucking activity was underestimated, as we have detected when we have separated the diurnal and nocturnal activity, because the eggs partially sucked during the day were exposed to the earwigs that have nocturnal activity.

## Impact of alternative insect management programs on the predatory arthropod complex of green apple aphids

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**Abstract:** The North Carolina apple industry has relied on organophosphate (OP) insecticides as the primary pest management tool for >40 years. Concern about the safety of these pesticides to human health and the environment has led to regulatory actions that have reduced the availability of these pesticides to growers. Hence, studies were conducted from 2002-2005 to assess the impact of reduced-risk (RR) pest management strategies on pest and beneficial arthropod populations. In nine commercial apple orchards, plots ranging in size from 2-5 ha were used to compare RR vs. conventional (OP) based pest management programs targeting 6-10 key pests. Reduced-risk strategies included mating disruption and new insecticides classified as reduced-risk. Comparatively similar numbers of the aphids (*Aphis pomi* and *A. spiraecola*) were found in the RR and conventional programs. A diversity of generalist predators that preyed primarily on aphids, including predators in the families Coccinellidae, Chrysopidae, Syrphidae, Cecidomyiidae, were found in slightly higher numbers in RR vs. conventional plots, but these differences were not significant. Results suggest that as apple growers switch from OP to RR based IPM programs, generalist predator populations common in North Carolina apple systems should not be adversely affected.

## Presence of the common earwig *Forficula auricularia* L. in apple orchards and its impact on the woolly apple aphid *Eriosoma lanigerum* (Hausmann)

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**Abstract:** Apple growers encounter increasing problems to control woolly apple aphid *Eriosoma lanigerum* (Hausm.). Various authors have shown that the common earwig *Forficula auricularia* L. preys on aphids and thus plays a role in controlling aphid pests. It was assumed that earwig numbers in orchards had decreased in recent years. Therefore an inventory was made to assess the number of earwigs in apple orchards and to identify factors that determine their presence. In 125 apple orchards shelter traps were used to measure earwig densities. In addition, a questionnaire regarding characteristics and management of the orchards was filled in by the growers. In 93 of these orchards the density of woolly apple aphid was measured.

The average number of earwigs in cardboard traps varied between 0 and 34 per trap, but in half of the orchards, average trap catches were less than 1 earwig per trap. There was a strong negative correlation between the numbers of earwigs and woolly apple aphid infestation, which shows that earwigs play an essential role in controlling woolly apple aphid in commercial orchards. Several factors seem to affect the presence of earwigs in the orchards, the most important one being the drainage of the soil. Organic orchards had slightly more earwigs than IPM treated orchards.

## **Biology and management of woolly apple aphid, *Eriosoma lanigerum* (Hausmann), in Washington state**

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**Abstract:** Woolly apple aphid, *Eriosoma lanigerum* (Hausmann) (Homoptera: Aphididae) has become a more severe pest in Washington apple production in the past few years. Milder winters have promoted overwintering survival on the aerial parts of the tree. A very low percentage of the current apple acreage is planted on resistant rootstocks, nor are such rootstocks used for new plantings. The transition from organophosphate insecticides to either insect growth regulators or neonicotinyl insecticides may also be contributing to higher pressure. In addition, this pest became one of quarantine concern in 2006. Alternatives to organophosphate pesticides have been tested for several years. Of these, petroleum oil shows some promise, as does a particle film used for sunburn protection. A neem-based insecticide provided temporary suppression, as did several neonicotinyl insecticides. A second approach to management, that of controlling the root colonies, was explored for the first time in this region. In potted tree assays, several compounds including imidacloprid, spirotetramat and oxamyl showed good root and systemic activity; in field trials, however, results were more variable. A greenhouse test of 8 clonally propagated rootstocks and 2 seedling rootstocks demonstrated that several of the new Geneva rootstocks to have virtual immunity to a Washington strain of woolly apple aphid, whereas the older Malling-Merton rootstocks had a lesser degree of antixenosis.

# Effects of exclusion or supplementary honey feeding of the common black ant, *Lasius niger* (L.), on aphid populations and natural enemies on apple

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**Abstract:** Two replicated experiments were conducted in an unsprayed apple orchard (cv Discovery) at East Malling Research in 2006 to evaluate the effects of the common black ant, *Lasius niger* (L.), on populations of rosy apple aphid, *Dysaphis plantaginea* (Passerini), and green apple aphid, *Aphis pomi* DeGeer. Ants were either excluded from trees by a sticky barrier band round the base of the trunk (experiment 1) or provided with honey baits at the base of the trunk or in the canopy (experiment 2). Trees where ants had free access and trees without artificial baits were provided for experimental controls.

Exclusion of ants resulted in increased populations of predators (Coccinellidae adults and larvae, predatory Heteroptera, Syrphidae larvae, Dermaptera, Neuroptera larvae and Araneae) and rapid decreases in the populations of both aphid species. In comparison, populations of both aphids increased rapidly on control trees where ants had not been excluded and where predator populations were lower. Thus, exclusion of ants greatly reduced crop damage due to both aphid species.

Provision of artificial baits, either at the base or in the canopy of the trees, also caused reductions in *D. plantaginea* numbers and their tending ants, but the effects were weaker. The influence on *A. pomi* and their tending ants was not remarkable, and effects on predators were unclear. On trees where no aphids were present or where aphid numbers were small, ants fed on the artificial baits allowing aphid colonies, where present, to increase in size. On trees with numerous aphids, ants showed a preference for feeding in aphid colonies and visited the artificial baits in smaller numbers having limited impact on aphid populations.

The implications of these results for management of aphid and other pest populations in apple orchards are discussed.

## **The light brown apple moth, *Epiphyas postvittana* (Walker) (Lepidoptera: Tortricidae), in UK pome and stone fruit orchards**

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**Abstract:** The light brown apple moth (LBAM), *Epiphyas postvittana* (Walker), is one the most important pests of tree fruits in Australia and New Zealand. It was unknown in Europe until 1936 when it was found breeding on ornamental spindle at Newquay, Cornwall, England. It established on a wide variety of plants in Devon and Cornwall and spread east but was not known to attack fruit crops.

A pheromone trap survey in 10 commercial apple orchards in Kent, Hereford, Essex, Oxfordshire and Somerset (England) in 1994 revealed no LBAM. However, in 2005, a severe and extensive attack of the pest occurred in a commercial cherry orchard at Yalding, Kent, causing considerable fruit losses. Larvae were reared to adult and identification confirmed. It is suspected that other reported attacks on cherry in 2003 and 2004, believed to be caused by summer fruit tortrix moth, *Adoxophyes orana* Fischer von Rösslerstamm, at the time, may well have been caused by LBAM as the larvae are difficult to distinguish.

Specialist lepidopterists report that the LBAM has spread throughout England where it has become common. In recent years, the pest has become a significant pest problem in hardy ornamental nursery stock throughout England.

In 2006 a pheromone trap survey aimed at determining the flight dynamics and occurrence of *E. postvittana* on commercial fruit trees (apple, pear, plum and cherry) in England was established, so that pesticide applications might be used more effectively. The growers (with 13 x apple, 10 x pear, 13 x plum and 12 x cherry orchards) in the counties of Buckinghamshire, Essex, Gloucestershire, Hereford, Kent, Oxfordshire, Somerset, Suffolk, Surrey and Sussex recorded the number of male moths caught in traps each week from May to the end of September.

In the UK *E. postvittana* has been reported to have two generations. Here we report the occurrence of three generations of the moth in 2006. Traps in a cherry orchard at East Malling Research showed that the peak flights were the end of May, the middle of September, and towards the end of October in this year. The greatest number of moths were found in cherry (compared to apple, pears and plums), probably because cherry crops are seldom sprayed with insecticides post blossom. Adjacent habitats (crops or natural) may also be involved in the incidence of LBAM on fruit crops.

## **Ecology and management of the obliquebanded leafroller, *Choristoneura rosaceana*, in New York apple orchards**

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**Abstract:** During the last 20 years, the obliquebanded leafroller (OBLR), *Choristoneura rosaceana* Harris (Lepidoptera: Tortricidae) has caused more economic damage of apples in New York than any other insect pest. Outbreaks of this pest occur in localized areas and persist in the same locations year after year. OBLR are resistant to organophosphates, carbamates, pyrethroids, and methoxyfenozide. Tests of reduced-risk insecticide programs without organophosphates, synthetic pyrethroids, or carbamates were set up in small plots, 2.5 ha in commercial apple orchards throughout NY. These studies showed that prophylactic sprays of methoxyfenozide at petal fall for overwintering larvae followed by summer sprays of spinosad for the summer generation provided excellent control when these programs were applied in the same plots for 3 consecutive years. During the last year of this 4-year study in 2005, monitoring programs were initiated in all blocks for overwintering and summer generations of larvae to determine if sprays were needed. Levels of overwintering OBLR larvae were very low in all of the monitored plots and no control sprays were recommended at petal fall for control of this generation. However, sampling during the summer showed that levels of infestation of terminals by the subsequent summer generation of larvae exceeded the recommended action threshold of 3% in most of the plots. Studies were also conducted to compare the effects of parasitoids and predators in unsprayed hedgerows, plots treated with the reduced-risk insecticide programs for multiple seasons and growers' orchards treated with standard insecticides, using implanted larvae on various types of mobile media. These studies showed that the total parasitism and predation levels were similar throughout the season in all three locations. The overall results of these studies shown that although OBLR can be effectively managed by reduced-risk insecticides there is no evidence that seasonal programs of these materials enhances opportunities for conservation biological control. Orchards, at least relatively small areas can be re-infested by the summer generation of OBLR and continuous use of insecticides may be necessary to insure adequate control. Future research should be conducted to test area-wide or whole farm management of OBLR, and improvement of current sampling protocols to determine if this pest can be managed in problem blocks without applying prophylactic applications of insecticides.

## Temperature effect on egg-laying timing in *Cydia pomonella* (L.)

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**Abstract:** Temperature is an important factor in the modulation of the timing of insect rhythms, such as calling or egg-laying. We studied egg-laying timing of *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), a key pest of pome fruits world wide, and how temperature affects this behavior. The results on attraction of *C. pomonella* females to host volatiles reached in laboratory bioassays have been usually poor, and our study aimed to determine better conditions to carry out these experiments.

Semi-field as well as laboratory experiments were conducted. Semi-field assays were made in summer 2005 in Sweden and in Spain. In these assays, couples of *C. pomonella* adults were individually placed on glass tubes on an apple orchard. Mating activity and number of eggs laid were checked at different times of evening and night. In the laboratory, groups of 9 to 12 females and 10 to 15 males were placed in mating boxes, and kept at different constant temperatures, from 12 to 32°C. The number of eggs laid was counted every hour during late-photophase and early-scotophase.

In semi-field assays, egg-laying began when temperature fell below 25°C and continued until temperature was below 21°C. In the laboratory, a delay on egg-laying onset and peak was observed as temperature increased. At the highest temperatures (27 and 32°C) a small percentage of the total number of eggs was laid before light off, and the number of eggs laid peaked during the first hour of the scotophase. On the other hand at mild temperatures (17 and 22°C), egg-laying activity was more constant through the studied period, and for some groups it peaked several hours before light off. At 12°C no egg-laying occurred.

## **Biological interactions between the apple leaf curling midge, *Dasineura mali* (Kieffer), and its inquiline, *Macrolabis mali* Anfora**

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**Abstract:** The apple leaf curling midge, *Dasineura mali* (Kieffer) (Diptera Cecidomyiidae), damages apple trees by leaf galling. Recently, a new species, *Macrolabis mali* Anfora (Diptera: Cecidomyiidae), was described and hypothesized to be an inquiline of *D. mali*. We studied the biology of *M. mali* and its interaction with *D. mali* by a laboratory bioassay and field observations. This work confirmed that *M. mali* females lay eggs in young galls caused by their host insect and the larvae dwell as inquilines. The inquiline population increases during the summer; at the end of the season it becomes larger than that of the host insect and may cause the withering of larvae of the host insect. Therefore the presence of *M. mali* could contribute to regulation of the population of the apple leaf curling midge.

## Effect of different pest control strategies on phytophagous and predatory mites in apple orchards of Girona (NE of Spain)

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**Abstract:** The European red mite *Panonychus ulmi* (Koch) (Acari: Tetranychidae) is a pest of apple orchards in Girona (NE Spain). Control strategies consist on acaricide sprayings or biological control by the effective conservation of the predatory mite *Amblyseius andersoni* (Chant) (Acari: Phytoseiidae). In this survey, three apple pest management methodologies were compared for their impact on tetranychid and phytoseiid mite populations. Species diversity and differences among orchards were evaluated under: i) Integrated Fruit Production methodology as is normally used in the area (IFP conventional), ii) IFP in which alternative to chemical pest control methods were used (less summer insecticide sprayings) (IFP APRI), and iii) organic fruit production system (OFP).

The IFP conventional system only used chemicals for pests control; the IFP APRI did not spray any insecticide since post-bloom till harvest, because of the use since 2001 to 2005, of mating disruption for codling moth *Cydia pomonella* L. (Lepidoptera: Tortricidae) and leopard moth *Zeuzera pyrina* L. (Lepidoptera: Cossidae), and mass trapping for Mediterranean fruit fly *Ceratitis capitata* Wied. (Diptera: Tephritidae). The OFP system had been managed according to the 2092/91 CEE rules.

Results from the two year survey (2004-2005) reflect differences in alpha diversity among apple orchards and OFP system showed the highest level. The IFP APRI management throughout five years was not enough to increase significantly tetranychid and phytoseiid diversity in relation to IFP conventional. Species of tetranychids as a potential food for *A. andersoni* were found. Functional diversity (*A. andersoni* / *P. ulmi* relationship) in all of the orchards was kept. With regard to the results, the future objectives of the IFP APRI system are pointed and interest in increasing it throughout the Girona fruit area are discussed.

## Effect of flat anti-hail nets on *Cydia pomonella* (L.) reproductive behaviour

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**Abstract:** In this study we investigated the effect of the flat anti-hail nets on the behavior of the codling moth *Cydia pomonella* (L.). We hypothesized that the net interferes with male flight behavior and acts as an enclosure, reducing pheromone losses to the sky in orchards treated with pheromone. To test these hypotheses, experiments were carried out in net-covered and uncovered apple plantations treated with mating disruption or with conventional insecticides. In a re-trapping experiment, the number of males recaptured in the net-covered orchards was significantly lower than in the uncovered plantations. Damage caused by codling moth larvae was found less severe in the net-equipped plantations. In addition, inhibition of mating under the net was demonstrated by exposing tethered virgin females. A portable electroantennograph device was employed to measure the concentrations of pheromone in the atmosphere of mating disrupted orchards. However, the same male antennal response was measured in both uncovered and net-covered plots as well as in a control orchard without mating disruption. Because of the reductions in male trap catch and in larval damage as well as the reduced female mating frequency, we conclude that the flat anti-hail net has a disruptive effect on the reproductive behavior of the codling moth.

## Competitive attraction as a primary mechanism of moth mating disruption in tree fruit crops

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**Abstract:** Over the past few years we have been exploring ways of achieving "high-performance" moth mating disruption. The foundation for this work has been a series of studies examining the mechanisms underlying pheromone-based mating disruption in tortricid moth pests of fruit. Collectively, our results support competitive attraction as an important, if not essential, component of communicational disruption of tortricid moths. Four main lines of evidence support this conclusion. Males are attracted to high-dosage dispensers in the field. Disruption efficacy is pest density-dependent. Effective mating disruption using high-dosage dispensers occurs in the field despite overall atmospheric concentrations not reaching levels high enough to desensitize moths by adaptation or habituation. Finally, the theoretical properties of competitive-attraction phenomena have proved consistent with the majority of disruption profiles obtained in the field. Key traits of competitive attraction are: concave profiles on untransformed axes, with an asymptotic approach to zero catch; a straight line with positive slope when  $1/\text{catch}$  is plotted against dispenser density; and a straight line with negative slope when catch is plotted against dispenser density  $\times$  catch. Key traits of non-competitive disruption profiles include: an initial linear disruption profile on untransformed axes; a concave inverse plot; and a re-curving complex plot. Of 13 published disruption profiles with sufficient data for analysis, 11 were a better fit to the predictions of competitive attraction than a non-competitive disruption mechanism. If competitive attraction plays a major role in achieving mating disruption, the following practical implications should guide us in developing high-performance approaches and formulations: 1) attractiveness should be competitive with females, 2) dispenser density should be high, and 3) distribution should be uniform rather than clumped.

## **New insights into codling moth, *Cydia pomonella* (L.), distribution and implications for mating disruption**

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**Abstract:** A study aimed at determining the location of searching codling moth (*Cydia pomonella* [L.]) (Lepidoptera, Tortricidae) males and calling females in mating disrupted and non-disrupted plots was conducted in Michigan, USA. A leaf blower, converted into a vacuum for sampling codling moth adults on branches and in the tree canopy, had a 20-24% success in recovering released moths in orchard conditions. A series of four collections were made during the hours of 09:00-18:00 from May 25 through June 15 and a second series of four collections were completed during the hours of 18:00-22:00 from July 20 to August 22. Only eight codling moth adults were collected during the four daylight samples; one female and two male moths were sampled from the top third of the tree canopy, four males were sampled from the middle third of the tree canopy, and one male was sampled from the lower third of the tree canopy. Distributions of adults were also assessed during daytime hours (09:00-18:00) by fogging trees with various pyrethroid insecticides. No codling moth adults were collected in any of these samples. In contrast to the paucity of moths collected in the daytime samples, 94 moths were collected during four twilight samples, with equal numbers sampled in disrupted and non-disrupted plots. In mating disruption plots, 42% of females were found in the top third of the tree canopy, 46% were found in the middle third, and 12% were recovered in the lower third. The 22 females sampled from non-disrupted plots were more evenly distributed, with 36.4% in the top third, 36.4% in the middle third, and 27.2% in the lower third of the tree canopy. Releases of marked moths were conducted in 2006 in screened tents to identify the daytime (09:00-18:00) habitats for adult moths within the orchard. Of males released, 11.2% were recovered from the tree canopy and 6.2% were recovered from the ground (drive row grass and vegetation under the tree). Of females released, 18.6 % were recovered from the tree and 8.2% from the ground.

## **Mating disruption of codling moth, *Cydia pomonella* (L.), using Puffer® CM, on apple orchards**

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**Abstract:** The performance of Puffer® CM, aerosol formulation of the codling moth pheromone that is uniformly applied by mechanical means at pre-programmed and periodical intervals irrespective of weather conditions, was investigated in 2005 in European trials. Trap catches and fruit damage were compared in ca. 10 ha plots with different mating disruption products, dispenser [CheckMate CM, applied twice at 300 dispensers/ha, or Isomate CTT, applied once at 500 dispensers/ha] vs. Puffer® CM (applied once at 2 puffers/ha), during the 2005 season in two trials conducted in Northern Spain: Monzón (Huesca) and Ager (Lleida). Puffer® CM performed extremely well, at least comparable to mating disruption with dispensers (either CheckMate CM or Isomate CTT), leading to an almost complete codling moth catch inhibition and to extremely low fruit damage situation. Moreover, Puffer® CM pheromone release was constant through the season not being affected by weather conditions and persistence of Puffer® CM (average 185 days) was longer than both reference dispensers.

## Field assays of new biodegradable controlled-release pheromone dispensers for mating disruption of *Cydia pomonella* (L.)

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**Abstract:** A new type of eco-friendly pheromone dispenser for mating disruption of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), based on sepiolite, has been developed. In order to evaluate its efficacy under field conditions, mating disruption trials were conducted during 2005 and 2006 in a 9.84 - ha orchard (Plot A) in Lleida, Spain. Pheromone dispensers were set up shortly before the beginning of the first flight of the pest in plots where apples and pears were cultivated. Each year, a reference orchard next to the trial (Plot C in 2005: 1.24 ha and Plot D in 2006: 1.29 ha) where insecticides were only applied when justified by the level of the pest, was considered as chemical standard. Results were compared with those obtained in a close 4.11 ha field (Plot B) with Isomate C-Plus dispensers (Shin-Etsu, Japan). The efficacy of the mating disruption technique was periodically evaluated with assessments of fruit damage and adult catches in monitoring traps, both in the mating disruption areas and in the reference plots. In addition, a comparative study of pheromone release patterns from new dispensers and a reference one (Isomate C-Plus), under field conditions, was conducted.

The new dispensers were, at least, as highly efficient as Isomate C-Plus. In plots A and B, adult catches were highly inhibited respect to those recorded in the reference plot. Moreover, damage levels were below the treatment thresholds, so less supplemental chemical application were required. In addition, new dispensers showed more adequate first-order kinetics than Isomate C-Plus, under field conditions. Thus, new dispensers could be an eco-friendly alternative for the control of *C. pomonella*, as they show good release patterns and they are biodegradable.

## **Towards high performance mating disruption of codling moth, *Cydia pomonella* (L.)**

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**Abstract:** Recently, we have explored novel approaches of achieving “high-performance” mating disruption, defined as exceeding 98 % efficacy even under high population densities and without the need for companion insecticides. This work has been grounded in earlier investigations of disruption mechanisms, which suggested that competitive attraction between calling females and synthetic pheromone sources is an important component of effective and economical disruption. For Oriental fruit moth (OFM), *Grapholita molesta* (Busck), we have developed a mechanized applicator for high-speed deployment of pheromone dispensers made of paraffin or microcrystalline wax to tree fruit. One ha of crop can be treated in ca. 20 min. By modifying our applicator to dispense larger 0.3 g wax drops at an intended rate of 20 / tree and increasing the pheromone concentration to 10 % (by weight) in an improved wax formulation manufactured by ISCA Technologies, we achieved high-performance disruption of OFM for more than 100 days with a single application of wax in early spring. For codling moth (CM), *Cydia pomonella* (L.), we are investigating experimental “Cidetrack” dispensers manufactured by Trécé Co. intended to better protect the active ingredient, codlemone, and to co-release both codlemone and the pear ester (ethyl (*E,Z*)-2,4-decadienoate). In 2005, Trécé Cidetrack dispensers loaded with codlemone (40%) and pear ester (60 %) disrupted CM better than standard Isomate-C Plus dispensers. In 2006, disruption of male CM with Trécé Cidetrack dispensers loaded with pear ester and codlemone (60:40 ratio) was not superior to Cidetrack dispensers loaded with 100 % codlemone; however, Cidetrack treatments loaded with codlemone were superior or equivalent to Isomate treatments. Deploying high densities (3,600 - 18,500 pieces / ha) of Cidetrack CM pieces containing ca. 1/7<sup>th</sup> of the standard codlemone loading each resulted in 92–99 % disruption of male CM. These results suggest that this new dispenser technology may enhance disruption of CM by better protecting codlemone from degradation, compared with Isomate dispensers, rather than because of an additive effect of the plant kairomone. Furthermore, high densities of Trécé Cidetrack pieces that are 1/7<sup>th</sup> the size of a standard dispenser provided “high performance” disruption, and thus superior efficacy compared to that achieved using a standard application of dispensers 1000 / ha.

## **Pheromone mating disruption of *Cydia pomonella* (L.) in California pears: Balancing dispenser emission rates and program performance**

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**Abstract:** Alternative pheromone mating disruption programs were explored that mixed multiple types of emitting devices either to improve program performance for high densities of codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) or to optimize application costs with program performance. Combination programs using either high dose aerosol emitters (Suttera Corp) at low numbers per ha (ca. 1 emitter per 2 ha) or sprayable formulations of codlemone were used to supplement treatments using traditional hand-applied dispensers. No additional efficacy was observed with the inclusion of sprayable formulations of codlemone. Stability of sprayable formulations was significantly influenced by position in canopy and canopy structure with fully light exposed microcapsules no longer emitting detectable codlemone within several days of application using EAG or extraction protocols. The addition of high dose emitters at low numbers of dispensers per ha increased control in all plots with significant codling moth pressure. The combination program increased program performance with relatively low increase in program cost. Use of experimental emitters that released at intermediate levels (e.g. 20-30 mg per day) were deployed at ca. 38 dispensers per ha. A modified membrane dispenser and a new wax matrix dispenser were evaluated in 2006 within orchards with high and low populations of codling moth. Low pressure orchards were untreated with insecticides for the season, whereas high pressure programs received insecticidal supplements given the preliminary nature of the trial. Seasonal suppression of traps >90% were achieved at all levels of codling moth pressure and no significant damage has been observed to date.

# Olfactory sensitivity of different populations of *Cydia pomonella* (L.) to sex pheromone *E8E10-12:OH* and kairomone ethyl (*2E, 4Z*)-2,4-decadienoate

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**Abstract:** Codling moth (CM), *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), has a close ecological association with its main host plants: apple, pear, and walnut. Ethyl (*2E, 4Z*)-2,4-decadienoate (Et-*2E,4Z*-DD), a kairomonal compound derived from ripening pears, has been found to be highly attractive to the CM larvae and both male and female (virgin and mated) adults in walnut and apple orchards. The main component of CM sex pheromone (*E,E*)-8,10-dodecadien-1-ol (*E8E10-12:OH*) (Codlemone) is widely used in monitoring systems and direct control methods.

The knowledge of the olfactory sensitivity to both compounds of the different populations coming from different host-plants may have a practical impact in the choice of the more appropriate quantities of attractants to be used in the diverse ecological contexts.

In the present study electrophysiological responses (electroantennography, EAG) *E8E10-12:OH* and Et-*2E,4Z*-DD of several CM populations coming from different host plants (apple, pear, walnut) were recorded. The dose-response curves to the volatile compounds were calculated and differences in olfactory sensitivity of virgin and mated males and females of the different populations are discussed.

Between physiological status (virgin and mated) of both sexes and among populations from different host-plants no significant differences were observed. As it was expected, females were highly less sensitive to codlemone than males, and males showed higher responses to the kairomone, too, thus confirming the results of our previous studies. It was also observed that adults of the walnut populations show a higher sensitivity (not significantly different) to both compounds. Instead, significant differences were sometimes recorded in populations coming from the same host plant.

Setting up the more effective dosage of attractants to be used in CM monitoring systems or control methods, the variability in olfactory sensitivity of different populations living on the same plant may be at least as important as the variability showed by populations living on different hosts.

## Use of ethyl (*E, Z*)-2,4-decadienoate for the control of *Cydia pomonella* (L.) on apple orchards

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**Abstract:** The ethyl (*E,Z*)-2,4-decadienoate (pear ester) is an adult and larval kairomonal attractant for *Cydia pomonella* (L.) (Lepidoptera: Tortricidae). The possibility of using a microencapsulated formulation of pear ester (Da-Mec, a.i. 5%, Trécé inc.) to interfere with the host location behaviour has been evaluated. Field efficacy trials were carried out on apple orchards with a sprayable formulation to verify the potentiality of the kairomone for direct pest control. The tests performed revealed a significant effect of the Da-Mec formulation in reducing the fruit injury compared to an unsprayed control. These preliminary results support the use of the pear ester in direct control of codling moth for improving the efficacy of larval contact insecticides.

## Experimental use of the micro-encapsulated pear ester kairomone for control of codling moth, *Cydia pomonella* (L.), in walnuts

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**Abstract:** The larval attractant kairomone, ethyl (*2E, 4Z*)-2,4-decadienoate or pear ester (PE), was tested in a Californian walnut orchard for its control efficacy against codling moth larvae, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) in a microencapsulated bait spray formulation (PE-MEC) combined with various insecticides (chlorpyrifos, phosmet, methoxyfenozide and a granulosis virus, Cyd-X). PE-MEC was tank-mixed as an adjuvant with reduced rates of insecticides and applied by a handgun-sprayer to replicate walnut trees in an 8 ha orchard. Results were significant, with PE-MEC adjuvant + insecticide treatments reducing CM harvest damage by 77% (chlorpyrifos), 85% (phosmet), 54% (methoxyfenozide) and 47% (Cyd-X) below the damage incurred with insecticides alone. Also with the secondary pest, the navel orangeworm, *Amyelois transitella* (Lepidoptera: Pyralidae), the PE-MEC adjuvant significantly reduced damage levels when combined with the two OP insecticides. The PE kairomone shows promise for improving insecticide efficacy and contributing to both resistance management and new IPM tactics for *C. pomonella* and the accompanying *A. transitella*.

## Behavioural responses of *Cydia pomonella* (L.) neonate larvae to a microencapsulated formulation of ethyl (2E, 4Z)-2,4-decadienoate

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**Abstract:** Codling moth, *Cydia pomonella* (L.) (Lepidoptera Tortricidae) is known as a key pest of apples, pears and walnuts worldwide. Ethyl (2E, 4Z)-2,4-decadienoate (Et-2E, 4Z-DD) has been found to be an effective attractant for both male and female of this pest, as well as for its larvae. The use of this attractant for direct control methods which target both male and female moths or larvae is important for Codling moth management.

Field studies, carried out using a microencapsulated formulation of Et-2E, 4Z-DD (5% A.I. DA MEC, Trécé Inc.), showed results not always coherent to exclude a biological role played on Codling moth neonate larvae by the coformulants in the microencapsulated formulation. Therefore, the aim of this study was to evaluate the biological activity of this formulation compared to the active ingredient alone and the coformulants present in the commercial product on the behaviour of codling moth larvae.

We show preliminary olfactory responses of *C. pomonella* neonate larvae to different doses (distilled water soluted) of the complete microencapsulated formulation (5% A.I. DA MEC, Trécé Inc.), its pure active compound (DA 2313 Neat, Trécé Inc.) and the coformulants (Blank MEC, Trécé Inc.) in separate behavioural bioassays (Petri dish multi-choice arena). As control stimulus only distilled water was tested.

Preliminary results showed that at lower doses of each tested compound, neonate larvae did not show any preference in comparison with control. As expected, only responses to the microencapsulated formulation and to the active ingredient were dose-related. In response to the pure complete microencapsulated formulation, codling moth larvae showed the stronger preference (64%) toward the tested compounds. Whereas the pure coformulant was tested, neonate larvae showed a similar response to the control.

So far, codling moth larvae behavioural responses lead on considering that the tested coformulants don't have a biological role on neonate larvae, if considered separated from the active compound.

## **Effect of Madex® (codling moth granulovirus) on *Cydia pomonella* (L.) egg laying on two apple varieties: Relationships with plant surface metabolites**

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**Abstract:** Variations of Madex® (codling moth granulovirus) treatment efficiencies against *Cydia pomonella* larvae were observed in San Michele orchard according to apple tree varieties. Our hypothesis was that it could be linked to a different population pressure due to an insect egg laying preference among varieties. We verified in two years the differential efficacy of Madex® on larval damage on Golden Delicious vs. Red Chief and observed an egg laying preference for Golden Delicious. But surprisingly we observed also i) a reduction of the numbers of eggs after Madex® treatment ii) and that the reduction was greater on Golden Delicious than on Red Chief. Water-soluble carbohydrates and sugar-alcohols have been already identified from surfaces of apple tree organs as signals for *C. pomonella* egg laying. The blend of glucose, fructose, sucrose, sorbitol, quebrachitol and *myo*-inositol particularly stimulates insect egg laying. The Madex® treatment modified the blend (quantities and ratios) differently according to the apple variety. Here we verified on artificial substrates impregnated with blends found on the corymb leaves of each variety, that Madex® modified blends reduce the number of eggs. The reduction could be explained on Red Chief by a more drastic effect on egg-laying stimulation than on Golden Delicious on which the reduction was partly due to less acceptance of the substrate by females for egg laying and fewer eggs laid per female.

## Effect of a potential biocontrol agent of apple diseases on the egg laying of *Cydia pomonella* (L.)

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**Abstract:** With the development of pest resistance towards pesticides and the decrease of chemical input, the research on alternative methods for plant protection, such as the use of microorganisms as biocontrol agents (BCA), is developing fast. But the side effects of BCA on non-targeted organisms and on the host plant are poorly known. Mass introduction of an organism into a system can change it substantially. Similarly, the introduction of an epiphytic microorganism may change the phylloplane chemical composition. Furthermore, sugar quantities and ratios in the phylloplane can influence the egg laying behaviour of *Cydia pomonella* (L.) (Lepidoptera Tortricidae). In this work, we studied the effect on the egg quantity laid by *C. pomonella* of an epiphytic yeast, as BC-model organism, introduced to apple canopy surfaces.

Two seasons of trial, during the second flight of *C. pomonella*, showed an effect of the yeast spray on the quantity of eggs laid on apple trees. In the preliminary greenhouse experiment, the number of eggs laid on the yeast treated trees was lower as compared with those laid on the untreated trees. But for the second year of experiment, performed in semi-artificial conditions, the yeast treatment increased significantly the quantity of eggs laid, especially on the sites close to the fruits. These conflicting results could be explained by the different environmental and experimental conditions, which may affect the yeast activity and as consequences the phylloplane chemical composition. We analysed the chemical composition of leaf water washings using gas chromatography. On the first year of analysis, we observed modifications of quantities and ratios within the sugar blend on the upper side surfaces compared to untreated ones. We are currently analysing the samples from the second season using liquid chromatography. Finally, the correlation between yeast treatment, sugar quantities and qualities and egg laying behaviour will be analysed.

## **Field assessment of behaviorally-based management tactics for *Conotrachelus nenuphar* (Herbst), and *Rhagoletis pomonella* (Walsh) in the northeastern US**

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**Abstract:** Field trials were conducted for 2 years to validate and demonstrate the effectiveness of advanced-level IPM tactics. For plum curculio (PC), *Conotrachelus nenuphar* (Herbst) (Coleoptera: Curculionidae), trap trees using benzaldehyde and grandisoic acid lures determined need and timing of insecticides compared with calendar-driven sprays or heat-unit models. For apple maggot (AM), *Rhagoletis pomonella* (Walsh) (Diptera: Tephritidae), odor-baited pesticide-treated spheres (PTS) were deployed for direct control of AM compared with calendar-driven sprays or monitoring trap capture-driven sprays. Trials were conducted in 24 commercial orchards in New York and 6 New England states: Connecticut, Massachusetts, Maine, New Hampshire, Rhode Island and Vermont. These "Advanced IPM" approaches proved effective in the majority of the sites over 2 years. In those few cases where fruit injury was above 1–2%, the cause could be attributed to a missed insecticide spray, the occurrence of intense pest pressure from within the orchard block, or to a planting arrangement consisting of very small apple trees. In both years there was a significant reduction in pesticide use in the "Advanced IPM" treatment.

## **Four years of Mediterranean fruit fly (*Ceratitis capitata* Wied.) control in fruit orchards of Girona (NE of Spain) by using the mass trapping method**

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**Abstract:** Mediterranean fruit fly (MFF) (*Ceratitis capitata* Wiedemann) (Diptera: Tephritidae) is a polyphagous pest that can be potentially very harmful in fruit orchards, particularly in temperate and hot growing areas. Common control strategies to avoid fruit damage are based on chemical insecticide sprayings just before harvest.

In 2001 there was serious fruit damage in the growing areas of Girona (NE of Spain), especially in mid and late season stone fruit cultivars. The production losses encouraged the use of the mass trapping control method, as an alternative to chemicals, in the context of Integrated Fruit Production methodology to which most of the fruit growers fit. From 2002 to 2005 several mass trapping trials were carried out on apple and stone fruit orchards with different attractants, number of fly-traps per hectare (from 50 to 75) and layout trap systems (homogeneous *versus* perimeter) in the field.

In the last four years, pressure of the MFF fluctuated between middle and low level in the Girona fruit area; in these conditions, the amount of 50 to 75 fly-traps per hectare with any of the used attractants and methods of the traps layout in the orchards, reached satisfactory control of this pest. The higher damage level estimated was 1.3 % in only one peach fruit orchard. The conditions of these trials and their results will be discussed.

## Exploiting the sex pheromone of the apple leaf midge, *Dasineura mali*, for pest monitoring and control

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**Abstract:** Work by East Malling Research (EMR) and Natural Resources Institute (NRI) to identify the female sex pheromone of the apple leaf curling midge, *Dasineura mali* Kieffer, is overviewed. The pheromone was collected by the trapping of volatiles which proved far more effective than gland extraction methods used previously. Even so the single component of *D. mali* was present at only 2 pg per female per hour. This was detected by electroantennography (EAG) linked to gas chromatographic (GC) analysis, and identified as (*Z*)-13-acetoxy-8-heptadecen-2-one by interpretation of the mass spectra and comparison with synthetic standards. A rubber septum impregnated with 1 µg of the synthetic, racemic pheromone proved highly attractive to male *D. mali*, and release rate measurements indicate this lure will remain active for several years in the field. Only the *S* enantiomer of the chiral component is produced by the insect and field experiments showed that only this enantiomer is attractive and that the *R* enantiomer has no activity. The *D. mali* sex pheromone is a keto-ester, a variation on a new class of midge pheromone structures that is currently the subject of a patent application. Other midge pheromones previously identified are mono or diesters.

The *D. mali* pheromone has proved very useful for monitoring pest populations in the field. Results from preliminary trials in the UK in 2004 are reported. White delta traps (20 x 20 cm), with rubber septum dispensers containing 3µg of the pheromone racemate and deployed at a height of 0.5 m are recommended as a standard. They were made available to growers in the UK for Beta testing in 2006 as part of a coordinated programme of experiments to establish treatment thresholds. An experiment in 2006 showed that the traps can be used to time sprays of synthetic pyrethroids for control of the pest but that multiple applications were required to give a high degree of control. Large scale field experiments started in the UK in 2004 to test the use of the pheromone for control by mating disruption and attract and kill approaches. Early season results were promising but control failed later in the season because the pheromone was degraded by UV light more rapidly than expected. Results so far have indicated the need to deploy the treatments on a large scale and in newly planted orchards where populations are initially low and to protect the pheromone from degradation by UV light.

## Investigations on the sex pheromone of pear leaf midge, *Dasineura pyri* (Bouché), and other gall midge pests of fruit crops

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**Abstract:** The pear leaf midge, *Dasineura pyri* (Bouché), is a pest of pear orchards, with nursery stocks and new shoots on young and fruiting trees being particularly vulnerable. Although a sex pheromone has not been demonstrated in this species, females of related midge species produce a sex pheromone to attract males for mating. Late larvae of *D. pyri* were collected from pear orchards and reared to adulthood individually. After sexing, volatiles were collected from both males and females by air entrainment. Collections were analysed by gas chromatography (GC) coupled to electroantennographic (EAG) recording from a male antenna, and by GC coupled to mass spectrometry (MS). Male midges responded to two components in the female volatile collections. The mass spectrum of the major compound indicated it was a 17-carbon diacetate with one double bond, and both mass spectrum and GC retention times were found to be identical with those of (*Z*)-2, 13-diacetoxy-8-heptadecene prepared previously. However, no male midges were caught in traps baited with the synthetic compound in pear orchards. Further work is required to confirm this identification, to determine which of the four possible isomers is produced by the female and to identify the minor component.

## The effect of aphid sex pheromone and plant volatiles on the behaviour of *Dysaphis plantaginea* and its parasitoid *Aphidius matricariae*

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**Abstract:** The objective of this research was to determine the practicability of exploiting the responses of aphids and their natural enemies to aphid sex pheromone and to plant volatiles in order to enhance biocontrol of the pest.

In experiments to determine the composition of the *Dysaphis plantaginea* Passerini (Homoptera: Aphididae) sex pheromone, coupled GC-EAG analysis of air entrainment samples from *D. plantaginea* oviparae using male antennae located four physiologically active components. The two major components were shown to be (1*R*,4*aS*,7*S*,7*aR*)-nepetalactol and (4*aS*,7*S*,7*aR*)-nepetalactone. A third EAG-active component was identified that elicited a strong behavioural response by male *D. plantaginea*. This demonstrates that the sex pheromone of *D. plantaginea* comprises at least a three component mixture.

Many plants respond to herbivore feeding by modifying their secondary metabolism to produce semiochemicals that act to reduce herbivore colonisation and increase attraction of beneficials, particularly highly mobile parasitoids. In our experiments, production of a number of compounds, from both the primary and secondary host plants, was shown to be increased in response to *D. plantaginea* infestation. Results from laboratory behavioural studies and from field experiments will be used to outline the effects of several of these compounds on pest and parasitoid behaviour.

# Different host plant odours influence migration behaviour of *Cacopsylla melanoneura* (Förster), an insect vector of the apple proliferation phytoplasma

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**Abstract:** In recent years the hawthorn psyllid *Cacopsylla melanoneura* (Förster) has been identified as one of the insect vectors of the apple proliferation phytoplasma which causes major damages in apple cultivation. *C. melanoneura* is univoltine, spending only a short time of its life cycle on apple or hawthorn – during copulation, egg laying and nymphal development. The adults of the new generation migrate soon after emergence to coniferous trees and spend the largest part of their life there. After overwintering, the adults return to apple or hawthorn for reproduction, in early spring. In order to elucidate the migration behaviour and ecology of *C. melanoneura*, different populations were investigated in field, over a two year period. A detailed description of their life cycle, supplemented by timing and duration of their two migration phases and the involved host plants are presented. Further, hawthorn psyllids of different ages (newly hatched adults and overwintered adults) were investigated in a dynamic Y-olfactometer setup for their preferences towards the odours of different host plants. The behavioural response of the two tested ages of the psyllids corresponds with the two different phases of migratory behaviour in the field. While there was a strong positive response for apple or hawthorn odours in overwintered adults, there was none in freshly emerged adults of the next generation. In contrast, the newly emerged adults showed a strong response for spruce volatiles.

## Reliability of resistance monitoring on diapausing larvae of codling moth, *Cydia pomonella* (L.)

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**Abstract:** Resistance monitoring in *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) has been mainly performed on non-target instars, and currently topical application on diapausing larvae is a widely used method. However, high differences in resistance ratios according to the developmental stage have already been documented and laboratory results are not ever consistent with observed field situations. Relating the expression of resistance mechanisms with resistance of a given instar to various insecticides could simplify the monitoring procedure.

We used topical application on diapausing larvae to evaluate the susceptibility to ten insecticides of four laboratory strains and 47 field populations, on which resistance mechanisms were also analyzed. All populations seemed to be less susceptible than the susceptible laboratory strain for at least one insecticide. The resistance to five of the studied insecticides was significantly correlated with the activity of enzymatic detoxication systems, mainly mixed function oxidases and Glutathion S-transferase, while target site mutations were not related to any reduction of susceptibility.

For few populations, assays on first instar larvae and field trials were also performed. Results were not always consistent with those of topical applications. For some compounds, monitoring test using diapausing larvae tends to overestimate the magnitude of resistance. Otherwise, the spectrum of insecticide resistance cannot ever be explained by known resistance mechanisms. Bioassays therefore remain a necessary tool for resistance monitoring and topical application on diapausing larvae allows a rapid and large-scale evaluation. However when a resistance is pointed out by such bioassay, it still has to be confirmed with a more reliable method involving the target instar of the insecticide.

## **A new bioassay to test insecticide resistance of *Cydia pomonella* (L.) first instar larvae: results from some field populations of Lleida (Spain)**

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**Abstract:** The insecticide resistance of first instar codling moth, *Cydia pomonella* (L.), larvae from wild female x wild male crosses has been tested using a new test. Neonate larvae were placed on pieces of semisynthetic diet treated topically with the insecticide solution evenly distributed on its surface using a humidified brush. Sixteen newly hatched codling moth larvae were deposited on each piece of diet and individually confined in a gelatine capsule. The mortality was recorded 24 hours and 5 days after the application. The repeatability of the bioassay was good, as the heterogeneity indexes obtained were low. The LC<sub>50</sub> of a susceptible population from Lleida (Spain) to the insecticides azinphos-methyl, phosmet and lambda-cyhalothrin were 200 mg/L, 420 mg/L and 0.35 mg/L, respectively. These values were used to assess the resistance of two field populations collected in the apple and pear growing area of Lleida. The populations were collected as larvae in damaged fruits during 2006, in orchards where chemical control had failed. The observed resistance ratios ranged from 1 to more than 38.

## **Susceptibility of codling moth, *Cydia pomonella* (L.) to tebufenozide in Trentino apple growing area**

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**Abstract:** The early detection of insecticide-resistant populations is of paramount importance for the correct and effective implementation of integrated resistance management programs. The present study aims to compare three different methods to detect the loss of insecticide susceptibility in field populations of codling moth to tebufenozide: results of the topical applications of a discriminating dose on overwintering larvae are compared with the enzymatic analysis of the adults as well as with the results of the bioassays performed on the neonates larvae. The study was carried out on four populations collected in orchards with different pesticide pressure. The two populations collected in the apple growing areas where the pesticide pressure was higher showed a significant reduction in the mortality when the overwintering larvae were treated topically. The loss of susceptibility was confirmed when the neonate larvae of the same populations were fed with apples treated with a discriminating dose of tebufenozide. According to the results of the enzymatic analyses performed on the emerged adults, the Mixed-Function Oxidase enzymatic system was involved in determining the loss of susceptibility. Approximately a third of the individuals of these both populations were resistant compared with the susceptible population. No differences were found between the reference strain and the two other populations that were collected in the apple growing areas where the pesticide pressure was lower.

The relationship between the results obtained with the time-consuming apple dipping method and with the more simple topical treatments of overwintering larvae validates the second one as standard method for detecting and defining resistance to tebufenozide in codling moth.

## **Evolution of codling moth, *Cydia pomonella* (L.), resistance in Swiss orchards, tested by topical application of insecticides**

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**Abstract:** Since 1996, resistant strains of codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) have appeared in insecticides treated orchards in Switzerland. From then, observations of more or less resistant populations have been recorded, on an increasing surface. Since the first resistant moth appears in an orchard, further treatments with insecticides (mainly IGRs) keep on killing sensitive moths when the population of resistant codling moth increases in time, sometimes reaching high levels of insensitivity to classical treatments.

A good pest control management combining mating disruption and CpGv (granulosis virus) can efficiently reduce population size within a few years.

Resistance levels of *C. pomonella* diapausing larvae have been evaluated for several years using topical application of different insecticides. Larvae collected in autumn in sensitive and resistant populations from several orchards are treated with one  $\mu$ l drop of insecticide at a discriminating dose, and laid on the back of the larvae. Larvae are then allowed to hide in corrugated cardboards and reared into climatic chambers until adult emergence. Survival rate is calculated compared to control.

This method allowed a survey of orchards populations over several years, often from quite resistant stages until after some years of mating disruption. At that time, population sizes often reach extremely low levels, making difficult the collecting of diapausing larvae for tests.

However, topical application tests made possible the observation of changes in sensitivity since the release of insecticide selection pressure on populations. Indeed, obvious recuperation was visible within a 5-years period of mating disruption technique.

## **Resistance to insecticides and baseline sensitivity in codling moth populations from Pennsylvania, USA orchards**

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**Abstract:** The codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), after years of relatively low importance recently become one of the most significant internally feeding apple pests in the mid-Atlantic region of United States. Codling moth male moths collected from commercial and abandoned fruit orchards in Pennsylvania, USA were tested for their sensitivity levels to azinphos-methyl and methomyl using adult topical bioassays. Larval sensitivity to older and newly introduced insecticides (i.e., acetamiprid, novaluron and rynaxypyr) was also assessed using diet surface topical bioassays. Adult codling moth populations expressed differences up to 13 fold in their sensitivity to azinphos-methyl and up to 5 fold towards methomyl. During codling moth larval bioassays we observed differences in larval sensitivity to various compounds as well as differences between compounds based on the timing of mortality readings.

## Baseline toxicity of new insecticides for *Grapholita molesta* management

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**Abstract:** In the mid-late 1990's, the oriental fruit moth, *Grapholita molesta* (Busck) (Lepidoptera: Tortricidae), became a serious pest of apples grown in the eastern U.S.A. Several factors were associated with these outbreaks, but insecticide resistance was the major reason for *G. molesta* control failures that resulted in infested apples at harvest. Resistance monitoring programs revealed that *G. molesta* populations had developed resistance to organophosphorous (OP), carbamate, and pyrethroid insecticides. In anticipation of new insecticides being used against this pest, laboratory bioassays were conducted to generate baseline susceptibility data for future resistance management efforts. Using a surface-treated lima bean diet assay, we determined base-line concentration-response parameters for acetamiprid, azinphosmethyl, esfenvalerate, indoxacarb, methoxyfenozide, novaluron, pyriproxyfen, spinosad, and thiacloprid for *G. molesta* neonates.

## Evaluation of pear psylla, *Cacopsylla pyri* (L.), susceptibility to cypermethrin in pear orchards of Lleida, Spain

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**Abstract:** *Cacopsylla pyri* (L.) (Hemiptera: Psyllidae) is a key pest of pear orchards in the fruit growing area of Lleida (NE Spain). Chemical control is the most common method used against pear psylla, but the number of insecticides registered to control it has been reduced in the last years.

The high selection pressure with these few insecticides applied repeatedly over the whole area can result in the appearance of resistance, as it has happened in France. With the aim of monitoring changes in the susceptibility of *C. pyri* to cypermethrin, we used topical application bioassays with adults. The bioassays were carried out for four years (2003-2004-2005-2006).

We collected populations from different areas of Lleida, where heavy use of insecticides is the common practice and we monitored the variation in time of the susceptibility within the season. At the end of the evaluation period we tried to detect the resistance mechanisms of the different populations with the application of synergists.

We obtained the baseline data, LC<sub>50</sub>, LC<sub>90</sub> of all the populations. No evidence of a high level of resistance has been found. However when we applied the recommended field concentration, mortality never reached 100 %, and after the application of the insecticide with synergists there was an increase of mortality in all the populations. Our results show that all the populations of our area have some level of resistance or at least a low level of susceptibility and that the susceptibility to cypermethrin was even lower in the summer adults

# **Is there a link between fruit pest phenology and climate change in Belgium? A comparative overview with the codling moth, *Cydia pomonella* (L.), as a case study**

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**Abstract:** Pest populations dynamics in perennial fruit crops show yearly changes, with a tendency to elongating phenologies in Belgium in recent years. We investigate over 50 years of data from the Royal Research Station of Gorsem to test two possible causes for this prolongation: (1) climatic changes and (2) shift from classical to integrated pest control. As most pests have temperature dependent phenologies, persistent climate changes must have an immediate effect on pest manifestation. Since the mid-eighties, average temperatures in spring and summer have risen consistently. On the other hand, the implementation of integrated pest management (IPM) strategies might act as a selective force favouring early or late morphs of a given pest. Corrective spraying is indeed often aimed at peaks of pest outbreaks only. Low pest occurrence prior or after this peak might escape chemical control and partial control by beneficial organisms.

We gathered data from abundant pest species in specific orchards that were monitored either 20 years (12 orchards throughout Belgium) or 50 years (orchards near Gorsem). Available life history parameters (emergence, egg-laying, peak of flights, abundance ...) were related to climatology and specific management strategies.

The phenology of a majority of pests follows climatic changes in mean spring temperatures, a trend that started in the early eighties in Belgium. Phenology changes do not correspond with the key shift towards IPM in the late eighties and early nineties, though we cannot exclude a partial added effect. Phenology elongation has consequences on IPM strategies and crop protection management. In the case of the codling moth, earlier start of flights and later end of the sole generation in Belgium necessitates at least one extra chemical application to obtain full control.

## Implementation of non-organophosphate pest management programs on pears in northern Oregon, USA

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**Abstract:** The work reported here was part of a collaborative, federally funded project in the western United States among several universities and research laboratories to reduce use of organophosphate (OP) insecticides on apples, pears and walnuts and replace them with selective control alternatives. In northern Oregon, the project began in 2001 in the Hood River Valley by comparing pest management programs with and without OP insecticides and studying their effect on key and secondary pests, and on natural enemies. Pear orchards were treated with mating disruption for codling moth control and supplemented with either OP or non-OP insecticides when treatment thresholds were reached. Codling moth control in blocks treated with mating disruption plus OP alternatives, such as methoxyfenozide, was as effective as mating disruption supplemented by the OP phosmet. In general, OP treated blocks had more serious secondary pest problems and fewer natural enemies compared to blocks treated with selective OP alternatives. Pear psylla levels were generally higher where OPs were applied, except in blocks where abamectin was used. The natural enemy complex consisted primarily of the predatory plant bug *Deraeocoris brevis* (Uhler) (Hemiptera: Miridae), earwigs, and spiders. In 2004 and 2005, the project was continued with the implementation of non-OP pest management programs in 10 commercial pear orchards. Instead of OP insecticides, growers used mating disruption and/or selective insecticides for codling moth control. Weekly updates on pest and natural enemy populations were sent to growers via electronic newsletters over the Internet to help them with pest management decisions. Growers applied insecticides when treatment thresholds were reached instead of following a calendar-based schedule which resulted in cost savings. This project demonstrated that pear growers can achieve acceptable control of codling moth and secondary pests without the use of OP insecticides.

## Population dynamics of *Cydia pomonella* (L.) in an area wide management program

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**Abstract:** The distribution and the population dynamics of pests in a wide area is determined by different factors, whose influence could be detected by the use of geostatistical techniques.

The aims of the present work were to know the spatial distribution of codling moth (*Cydia pomonella* (L.) Lepidoptera: Tortricidae) and other pests in large areas in order provide useful information to the Technical Advisers of the growers' crop protection organisations.

The program has been run in the county named Pl d'Urgell (Lleida, Spain) from 1996, using the total number of catches in pheromone traps in the first years, and the weekly catches from 2004. A total number of 580 traps are currently been used in a 90,000 ha area.

The traps are revised weekly by the pest control advisers. They receive back the maps of the distribution of the different pests in 2 – 3 days, as pdf or ArcView files. The program is now being extended to other areas of Lleida.

# Effect of centrifugal tree training on pests and pathogens in apple orchards

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**Abstract:** The effect of tree architecture on the development of the main apple pests and pathogens was investigated from 2002 to 2005 at the INRA Gotheron experimental station. The original Solaxe (OS) was compared to the centrifugal training (CT) system, in which the thinning out of fruiting spurs along the trunk and on the proximal and underside parts of branches modifies within-tree environment conditions. Infestation levels of the rosy apple aphid *Dysaphis plantaginea* (Passerini) (Hemiptera: Aphididae) and of the European red mite *Panonychus ulmi* (Koch) (Acari: Tetranychidae) were significantly lower in the CT than in the OS system, in 2002 and 2004 for *D. plantaginea*, and in 2003 for *P. ulmi*. For the green apple aphid *Aphis pomi* De Geer (Hemiptera: Aphididae), differences between systems varied with years. Fruit damage by the codling moth *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) tended to be higher in the CT than in the OS system. The incidence of apple scab *Venturia inaequalis* (Cooke) G. Wint. was lower in Spring (2002, 2004) in the CT than in the OS system, but increased faster in CT than in OS in Summer, with no difference in fruit damage at harvest. Due to several factors, including pest or inoculum removal when thinning out spurs, within-tree microclimate, shoot density and/or growth dynamics, tree architecture influences the development of pests and pathogens. These results open a wide field of research on the use of tree architecture as a means to modulate pest and disease development.

## Abundance, spatial distribution and sampling of leafminers in cider apple orchards: a 3-year survey from Asturias (NW Spain)

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**Abstract:** Field studies were carried out to assess the abundance and the spatial distribution of mines on apple leaves, and to develop a reliable sampling method. Four apple orchards in Asturias (NW Spain) were sampled from 2003 to 2005. A total of 5,120 mines belonging to six different leafminer species were identified: *Phyllonorycter blancardella* (Fabricius) (Lepidoptera: Gracillariidae) (40.7 %), *Leucoptera scitella* (Zeller) (Lep.: Lyonetiidae) (17.3 %), *Stigmella malella* (Stainton) (Lep.: Nepticulidae) (15.3 %), *Lyonetia clerkella* (L.) (Lep.: Lyonetiidae) (13.8 %), *Phyllonorycter corylifoliella* (Hübner) (Lep.: Gracillariidae) (11.4 %) and *Callisto denticulella* (Thunberg) (Lep.: Gracillariidae) (1.5 %). Based on the low densities observed, leafminers could not be considered as a key pest in Asturian apple orchards. Taylor's parameters obtained for the different leafminer species show that mines are distributed randomly. The absence of both aggregation and avoidance implies that sample size requirements for any given level of precision are low. Based on Green's formula, the sampling of around 20 leaves would be enough for estimating populations of 1 mine per leaf. This study has partially filled the lack of knowledge on the leafminer status for Asturian cider groves. Moreover, an enumerative sampling plan for apple leafminers has been developed.

## Population injury levels of the apple rust mite *Aculus schlechtendali* (Nal.) on *Golden Delicious* and *Red Delicious* apple fruits

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**Abstract:** Field trials were carried out in replicated blocks from 1996 to evaluate the biology and quantify the influence of apple rust mite, *Aculus schlechtendali*, (ARM), on fruit-yield and market-quality of *Golden Delicious* and *Red Delicious* apple varieties.

The market quality of fruit specified by weight, fruit size, ground colour, presence of russetting, as well as internal quality, i.e. soluble solids, acidity and Perlim index, were evaluated in relation to three population levels of ARM. Long-term effects on tree productivity were assessed by measuring return bloom. Populations of ARM developed in a similar way on the two varieties although it reached higher densities earlier on *R. Delicious* than on *G. Delicious*. No correlation between eriophyd population and russetting on the skin of fruits was observed on *G. Delicious*, while it was clearly perceivable on leaves. This study demonstrated that ARM affects some intrinsic and external fruit quality parameters on *G. Delicious*. On the contrary no influence of the eriophyd population density on return bloom or on yield in the following year was observed.

## Can apple aphids be vectors of “*Candidatus Phytoplasma mali*”?

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**Abstract:** Apple Proliferation (AP) is a phytoplasma associated disease spread in all countries of central and southern Europe. In 2000, we demonstrated that *Cacopsylla picta* (F.) (Homoptera: Psyllidae) was a vector of “*Candidatus Phytoplasma mali*” in the apple growing area of Trentino. In order to investigate the existence of further vectors, different insects were tested by PCR techniques. AP was primarily detected in 3 aphid species: *Aphis pomi* (DeGeer) (Homoptera: Aphididae), *Dysaphis plantaginea* (Passerini) (Homoptera: Aphididae) and *Eriosoma lanigerum* (Hausmann) (Homoptera: Aphididae). Phytoplasma load in the positive individuals was assessed by quantitative PCR and the vector capacity was evaluated after experimental transmission trials. Moreover preliminary analyses were carried out aiming to establish where phytoplasmas could be located in the aphid's body. Based on our results, aphids seem to acquire a quite high load of “*Ca. Phytoplasma mali*”. However pathogen titre found in these insects appears definitely lower when compared to the concentrations detected in infectious psyllids. Taking into account also the unsuccessful transmission, we can suppose that aphids don't play any relevant role in AP spreading.

## Transmission of “*Candidatus Phytoplasma mali*” by psyllid vectors in Trentino

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**Abstract.** Since the identification of psyllids as vectors of *Candidatus Phytoplasma mali* in 1999, a thorough research has been carried out in Trentino (Northern Italy) in order to investigate the role of psyllids in the transmission of apple proliferation disease. Among the psyllid species found on apple trees in Trentino, *Cacopsylla melanoneura* (Förster) (Homoptera: Psyllidae) and *Cacopsylla picta* (Förster) were the most abundant. Transmission trials were conducted from 1999 to 2004 to evaluate the transmission efficiency of both species. The transmission efficiency of *C. melanoneura* was very low. Only 0.36% of the test plants showed symptoms and were tested phytoplasma-positive by ELISA. *C. picta* was the most efficient vector and transmitted the phytoplasma repeatedly. In total, 3.8% of the test plants became infected with *C. picta*. The overwintering as well as the springtime generation transmitted the phytoplasma. The life cycle of both vector species on apple was described in order to develop suitable control strategies. Both species complete only one generation per year and are present in the apple orchards from end of January to June (*C. melanoneura*) and from end of March until July (*C. picta*). An efficient control of the population of *C. melanoneura* could be achieved when insecticide treatments were applied at the beginning of oviposition of the overwintering generation. *C. picta* was more difficult to control as oviposition often took place during blossom. Therefore, the best period for insecticide treatments against *C. picta* was after blossom controlling the new generation. Furthermore, treatments applicable in organic farming were studied.

## **A secondary sexual character for sex determination of *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) adults, trapped with kairomone lures**

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**Abstract:** Since the introduction of the pear ester, ethyl (*E,Z*)-2,4-decadienoate, in order to monitor adult *Cydia pomonella* (L.) (Lepidoptera: Tortricidae) populations, a fast, reliable and easy way to discriminate between sexes is imperative. Up to now, the main character used is the structure of the tip of the abdomen. The presence of a rectangular “black spot” in the centre of the under-side of the forewing of males has also been reported.

Our objectives were to prove the occurrence of the secondary sexual character named as the “black spot” on the underside forewing of male codling moth, and to detect possible differences in the wing scales present in males and females inside and outside the “black spot” area.

Adults from 9 lab and field codling moth populations from Spain, Argentina, Italy and France were collected. All the adults were checked for both characters: the tip of the abdomen and the forewing spot and they were classified as “positive” when the concurrence was confirmed and “negative” when there was not coincidence. The wings were observed under the Scanning Electro Microscope (SEM).

More than 1,500 adults were observed. The “black spot” was visible with the naked eye in all but 3 males, but in these cases, it was observed under the stereoscopic microscope. Any female showed the “black spot”. The scales present inside the “black spot” had more rounded edges at the tip compared to those on other areas of the same wing. On the other hand, female scales in different parts of the under-side of the forewing were comparable to those of the male outside the “black spot” area. However, female scales have more acute spikes at the tip.

We conclude that the “black spot” in the under-side of the forewing of codling moth males is a reliable character to be used to distinguish between male and females of the species.

# Electrophysiological and behavioural responses of *Dysaphis plantaginea* and the parasitoid *Aphidius matricariae* to host plant volatiles

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**Abstract:** In designing integrated pest management strategies, it is important to understand how aphids and parasitoids respond to host and insect induced volatiles. *Dysaphis plantaginea* Passerini (Homoptera: Aphididae) (the rosy apple aphid) develops on plantain (*Plantago lanceolata*) from July to October, at which time it returns to apple to mate and lay eggs which overwinter. In autumn, males and gynoparae (autumn migrating females) may use a combination of apple volatiles and aphid sex pheromones in host plant and mate location. One objective of this research was to determine the response of *D. plantaginea* to volatiles of the primary host, apple, and the secondary host, plantain, using electroantennogram (EAG) recordings and olfactometry studies. A second objective was to determine the responses of *Aphidius matricariae*, a parasitoid of *D. plantaginea*, to volatiles which have been shown to be produced in higher concentrations in aphid-infested apple plants compared with uninfested plants.

A range of chemicals, which we have shown to be produced by either uninfested or aphid-infested apple or plantain, were tested against *D. plantaginea* males and gynoparae. Two such compounds, methyl salicylate and benzaldehyde, elicited significantly larger EAG responses than the paraffin control, in both aphid morphs. Gynoparae also produced larger responses to methyl benzoate and (Z)-3-hexenyl alcohol than the control.

In behavioural bioassays using a Pettersson style olfactometer, *D. plantaginea* spring migrants responded positively to *P. lanceolata* leaves, but not to apple leaves or to a 5:1 ratio of the major sex pheromone. Gynoparae also responded positively to both the apple leaf and the *P. lanceolata* leaf but not to the apple leaf presented together with the aphid sex pheromone components. Males also responded positively to the sex pheromone components presented together with the apple leaf, but not to either presented alone. Specific plant volatiles, such as methyl salicylate, also elicited a behavioural response.

*Aphidius matricariae* showed significant electrophysiological, but not behavioural, responses to methyl salicylate and a component of the aphid pheromone, (-)-(1R,4aS,7S,7aR)-nepetalactol, normalised against nepetalactone. Following oviposition experience with aphids on apple, *A. matricariae* responded positively to apple leaves and a specific stress related volatile.

The results form part of a project funded by the UK Department for the Environment, Food and Rural Affairs. More work is needed to determine effects of other plant volatiles on aphid and parasitoid behaviour.