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Control of codling moth with mating disruption in pear orchards and effects on beneficials and non-target pests

presented by

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has been accepted towards fulfillment of the requirements for

<u>Masters</u> degree in <u>Entomology</u>

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CONTROL OF CODLING MOTH WITH MATING DISRUPTION IN PEAR ORCHARDS AND EFFECTS ON BENEFICIALS AND NON-TARGET PESTS

By

Saturnino Núñez

A THESIS

Submitted to Michigan State University in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Department of Entomology

ABSTRACT

CONTROL OF CODLING MOTH WITH MATING DISRUPTION IN PEAR ORCHARDS AND EFFECTS ON BENEFICIALS AND NON-TARGET PESTS

By

Saturnino Núñez

Pheromone trap captures at 1.5 m height were almost totally disrupted in the pheromone treated orchard. However, traps located at 3.5 m high had high captures, mainly in the border near to the open field. Fruit damage in the mating disruption treatment was not commercially acceptable, with damage at harvest reached 9.2%, while in the conventionally sprayed orchard damage was only 0.2%. Overwintering larval populations averaged 8.47 larvae/tree in the pheromone treatment, and 0.26 larvae/tree in the conventional treatment.

Plum curculio and apple maggot produced moderate levels of fruit damage in the pheromone treated orchard.

Arthropod populations evaluated with suction sampling had an overall significantly higher Shannon-Weaver diversity index in the pheromone treated block, with significantly higher numbers of parasitic Hymenoptera and Araneae, and significantly lower numbers of pear psylla.

These results indicate that mating disruption is a viable pest management technique, but additional research is needed to fully integrate this technology into commercial orchards.

ACKNOWLEDGMENTS

I would like to express my gratitude to my Major Professor, Dr. James Johnson, for his advice, time, patience and friendship throughout my Master's Program.

Also I am grateful to Dr. George Ayers for his assistance and his conversations about Entomology and Science.

I would also like to thank the other members of my committee: Dr. Edward Grafius and Dr. Martin Bukovac for their guidance.

Special thanks to the members of the Entomology Department who contributed to my education and always showed me friendship and humor.

My thanks to John Wise, Robert Kriegel and the staff of Trevor Nichols Research Complex for their generous help.

I am also grateful to the staff of the Institute of International Agriculture, M.S.U. for their assistance.

My special recognition to my wife and kids for their love, support and patience.

Finally, my special thanks to my country, Uruguay, and the authorities of I.N.I.A. Uruguay for economic support and confidence.

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INTRODUCTION

INTRODUCTION

The codling moth, Cydia pomonella (L), is considered the major pest of pome fruit worldwide (Rothschild, 1982). In general, in areas where two or more generations exist, effective control by natural enemies or environmental factors seldom occurs, and its control depends almost exclusively on insecticide sprays (Hoyt et al., 1983). Chemical control of codling moth is one of most well-documented topic in all applied entomological literature (Croft and Riedl, 1991). However, public concern in the U.S. about pesticides and recently discovered organophosphate codling moth resistance suggests that future codling moth management will be more difficult than in the past, and it is clear that we are on the threshold of change (Beers, 1990). Mating disruption is one of the future scenarios in pest control in the fruit industry (Brunner, 1990).

Mating disruption as a control technique has been proposed for well over 25 years, following the recognition that olfactory guidance systems of flying insects can be potentially vulnerable to disruption (Kirsch, 1988). There are two clear examples of consistent success of this technique, oriental fruit moth in peach in Australia, and pink

bollworm in North America. Commercially acceptable control has also been demonstrated in Japan for the tea tortrix and smaller tea tortrix (Kirsch, 1988).

Research conducted in Switzerland (Charmillot and Bloesch, 1987) for many years showed the utility of mating disruption to control codling moth, while results in the United States have produced mixed results. Most of the research reported to date has been conducted on apple, the research reported here is one of few research trials conducted on pear.

Under certain conditions mating disruption provides very good control of codling moth, but research is necessary to clarify the main factors that affect the success of this strategy (Brunner, 1991). LITERATURE REVIEW

LITERATURE REVIEW

Although pheromones for monitoring purpose have been developed since the early 1970's (Kirsch, 1988) pheromonemediated mating disruption is a relatively new technology. This technique is not a conventional control measure that kills its target; in fact, the non-toxic nature of pheromone disruption should allow for supplementary control by natural enemies. Since no toxic materials are introduced into the test system, there is also the potential for development of a pest problem that was being controlled by insecticides.

Due to the unique mechanism of mating disruption, it is important to understand it well and to carefully evaluate the nature of the target pest.

Mechanisms of disruption mating.

Disruption of mating is based on mediating male behavior by permeating the atmosphere surrounding the crop with the target insects pheromone. Bertell (1982) proposed five mechanisms to explain the disruption produced by artificially released pheromones:

1. <u>Peripheral and central nervous system effects.</u> When insects are exposed to a constant concentration of an odor the

output of the insect's olfactory receptors declines rapidly, and shut down their ability to orient to a source of the pheromone. Habituation could play an important role in reducing the orientative and close range responses of male population, at the normal time of sexual activity.

2. False trails. In this case it is assumed that adaptation and habituation have no significance and males respond to the odor source. In this disruption mechanism males spend time and energy following the false sources. If these sources are numerous enough the probability of finding In the case of codling moth, a females is very low. significant number of males have been observed flying in the vicinity of trees in which dispensers were releasing the pheromone. When the moth population is high the ratio of dispenser to wild females is reduced, allowing less competition and hence less disruption of mating. The concept of "confusion technique" is related to this disruption mechanism.

3. <u>Inability to distinguish individual odor from odor</u> <u>background.</u> In this case the background level of the pheromone is high and uniform enough to mask the odor from calling female. For the initiation of orientation the insect needs to detect only presence or absence of the pheromone. With the background odor, the difference between concentration boundaries might be much less well defined.

4. Balanced component pheromone system. Pheromones in

lepidoptera are almost exclusively multi-component systems with specific ratios for each species. In the case of closely related species, reproductive isolation is maintained through differences in the proportion of the components of the pheromone. The liberation of large amount of one component will affect the atmospheric mixture, and males could not orient to the pheromone sources. If a compound by itself mediates a particular element of behavior, its release in large amount might disrupt that behavior.

In codling moth, there are indications that the three component mixture, resembling the natural pheromone blend is better disruptant than codlemone (E8,E10-12:04) alone (Minks and Carde, 1988).

5. <u>Antipheromones.</u> Compounds that inhibit mate location are called antipheromones. These compounds may be structurally related to the real pheromone or may be totally different. It is thought that some antipheromones act by competing for the same receptor sites on the male antennal sensilla.

In codling moth, the acetate of the codlemone showed a very active inhibition effect. This compound alters male responses to codlemone or virgin females, when present in the same trap, or as a background area treatment. In this specific case electrophysiological studies indicate that codlemone and codlemone acetate are perceived by separate antennal receptors, and inhibition could be the result of a

central rather than peripheral sensory process (Rothschild, 1982). The pheromone release technology will largely depend on the mechanism of mating disruption involved (Kirsch, 1988).

Pest characteristics for mating disruption technique.

Because of the unique mode of action of mating disruption, not all pests are suitable for control by this technique.

For successful adoption of mating disruption, it is desirable that only one important pest be involved in the crop, (Kirsch, 1988). When a pest complex attacks the crop, pheromone-based control is less attractive (Vickers and Rothschild, 1991). Pests with high mobility make them less suitable candidates for disruption purpose. Frequently mating disruption of many pests has not proved very successful due to invasion of gravid females (Kirsch, 1988).

Rothschild (1982) pointed out that codling moth is a suitable candidate for mating disruption because it has a narrow host range, attacks only the fruit of these plants, it has relatively low fecundity, and it is claimed that the adult females do not disperse far from their emergence sites. It was also determined that mating disruption of codling moth not only reduced mating, but also delayed it. Therefore its ability to mate is significantly reduced if no mating occurs in the first 4 days (Rothschild, 1982).

Codling moth behavior.

The flight range of codling moth is usually limited to about 50 m around their orchard origin (Audemard, 1991). Adults tend to remain near the point of emergence. More than 90% of the moths are found less than 500 feet from their emergence point, with both sexes having similar flight habits (Worthley, 1932). However, migration from fruitless to fruitproducing orchards has been observed (Audemard, 1991). Females can move from 50 m to 100 m inside the orchard, and tend to aggregate at the borders (Charmillot, 1990).

Maximum moth flight occurs in the period 20 minutes immediately before and after sunset. At this time, flight is very short and close to the tree. When light intensity decreases, flight duration becomes longer. The manner of flight has been described as a quick zig-zag movement. The starting of a breeze is an important factor that affects flight (Borden, 1931), and male flight is affected by temperature which has to be higher than 15°C. Sexual activity is greatest during the next hour when the light intensity falls from about 1000 lux to less than 10 lux, but may continue at low levels if temperature is sufficiently high (Rothschild, 1982). Borden (1931) observed on different evenings, that female moths congregated at the tops of trees, and up to 15 or 20 males moth were swarming around one or more After the swarming had ceased, copulation took females. place. After sunset, females become sedentary and call with

pheromones for about 1-1.5 hours. Females cease calling when copulating or when the temperature is below 12°C (Howell, Rothschild (1982) observed that proportionally more 1991). males are able to locate virgin female-baited traps in the upper rather than lower part of the tree. Charmillot (1990) also noted in mating disruption conditions that higher trap captures were obtained at the top of the trees than at medium height (1.7 m), however, the success of mating disruption control was not compromised. Numerically, the optimum male response to the pheromone sources was at 3 m in height, or approximately 1.0-1.5 m from the top of the tree, but statistically there was no height effect (Howell et al., The authors conclude that there are not important 1990). differences in male response and moth captures between traps located within a person's reach and those placed near the top of the tree.

The pheromone released by the female is carried downwind in a plume and is dissipated by atmospheric turbulence. When a randomly flying male moth of the same species perceives the odor by impact of the vapor on its antennal receptors, it orients its body into the wind and begins upwind flight using visual ground cues as a directional guide. The level of pheromone in the air also affects the flight. If concentration is high, flight is within the plume area, whereas if the concentration is low, the degree of lateral movement is greater (Caro, 1982). Male orientation to a fine

pheromone plume is much more likely than orientation to a scattered pattern. McNally and Martin, (1981) examined the effect of trap alignment relative to prevailing air movement and observed that traps aligned parallel to the prevailing evening air movement caught more moths than traps aligned perpendicularly. After following the pheromone plume, males land near the female, searching for the female with vigorous wing fanning and walking in a zig-zag pattern within 1-2 cm from the female apparently also using visual cues (Howell, 1991). A male will spend more time walking and fanning, and attempting to copulate with an object providing visual cues than with a pheromone source alone (Castrovillo and Carde, However visual communication is not essential since 1980). mating will occur in complete darkness (Howell, 1991). Also courtship and other aspects of "close-range" precopulatory behavior may involve additional pheromone components different from codlemone (Rothschild, 1982).

Males mate an average of three to four times while females mate one to two times as an average (Gehring and Madsen, 1963).

Factors that affect mating disruption.

The presence and amount of the pheromone in the orchard atmosphere depends on many parameters that can be summarized in the chemical structure of the pheromone, support, concentration, shape of the plot, nature of the crop and

climatic conditions (Audemard, 1988).

Chemical structure of the pheromone affects its release rate. Longer chain compounds are released more slowly than shorter ones, and their functional groups also play an important role (Vickers and Charmillot, 1991).

Physico-chemical characteristics of the dispensers such porosity, color and affinity with the pheromone also affect their release. For these reasons many different dispensers have been used in mating disruption experiments; Vickers and Rothschild (1991) classify them in two basic categories: the broadcast application and the dispensing stations.

The broadcast applications are intended to provide a uniform distribution of the pheromone throughout the orchard. Microcapsules and chopped hollow fibre are the two types that have been tested.

For microcapsules, there was a very limited persistence of codlemone and they were effective for not more than 14 days (Rothschild, 1982).

The chopped hollow fibre releases the codlemone from the open ends of polymer fibres and is applied to the crop from the air or from the ground with specially modified applicators (Vickers and Rothschild, 1991). Moffit and Westigard (1984) used this kind of formulation for two years in pear orchards and they got up to 90% of control when codling moth density was low, but little or no control was achieved where initial populations levels were high.

Dispensing stations produce locally high levels of pheromone from discrete release points and manual methods of application are generally used. Hollow fibre tapes, rubber tubing and laminates are the most commonly used (Vickers and Rothschild, 1991).

In the hollow fibre tapes the pheromone is released from the open ends of fibres made of polyester terephthalate, and attached in parallel arrays to strips of adhesive tape. The release rate depends on the fibre's internal diameter, length and numbers of fibers (Vickers and Rothschild, 1991). This superior to chopped hollow method is fibers and microencapsulation in reducing wastage of codlemone, but few tests have been undertaken to assess the practical value of these fibers (Rothschild, 1982).

Rubber tubing has been tested extensively in Switzerland. The most common design consists of a 20 cm length of rubber tubing (2 mm in diameter) loaded with 50 or 100 mg of codlemone. The tube ends are sealed and the compound passes through the rubber walls at a rate determined by the temperature and the amount of codlemone remaining (Rothschild, 1982). Using rubber tubing from 1976 to 1979, and laminated plastic flakes since 1980, Charmillot and Bloesch (1987) got effectively controlled codling moth with two to three applications per season.

Laminated plastic flakes consist of several layers of laminated polymeric material with the active ingredient sealed

in a layer between outer plastic layers. The release rate of the pheromone depends on the concentration, membrane thickness and polymer stiffness (Quisumbing and Kydonieus, 1982).

The most common dispenser systems incorporate pheromones in plastic tubes that provide a slow release of the product over several months (Brunner, 1991). Gut et al. (1991) estimate that one application of 400 of these dispensers is sufficient where codling moth levels at the end of the first generation are low. If satisfactory control is not achieved, a second application of pheromone dispensers is necessary.

For successful disruption of mating, the presence of a specific minimal concentration of the pheromone is necessary in the atmosphere of the orchard during the period when the insect is sexually active (Vickers and Charmillot, 1991). Audemard (1988) estimated that for codling moth it is necessary a release rate of 10-20 mg/ha/h and the total amount during the growing season has to be between 45-78 g/ha. Rothschild (1982) pointed out that males were unable to locate virgin females when the evaporation rate exceeded 1 mg/ha/h. The amount of attractant that has evaporated can be calculated by regularly weighing the dispensers exposed in the orchard (Charmillot, 1990).

Besides the amount of pheromone released from the dispensers, another important factor to consider is the behavior of pheromone molecules in the crop system. Many researchers have attempted to measure the behavior of volatile

plumes released from their sources, but little is known about the pattern of atmospheric dispersion of the pheromone in field conditions (Kirsch, 1988). Physical characteristics of the crop and meteorological condition have the most effect on the distribution of the pheromone, and an understanding of these differences could help to maximize the pheromone dispersion throughout the crop canopy (Kirsch, 1988).

In most of the orchard trials, dispensers have been hung at a height that was convenient for the operator, about 1.5-2 m, but optimal height will be that which allows the emission of the pheromone to areas where the adults are sexually actives (Vickers and Charmillot, 1991). For example, when Charmillot and Bloesch (1987) placed dispensers at the soil surface instead of the standard location (1.5-2 m height), they found that even though pheromone trap capture was reduced, fruit damage increased significantly.

The rate of dispersion of pheromones in the atmosphere depends on wind velocity. The wind-generated turbulent dispersion overwhelms the diffusion properties of the pheromone, so that molecular diffusion is relatively unimportant. As wind velocity increases from 0, the pheromone is dispersed over greater distances until a maximum is reached, then, higher velocities produce greater turbulence and more rapid dispersion resulting in a decreased range of the pheromone (Caro, 1982).

In forests, because of their aerodynamic and temperature

inversion condition during the day, winds under the canopy are very light and pheromone plumes exhibit little turbulent transfer until they reach an area under an opening in the canopy, where the vapors are rapidly dispersed (Caro, 1982).

Pheromone concentration will increase down wind through the treated area, particularly when the long axis of the orchard is parallel with the prevailing winds (Vickers and Charmillot, 1991). Pheromone concentration will also vary vertically because of the air movement in the higher strata. Difficulties in mating disruption may appear if trees are higher than 5 m due to the pheromone removal from the top of the trees by wind (Charmillot, 1990; Pari et al., 1989). The uniformity of the orchard canopy is also important because it may influence the distribution of the pheromone, leaving regions where control fails. Orchards in windy areas or on step slopes may not be suitable for mating disruption, because the pheromone concentration throughout the orchard would not remain uniform (Charmillot, 1990). Sometimes mating disruption breaks down in the borders of the crop due to the effect of winds that remove the pheromone from the borders (Charmillot and Bloesch, 1987). For this reason it is necessary to increase the dispenser density in these areas (Charmillot, 1990; Molinari and Cravedi, 1989). The application of dispensers from 30 to 50 m outside of the orchard may also reduce this effect (Charmillot, 1980). The creation of a buffer zone with the increase of dispenser density or with insecticide sprays, is desirable in some conditions (Audemard, 1988).

Pheromone release is also affected by ultraviolet light and heat, promoting their degradation. The presence of breakdown products within a dispenser might affect the release rate (Vickers and Charmillot, 1991). On the other hand, temperature is an important factor in the rate of pheromone release, Brown et al., (1992) found that an increase in temperature produces an exponential increase in the release rate of each component of the pheromone. Orchards in regions with high summer temperatures may require dispensers with different release rates than those in cooler regions (Charmillot, 1990). The close resemblance of the long chain hydrocarbon structures of many pheromones to the structures of plant leaf waxes might favor the adsorption of the airborne pheromones on the plant surfaces (Caro, 1982). Mani et al. (1987) pointed out that some codling moth catches detected during the first weeks of mating disruption could be due to the leaf surfaces that took time to charge up with the pheromone.

Another important factor that may affect the success of mating disruption is pest density. High populations of the target pest allow encounters through secondary and shorter range stimuli, (Kirsch, 1988; Audemard, 1988). Charmillot (1990) estimates that for good success with this technique overwintering larvae can be no higher than two or three per tree, while, Mani et al. (1987) found that when there is more than 2000 mature larvae per ha problems may appear with this technique.

Populations of codling moth may decrease year by year when using mating disruption techniques (Charmillot, 1990). However, in low codling moth populations, density dependent mortality factors can be greatly reduced and the surviving codling moth larvae may still be capable of inflicting economic damage (Rothschild, 1982).

No isolation of pheromone treated orchards from sources of mated females is one of the most common reason of failure of this technique (Rothschild, 1982). Isolation between 110 and 220 yards from sources of gravid females is considered adequate (Charmillot, 1990). When isolation is not possible, insecticide sprays in the borders of the pheromone treated orchard may overcome the problem (Kirsch, 1988).

There is also the possibility that males could be attracted into plots receiving codlemone, and resident males may not emigrate from such areas. This would tend to increase the ratio of males to females, and increase the opportunities for encounters between sexes (Rothschild, 1982).

Evaluation methods for mating disruption experiments.

In mating disruption experiments it is not possible to replicate the treatments as with insecticide trials, because gravid females can move from one area to another (Charmillot, 1980). Therefore, it is necessary to use relatively large plot areas to maintain the plot integrity (Moffit and Westigard, 1984). However, recently Howell et al., (1992) used 0.3 ha pheromone-treated and untreated replicated plots, by releasing fixed numbers of virgin females in each plot, limiting immigration of moths with insecticide-sprayed buffer rows, and using areas with low codling moth populations.

The most common methods used for evaluation of mating disruption trials are: virgin female traps, pheromone traps, food traps, tethered moths and pest damage (Audemard, 1988). Corrugated cardboard bands can also estimate the efficiency of mating disruption through the evaluation of the codling moth population larval density (Charmillot, 1990).

Inhibition of captures in pheromone traps is a good indication that pheromone released from dispensers disrupted male orientation to codlemone and thus to "calling" females (Gut et al., 1991). While, the inhibition of captures in pheromone traps is a necessary indication of disruption, trap catch alone is not a sufficient criterion for evaluating success in mating disruption trials (Molinari and Cravedi, 1990). Unacceptable levels of fruit damage by codling moth can occur in mating disruption orchards where trap catch is low. This most often results where mated females move in from a nearby source or from improper placement of pheromone traps. Pheromone traps must be placed at mid-canopy height (Gut et al., 1991).

The proportion of decoy females (tethered) that mate with wild males in treated and untreated sites may also provide a meaningful assessment of mating disruption (Rothschild, 1981).

Virgin female traps also may provide a indication of the disruption of mating. However, due to the variation of the pheromone emission by the female, this method may not be very reliable (Audemard, 1988).

Feeding lures have been used to trap females, but samples appear to be biased toward mated individuals and contain a small proportions of virgins. However, feeding lures provide a rough measure of oriental fruit moth disruption when making comparisons between pheromone treated or non-treated areas (Rothschild, 1975). If the disruption treatment increases the proportion of virgin females, there will be an increased probability of catching them (Vickers et al., 1985).

Corrugated cardboard bands around the trunk provide a measure of the population density. If this measure is compared year after year, we can estimate the efficiency of the mating disruption technique (Charmillot, 1990). Fruit damage is proportional to the number of larvae captured in cardboard bands, and inversely proportional to the number of fruit per tree, however this relationship changes between first and second codling moth generation because mortality and fecundity are different in both generations (Charmillot, 1980).

Plant damage provides the most reliable information about

the results of the mating disruption tactics (Audemard, 1988), and from an economic stand point is the only relevant criterion of successful disruption (Rothschild, 1981).

The results of the different trials carried on by different researches have been variable, primarily when success is measured in terms of fruit damage, rather than only male captures at traps or mating of "decoy" females (Rothschild, 1982). Reasons of this variability can be summarized in (Rothschild, 1982):

- Inadequate release or aerial distribution of the pheromone.
- 2) The existence in the female pheromone secretion of compound in addition to codlemone that enables some males to locate females, especially if adult density is high.
- 3) Mated females that immigrate to the treated areas .
- Reduction of effect of density-dependent mortality processes.

Advantages and disadvantages of mating disruption tactics.

The main advantages of mating disruption are:

1) The use of mating disruption over several years could result in the suppression of a pest population to very low levels (Kirsch, 1988). Based on the survival curves from life-table of codling moth, 50% reduction in the number of viable eggs would allow a progressive decline in the population, and this decline would became more marked as fertile egg numbers are further reduced as might occur in a disruption treatment (Rothschild, 1982).

2) It offers an opportunity to eliminate the broad spectrum insecticides used to control codling moth, allowing a better survival of natural enemies, and secondary pests would be controlled primarily by them (Rice and Kirsch, 1990).

3) The exposure of farm workers to insecticide residues during thinning and harvesting operations will be greatly reduced (Rice and Kirsch, 1990).

The main disadvantages can be summarized as follows:

1) Results may not be commercially acceptable due to migration of mated females or other factors (Rice and Kirsch, 1990).

2) Damage from other pests such as pandemis and other leafrollers can be economically important (Gut et al., 1991).

3) Cost of pheromone disruption may be still higher than insecticides (Kirsch, 1988).

4) If the target pest population is high, additional sprays of insecticide may be necessary (Rice and Kirsch, 1990), which increase the cost of the control program.

5) An additional concern is the real or perceived increased risk when adopting this technique.

CHAPTER 1.

CHAPTER 1

Field evaluation of mating disruption with pheromones to control codling moth (Lepidoptera: Tortricidae).

INTRODUCTION

Mating disruption with pheromones in codling moth, <u>Cydia</u> <u>pomonella</u> (L) has been extensively tested in different places of the world, but results have been variable. While in Switzerland it is now used commercially (Audemard, 1988), it is still controversial in the U.S.A. with successes in some cases, and failures in others. (Beers, 1990). This technique has considerable promise, but much more research has to be done before we can use it with total safety (Beers, 1990).

The development of this technique to control codling moth is very important, not only because of the potential for reducing substantially the number of insecticide sprays in apple and pear, but also because of the recent discovery of resistance to azinphos-methyl, the most common organophosphate insecticide used for their control (Brunner, 1991). Theoretically, codling moth should be a very good candidate

for mating disruption management (Croft and Bove, 1983). Mating disruption could provide an alternative control tactic that could reduce selection pressure for develop resistance development to currently used insecticides (Brunner, 1991).

The major recommendations from early workers, to avoid or decrease failures in mating disruption tests can be summarized as follows:

1) Orchards have to be 3 hectares or larger (Charmillot, 1990). However, there have been suggestions that a minimum orchard size of 1.4 to 3.0 hectares could be acceptable, depending on the degree of infestation (Kirsch, personal communication).

2) Isolation from external infestation sources of codling moth must be at least 100 meters (Charmillot, 1990).

3) The orchard borders have to be protected with more pheromone dispensers than inside the orchard (Audemard, 1988; Charmillot and Vickers, 1991). This is especially important in open areas (Molinari and Cravedi, 1990).

4) The initial insect population must be relatively low (Audemard, 1988; Pari et al., 1990). Charmillot (1990) estimates that codling moth population has to be lower than 2 to 3 diapausing larvae per tree. When the population is relatively high, one spray of insecticide at the beginning of the growing season may increase the effectiveness of mating disruption (Kirsch, 1988; Rice and Kirsch, 1990).

5) There is evidence that mating disruption can be improved by
using a pheromone blend that more closely resembles that of the female, rather than only the codlemone (Vickers and Rothschild, 1991).

Most of the U.S. experiments with mating disruption of codling moth have been done in the West Coast, while there is little information from the Eastern U.S. fruit producing regions. Likewise, fewer experiments have been conducted on pear than on apple, even though mating disruption could have relatively more potential for success on pear. Pear orchards may have fewer codling moth generations per year, and a lower potential for fruit damage during the first generation.

The objectives of this study were to evaluate the feasibility of mating disruption to achieve similar codling moth control to the standard insecticide sprays, and to determine possible environmental and biological factors that may affect its efficacy.

MATERIALS AND METHODS.

This study was conducted in 1991 and 1992 in Fennville, Michigan, at Michigan State University's Trevor Nichols Research Complex. A two ha. orchard was divided into two pear blocks of 0.8 ha. each, (designated East and West blocks) and separated by a 0.4 ha. apple orchard. The pear orchards had been abandoned in previous years, but in 1990 mating disruption was initiated in the Eastern block and a standard

insecticide spray in the Western block. The pear orchards consist of mature trees spaced at 6.4 m by 6.1 m. The experimental site has a woodlot on the south side, residential housing on the north , a soybean crop on the east and a corn crop on the west (Fig.1). Mating disruption was conducted in the Eastern block, using no insecticide sprays to control codling moth. Fungicide sprays to control apple scab and one avermectin spray to control pear psylla were used. The West block was conventionally sprayed as in Table 1 (half of this block did not receive amitraz sprays). The apple block was sprayed with methyl parathion every 7-10 days and also was This served as a buffer zone to under mating disruption. prevent adult migration from the conventionally sprayed block to the mating disruption treatment. Dispensers were commercial products (ISOMATE -C, Biocontrol Ltd.) formulated with 155 mg of the pheromone, to last the entire growing season. The pheromone was composed of the three main components (E8,E10-12:OH, 12:OH and 14:OH) in the proportion of 100:57:18. Dispensers were tied 1.5 m to 2 m above the ground, at a density of 4 dispensers per tree, (1000/ha) uniformly distributed around the tree. Dispenser density was doubled in trees in the border row to reduce potential border effects on pheromone distribution. Dispensers were placed before first codling moth emergence on May 2 in 1991 and May 13 in 1992.

Environmental data from the NOAA weather station at the



Table 1.Spray schedule in standard and mating disruption treatments (1991).

Standard treatment					
Date	Pesticide				
5/10 5/29 5/31 6/17 6/24 7/1 7/23 8/2	Azinphos-methyl + Dicofol Amitraz Azinphos-methyl Ferbam + Azinphos-methyl Amitraz Ferbam + Azinphos-methyl Azinphos-methyl Azinphos-methyl				
Mating disruption	treatment				
Date	Pesticide				
5/14 6/17 7/1	Avermectin Ferbam Ferbam				

Trevor Nichols Research Complex were collected to calculate degree days for the codling moth phenology model.

Because of the size of the orchards, replications were not possible. Hence, each block was considered an unreplicated unit.

Assessment of mating disruption.

1991 Experiment:

Traps baited with synthetic pheromone were used as a method for determining disruption communication between the two sexes. Pherocon II traps, (TRECE INC), baited with 1 mg of codlemone in grey rubber septa, were placed at about 1.5 m in height. Five traps were distributed in each pear block, one in the middle of each border and the other in the center of the orchard. All traps were placed on May 2. Traps were cleared at weekly intervals and rubber septa was changed every 4 weeks. Traps were changed when the sticky surface became dirty.

In the mating disruption treatment, a second set of pheromone traps were placed during the second generation flight of codling moth, at 1.5 m and at 3.5 m high in the West and East borders and in the center of the block. Each trap location was replicated two times and the distance between them was at least 20 m. We increased the number and locations of pheromone traps due to low trap capture during the first generation in the traps located at 1.5 m, despite the fact that codling moth damage was found in fruit. For statistical analysis, data were transformed by Log(x+1), where x is the number of moth captured.

Feeding lure traps were used as indicators of wild females codling moth mating status. For this purpose, 3.8 liter plastic pails (20 cm diam) were filled with 1 liter of 5% brown sugar solution plus 0.8 ml of terpinyl acetate and 0.02 ml of Tween 20. (Chisholm et al.,1946). Traps were placed on May 16 at 1 to 1.5 m in height, one in the middle of each border of each block, the other in the center, for a total of five per block. Traps were emptied at weekly intervals and catches retained in 70% ethyl alcohol for identification.

To determine the amount of pheromone released through the growing season, fifty additional pheromone dispensers were weighed and labeled prior to placement in the mating disruption treatment. Every 2 weeks 5 dispensers were removed and weighed again. Differences between initial and final weight allowed us to calculate the amount of pheromone released throughout the season.

<u>1992 Experiment:</u>

In order to confirm the results from 1991, mating disruption was again tested with pheromone traps placed at the same locations as the second set in 1991. However, in 1992 an additional set of pheromone traps were also placed in the standard treatment. Then, trap locations tested for each

treatment were: east border, center and west border, and two height per location (1.5 m and 3 to 3.5 m). Each height and location were replicated two times. Traps were cleared once per week. For statistical analysis, data were transformed by Log (x+1).

To complement the information obtained with the pheromone traps and to better represent nature, sticky traps were baited with virgin females. Wing-style sticky traps contained a female codling moth in a plastic vial with their ends sealed with plastic mesh to allow pheromone release and prevent female escape. Females, which were replaced once a week, always had access to a cotton plug with water and sugar. This evaluation was done during the main peak flight of the first generation of codling moth, from May 27 to June 19. One virgin female per trap was used in the first and third week of the evaluation, while in the second week, two virgin females were used per trap. Traps were placed at two heights (1.5 m and 3 m) in the borders contiguous to an open field, and in the center of each treatment. Each location and height was replicated twice.

Due to the failure in the capture of the food bait traps in 1991, it was decided to test the mating status of wild females by capture in black light traps in 1992. One black light with a white sheet was placed in each treatment, from half hour before dark to one hour and half after dark. This evaluation was done weekly from June 2 to July 8, during the

main flight of codling moth. After moths were captured, they were retained in 70% ethyl alcohol for sexing and dissection of codling moth females. Mating status of females were determined by the presence or absence of a spermatophore.

Assessment of population density.

Population density was evaluated during 1991 with larval traps (5 cm wide of corrugated cardboard band) attached to the base of the trees, below the beginning of the branches in 36 uniformly distributed trees per block. Biweekly after first generation larvae (July 2 to August 14), codling moth last instars, pupae, and empty pupae were removed and counted. For evaluation of the overwintering larvae, larval traps were attached to the trees on August 14 and removed on October 11.

Assessment of fruit damage.

Fruit damage evaluation was performed during 1991 in 25 trees per treatment (5 replications with 5 trees each). One replication was in the center and four in the middle of the four borders of each block. For the first generation (25 July) 50 fruits, randomly selected per tree (250 per replication) were externally evaluated for feeding damage. At harvest (August 14) 20 fruits per tree (100 per replication) were randomly picked and internally evaluated for fruit feeding larvae. All larvae found were retained in 70% ethyl alcohol for later identification. As a rough index of codling moth damage distribution, the 36 trees with larval traps were also evaluated for fruit damage. Fifty fruits per tree were evaluated twice, after first generation larvae (July 25) and at harvest (August 14). For statistical analysis, data were transformed by $\sqrt{x+0.5}$, where x is the % of fruit damaged.

RESULTS AND DISCUSSION.

Assessment of mating disruption.

1991 Experiment:

Total pheromone trap captures indicated a significant difference between the standard and the mating disruption treatment (Fig.2). The magnitude of this difference seems to demonstrate a disruption in codling moth mating over the entire season. Only a few moths were captured during each peak activity period. In the mating disruption treatment, nine moths were captured in pheromone traps throughout the season, versus 272 in the standard treatment. Eight of these nine moths were captured in the borders next to the open field (5 in the east and 3 in the north), and only 1 in the center of the block. In the standard treatment, all 5 traps had large captures (272), but again the highest captures were in the borders next to the open field (west and north) (Fig.3).

Although our pheromone trap captures in the mating disruption treatment were low, fruit damage was evident by the middle of the season. As a result we decided to hang



Figure 2. Mean weekly codling moth captured in pheromone traps at 1.5 m, in standard and disrupted treatments



Figure 3. Accumulated codling moth captures in pheromone traps at 1.5m in different locations in standard and mating disruption treatments

additional pheromone traps in the tops of the trees. Because calling females are most often found in the upper part of the host tree (Rothschild 1982), we speculated that the top of the tree might be a critical zone for mating disruption. Results of this new evaluation through the second codling moth generation show that all traps at 3 m to 3.5 m height had higher captures (Table 2). Traps located in the upper part of the tree in the east border had significantly higher captures than at 1.5 m. Hence, not only height of the traps was important, but also the proximity to the open field. Trap catch decreased the farther the traps were from the open field (Table 2). Potentially, the pheromone atmosphere in the top of the trees and near the open field is greatly affected by the wind, and males apparently can find pheromone sources. Also, migration of moths from outside of the orchard could increase captures. However, the most important fact is that males from outside or inside of the block were able to find the pheromone sources near the top of the tree, and likely could locate females in the same manner.

Codling moth captures in bait traps were extremely low (Fig.4) and meaningless with regards to mating status. Most captures were during the second generation in the mating disruption treatment. This was probably the result of a higher moth population and the elimination of insecticide sprays in the mating disruption treatment allowing females to live longer. In contrast to codling moth, oriental fruit

Table 2.Total codling moth captures in pheromone traps at different height and locations in mating disruption treatment (1991).

Pheromone tr	Total cap	ture	
East border	3.5 m height	38	a
Center	3.5 m height	8	b
West border	3.5 m height	4	bc
East border	1.5 m height	1.5	cd
Center	1.5 m height	1	d
West border	1.5 m height	1	d

Means followed by the same letter are not significantly different at P< 0.05 (Duncan's NMR test).

codling moth
30
25
Standard treatment
25
20
15
10
5
0



Figure 4. Weekly captures of codling moth and oriental fruit moth in food traps in mating disruption and standard treatments

moths were strongly attracted by the bait traps, and unusually high populations were captured just prior to harvest. However, fruit damage by oriental fruit moth was virtually non existent probably because they appeared too late in the season to cause damage.

Pheromone release from the dispensers was represented by a regression line in log. scale (Fig 5), indicating that the release rate decreased gradually through the season. After 30 days, the release rate was 1,429 mg/ha/day, after 60 days, 743 mg/ha/day, and after 100 days (harvest time), 438 mg/ha/day. The release rate was consistently above the threshold of 240 to 480 mg/ha/day cited by Audemard (1988), and only approached the threshold level at harvest .

1992 Experiment:

The same capture pattern in the mating disruption treatment was observed during the second year of this experiment, for the first generation of codling moth (Table 3). There were significantly higher captures in the top of the trees in the east border, followed by captures in the top of the trees in the west border and in the center. In the standard treatment, there were no significant differences between height and locations, but higher captures were registered in the top of the trees. Males seem to have higher response to traps located at 3.5 m than those at 1.5 m (Howell et al., 1990).

Since naturally "calling" females tend to congregate in



Figure 5. Relationship between pheromone release per dispenser (Y) and days in the field (X)

Table	3.	Total	1st	genei	ratio	n codli	.ng i	noth	captur	es	in
pheron	none	e traps	at	diffe	erent	height	and	loca	ations	in	mating
disrup	oti	on and	sta	ndard	trea	tments	(199	92).			

Pheromone trap location (treatment)	Total capture		
Mating disruption east 3.5 m height	47	a	
Mating disruption west 3.5 m height	19.5	ab	
Mating disruption center 3.5 m height	18.5	b	
Standard east 3.5 m height	9.5	bc	
Standard west 3.5 m height	8.5	bc	
Standard center 3.5 m height	7.5	bc	
Standard east 1.5 m height	4.5	cd	
Standard west 1.5 m height	4.0	cd	
Standard center 1.5 m height	1.5	de	
Mating disruption east 1.5 m height	1.5	de	
Mating disruption west 1.5 m height	0.0	е	
Mating disruption center 1.5 m height	0.0	e	

Means followed by the same letter are not significantly different at P< 0.05 (Duncan's NMR test).

the top of the trees (Borden, 1931) pheromone traps in the tops of trees could more closely simulate natural behavior. In general, male moths are not strongly attracted to traps located at heights other than those encompassing the normal behavior of the insects (Caro, 1982).

Comparing pheromone traps captures in both treatments, the highest captures were at the top of the trees in the mating disruption treatment, intermediate captures in all traps from the standard treatment, and the lowest captures (almost 0) were in the mating disruption treatment at 1.5 m height. These results also demonstrate that disruption of mating took place mainly in the middle part of the trees, while in the upper part it was insignificant. Trap captures were highest in the top of the trees at the mating disruption treatment, probably due to the higher overwintering population in that treatment (Table 4). However, emigration of mated females from outside was also possible.

Captures in virgin females traps (Fig. 6) did not show statistically significant differences, but the pattern was the same as in the pheromone traps. The reason for the nonsignificance in this evaluation may be due to the variation in captures among replications of each treatment, and likely was due to the differences in pheromone release from the females.

Moth captures with black light were relatively low (fig.7). This could be due to the adverse weather conditions during each evaluation, primarily temperatures near the lower



Figure 6. Mean capture of codling moth in virgin female traps at different locations in standard and mating disruption treatments

Mating disruption treatment



Standard treatment



Figure 7. Codling moths captured with black light during 1st generation in mating disruption and standard treatments

threshold for moth flight. The higher captures in the mating disruption treatment were probably due to the higher overwintering population. While, the discovery that 50% of captured females (2 in 4) were mated indicates that successful mating may occur in the mating disrupted treatment or that they immigrated from outside.

Assessment of population density.

Evaluations of codling moth larval traps (corrugated cardboard bands) indicated significant differences in the numbers of overwintering larvae, 8.47 larvae per tree in the mating disruption treatment versus 0.26 larvae per tree in the standard treatment (Table 4). The population increase from the first generation to the overwintering generation was extremely high in the mating disruption treatment, showing that mating disruption was not effective in keeping codling moth population at low levels. We also found larvae to be largely distributed in the Eastern border (16 overwintering larvae/ tree versus 4 overwintering larvae/tree in the center of the block) (Fig. 9). While no special pattern was observed in the standard treatment, only 0.5 larvae per tree was the highest density found (Fig. 8).

Assessment of fruit damage.

Fruit damage due to first codling moth generation was not significantly different between treatments, although it

Table 4. Mean overwintering larvae and pupae per tree captured with corrugated cardboard bands in mating disruption and standard treatments (1991).

Treatment	<pre># of larvae /tree</pre>				
	1st.	gene	ration	Overwinterin generat:	ng (2nd) ion
Mating disruption		1.69	a	8.47	a
Standard		0	ъ	0.26	b

Means followed by the same letter across each column are no significantly different at P<0.05 (Student's t-test).



Figure 8. Spatial distribution of codling moth second generation larvae and pupae per tree (+SE) in standard treatment





Figure 9. Spatial distribution of codling moth larvae and pupae per tree (<u>+</u>SE) in mating disruption treatment

was somewhat higher in the mating disruption treatment (Table 3). At harvest, fruit damage remained low in the standard treatment (0.2%), but increase dramatically in the mating disruption treatment (9.2%) (Table 5.)

The spatial distribution of fruit damage in the mating disruption treatment (Fig.10) followed the same pattern observed for overwintering larvae. The highest damage was detected in the Eastern border and the lowest in the center. Fruit damage and larvae/tree were significantly correlated (r=0.96) (Fig.11).

All our evaluations showed that the main failure of the mating disruption was related to the top of the trees and to border effects next to the open field. Because of the shape and size of the block used for the experiment, borders had an important effect over the whole block. Because trees were not pruned in recent years, the height was probably higher than Similar experiments carried on in the same orchard normal. (J.W. the previous year (1990) Johnson, personal communication) showed a similar damage pattern, with 31% fruit damage in the eastern side and 16% in the center and western side. It is interesting to note that total fruit damage in the 1991 experiment was quite low in comparison with the previous year. Charmillot (1990) pointed out that codling moth population size decreases gradually year after year, when mating disruption is implemented. In a commercial orchard, where resident populations of codling moth are initially





Figure 10. Spatial distribution of fruits damaged by codling moth (±SE) in mating disruption treatment



Figure 11. Relationship between distribution of larvae per tree and distribution of % fruit damage in mating disruption treatment

Table 5. Mean percentage of fruit damage, after first codling moth generation and at harvest in mating disruption and standard treatments (1991).

Treatment	<pre>% fruit damaged</pre>			
	After 1st generation	After 2nd gen. (harvest)		
Mating disruption	0.90 a	9.20 a		
Standard	0.08 a	0.20 b		

Means followed by the same letter across each column are not significantly different at P<0.05 (Student's t-test).

lower and orchards are larger, greater control of codling moth is more likely than in this experiment.

The non-toxic nature of mating disruption may allow for supplemental natural control of codling moth and other pests, and has the obvious food-safety benefit of fewer pesticide applications.

Mating disruption of codling moth needs to be more fully investigated to understand the dynamics of pests, natural enemies, and non-target arthropods in orchards using this control strategy.

For future trials, pheromone air concentration near the top of the trees could be increased by placing the dispensers in the upper third of the trees. Border effects could be also decreased with larger orchards and by spraying insecticides in the border rows and/or placing a row of dispenser outside the orchard. CHAPTER 2.

CHAPTER 2

Impact of codling moth control with mating disruption on nontarget pests and natural enemies.

INTRODUCTION

Current control programs for codling moth use broad spectrum pesticides, causing significant disruption of nontarget species by reducing natural enemy populations (Westigard, 1979). A major objective in integrated pest management programs (IPM) is the reduction of insecticide sprays to decrease this adverse effect. The potential for disrupting mating with semiochemicals and compatibility of this strategy with other tactics in IPM have been clearly demonstrated for a variety of major pests (Kirsch, 1988; Rothschild, 1981).

Mating disruption to control codling moth could reduce the use of broad spectrum insecticides and, consequently, increase biological control of pests (Brunner, 1991). Control of codling moth with mating disruption has enhanced biological control of the pear psylla, <u>Cacopsylla pyricola</u> (Forster), through the increase in the populations of

predators, primarily <u>Deraecorus brevis piceatus</u> Knight, and <u>Chrysopa carnea</u> Stephens (Westigard and Moffitt 1984).

In Oregon the arthropod complex in pears is comprised of 230 different species of insects, mites and spiders; only 5 percent of these can be considered serious pests, while 40 percent are natural enemies. However, in pear orchards with standard spray programs, it is difficult to find natural enemies since they are very susceptible to insecticides (Riedl, 1991).

The stability of the fruit orchard ecosystem depends greatly on the species diversity of the community members. In all probability, the use of fertilizer and pesticides influences species diversity and stability in commercial orchards to a greater degree than plant successional features (Croft and Hull, 1983).

Using mating disruption for control of codling moth, populations of natural enemies will be able to build, and assist in reducing non-target pests below damaging levels. For some insects, however, the release from insecticide controls will mean that they have the potential to increase to damaging levels (Brunner, 1991). Species like plum curculio, apple maggot and tarnished plant bug tend to invade the orchard anew each year and could become important pests in the absence of insecticide sprays (Croft and Hull, 1983).

The objective of this study was to compare mating disruption to a standard insecticide regime for controlling

codling moth, and to compare how these treatments affect populations of beneficial and non-target insects.

MATERIALS AND METHODS

This study was conducted during 1991 in the same blocks and with the same treatments described in Chapter 1. Each block was considered an unreplicated unit.

Assessment of beneficial species and non-target pests.

Every two weeks from June 5 to September 20, populations of beneficial and other arthropods were sampled with a modified leaf blower/vacuum as a suction sampling device. There were 5 replications (4 trees per replication) uniformly distributed in each block (Fig.12). Each sample consisted of 2 minutes of suction (30 seconds per tree) of tree branches located at about 1.5 m height. The suction was done on selected branches from base to top. Samples were collected in nylon stockings through the suction device and immediately were frozen to kill arthropods and to avoid deterioration. For processing, samples were submerged in water with a small amount of liquid soap to rehydrate the arthropods and facilitate their screening from plant residues. After that, arthropods were transferred to 70% alcohol for later For the major insect orders (Homoptera, identification. Neuroptera, Hemiptera, Hymenoptera, Coleoptera and Diptera),





identifications were done to the family level, with the exception of Chalcidoidea (Hymenoptera), which were identified to superfamily and some families of Diptera, identified as acalypterate muscoids. As an indication of the stability of the system, the Shannon-Weaver diversity index (Price, 1984) was calculated with the following equation:

$H' = -\Sigma p'Ln p'$

where p' is the proportion of the considered family in the total sample. Then, H' depends on the number of families and their abundance (Price, 1984).

For statistic analysis, number of individuals per order was transformed by Log (X + 1) and Student's t-test (Steel and Torrie, 1980).

Assessment of pear psylla and pear rust mite populations.

Population density evaluation of pear psylla and pear rust mite was done with biweekly leaf sampling. From May 29 to September 20, 25 leaves per replication were taken and observed under a stereo microscope. Numbers of eggs, pear psylla nymphs, and pear rust mites were recorded. There were five replications (one tree per replication) uniformly distributed in each block (Fig.12).

Assessment of non-target pest fruit damage.

At harvest, fruit damage evaluation was done in 25 trees per block (5 replications with 5 trees each). One replication was in the center and the others were in the middle of the borders of each block (Fig.12). Twenty fruits were randomly picked per tree from the periphery of trees at head height (100 fruit per replication), and evaluated for damage of: pear rust mite <u>Epitrimerus pyri</u> (Nalepa), pear psylla <u>Cacopsylla</u> <u>pyricola</u> (Forster), plum curculio <u>Conotrachelus nenuphar</u> (Herbst), leafrollers, fruitworms, apple maggot <u>Rhagoletis</u> <u>pomonella</u> (Walsh), and plant bugs.

Percentage of damage was transformed by $\sqrt{x+0.5}$ and analyzed by Student's t-test (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Assessment of beneficial species and non-target pests.

In the mating disruption treatment the analysis of the diversity index values showed little variation throughout the season (Fig.13). In general, it varied from 2.2 to 2.5, however, at the end of the season (September 20), it decreased abruptly to less than 1.5. This decrease could be due to the emigration of some species out of the orchard, or onset of overwintering. The standard treatment showed a significantly lower diversity index with the exception of the September 20 evaluation. There was a clear decrease in its value from the beginning of June to the end of July, while there was a slow increase from August to the end of September. This change in the diversity index was likely due to the insecticide


Figure 13. Mean (\pm SE) diversity indices in different dates in mating disruption and standard treatment. Means follow by the same letter on each date are not significantly different (Student-t test P< 0.05)

applications during June and July, and the lack of insecticides during August and September.

In general, the higher the diversity index, the more balanced the arthropod community. In mating disruption treatment, families from the orders Homoptera, Hemiptera, Hymenoptera, Coleoptera, Diptera and Araneae were nearly equally abundant, while in the standard block, by far, the most abundant family was Psyllidae (Table 6).

Insecticides may greatly reduce the number of insect species occupying the orchard ecosystem, favoring organisms with high dispersal capabilities and pesticide resistant forms (Croft and Hull, 1983). Oatman et al., (1964), noted approximately 763 arthropod species in unsprayed apple orchards in Wisconsin, including approximately 100 plant feeders, but in commercial orchards in the same region, only 5 -15 pest species were present at high densities, and most natural enemies were absent (Croft and Hull, 1983). Intensively sprayed orchards had also higher relative abundance of r-strategist species while the IPM managed orchard had higher abundance of k-strategist species (Croft and Hull, 1983).

The response of different insect orders to both treatments (insecticide and non-insecticide) was different depending on the specific order considered (Table 6).

Homoptera was consistently higher in the standard treatment (Fig.14). The main reason for this is the Psyllidae

ORDERS	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Homopter	a							
ST	111.0	95.0	75.0	301.0	378.0	394.0	288.0	30.0
MD	48.2	41.0	48.6	24.0	40.0	14.7	36.8	5.0
	*	*	NS	*	*	*	*	*
Neuropte	era			······································				
ST	0.2	0.2	0.4	1.4	0.2	0.4	0.4	0.0
MD	0.2	0.2	0.2	2.6	2.2	1.2	2.2	1.0
	NS	NS	NS	NS	*	NS	*	NS
Hemipter	a							
ST	0.4	1.6	0.0	1.0	2.0	20.6	34.9	0.8
MD	2.2	3.0	2.6	2.8	2.6	1.7	9.8	0.4
	*	NS	*	NS	NS	*	*	NS
Coleopte	era							
ST	2.8	4.8	8.6	13.6	2.8	3.8	0.8	0.0
MD	6.0	10.2	17.6	22.2	21.4	11.5	4.6	0.2
	NS	*	*	*	*	*	NS	NS
Parasitic Hymenoptera								
ST	11.0	4.2	3.0	5.0	2.0	3.6	4.2	0.0
MD	12.0	12.4	19.0	21.8	28.4	11.2	17.8	0.8
	NS	*	*	*	*	*	*	NS
Non para	sitic H	iymenop	tera					
ST	0.4	0.8	0.4	1.4	0.2	0.4	20.2	5.8
MD	2.8	1.2	1.6	0.4	0.0	0.0	0.4	0.2
	*	NS	NS	NS	NS	NS	*	*
Diptera								
ST	44.8	14.8	11.0	14.6	7.8	8.2	5.8	2.4
MD	28.0	26.2	13.0	13.2	15.4	16.2	21.8	2.0
	NS	NS	NS	NS	*	*	*	NS
Araneae							_	
ST	0.4	0.6	0.4	3.0	1.2	1.2	1.0	0.2
MD	1.5	2.8	10.6	13.2	16.0	11.8	8.2	4.6
	*	*	*	*	*	*	*	*
Others								
ST	0.2	1.2	0.0	1.0	1.8	0.0	0.8	0.0
MD	4.2	2.8	0.8	3.4	2.4	2.0	1.4	0.2

Table 6. Mean arthropod numbers per sample in standard (ST) and mating disruption (MD) treatments over the growing season.

* : Student's T-test (P>0.05), significantly different between treatments in each date and each order.





Standard treatment

Figure 14. Mean Homoptera numbers in suction samples in mating disruption and standard treatments

family, specifically pear psylla. Avermectin, used only once in the season in the mating disruption treatment, was enough to keep the psylla populations at very low levels, while standard insecticide sprays (azinphos-methyl and amitraz) were unable to do that in the standard treatment. Cicadellidae was another abundant family, but it was much more common in the mating disruption treatment than in the standard treatment. However, leafhopper damage was not observed in this treatment.

Neuroptera (Fig.15) had the highest population in the middle of July, but in general it was not very abundant. For most of the season, there were non significant differences between the two blocks, and only on July 31 did the mating disruption treatment have statistically higher populations. Chrysopidae was slightly more common than Hemerobiidae.

Hemiptera (Fig.16) populations were relatively low and stable during June and July, however, in August and September there was a tremendous increase of Anthocoridae, mainly in the standard treatment. Two main reasons for this increase could be that during this period, there were no insecticide sprays, and probably, food for these predators was much more abundant in the standard than in the mating disruption treatment. Generalist predators migrate from surrounding areas, depending of the food availability, thus surrounding vegetation and its attendant complex of prey and predators may have an indirect, but important effect on biological control of psylla within particular orchards (Gut et al., 1981). For successful



Standard treatment



Figure 15. Mean Neuroptera numbers in suction samples in mating disruption and standard treatments



Mating disruption treatment

Standard treatment



Figure 16. Mean Hemiptera numbers in suction samples in mating disruption and standard treatments

seasonal biological control of pear psylla, it is important that the interaction between natural enemies and pear psylla begins early in the season and continues through the summer into fall. Late immigration of natural enemies is often the cause for failure since pear psylla has a high reproductive potential, and if natural enemies arrive too late, they cannot catch up to psylla population before an economic threshold is reached (Riedl, 1991).

The brown and the green lacewings (Neuroptera), and the minute pirate bugs and <u>Deraecoris</u> are very important and common predators in fruit orchards, but the timing when these predators are present in relation to the developmental stage of the prey is crucial (Cossentine, 1990).

Information showed by Riedl (1991) for Northern Oregon conditions pointed out that Hemipterans were the predominant psylla predators (87%) late in the season in unsprayed pear orchards.

Parasitic Hymenoptera (Fig.17) populations were dominated by the superfamily Chalcidoidea, followed by Braconidae. Parasitoids are one of the most important biological control agents for many pests, however there are many conflicts with their use in commercial orchard crops, due to the desvasting effect of the chemical control (Croft and Bove, 1983). This effect is clearly noted in the seasonal pattern of Hymenoptera in the two treatments. In the mating disruption treatment Hymenoptera populations increased gradually over the season



Standard treatment



Figure 17. Mean parasitic Hymenoptera numbers in suction samples in mating disruption and standard treatments

with a peak at the end of July, while the standard treatment had a very low population level throughout the season. At the beginning of the season, before many insecticides were applied, there were no significant differences between the two treatments. Oatman et al., (1964) found in unsprayed apple orchard in Wisconsin, that Hymenoptera was the largest order represented by 28 families.

Non-parasitic Hymenoptera (Fig.18) were mainly and some few specimens from Vespidae and Formicidae, Halictidae. The role of Formicidae as a biological control agents is still not clear, but behavioral observations in Washington indicate that ants are effective predators of pear psylla and could play an important role in future pear psylla management (Akre, 1988). Our results show similar population trends in Formicidae in both treatments up to August. Late in the season, the standard treatment had a significant increase in the ant populations. High psylla populations and no insecticide sprays late in the season, could play an important role in this high population level.

Lathridiidae and Corylophidae were the most abundant Coleoptera families (Fig.19), with similar seasonal pattern variation in both treatments. However, in the mating disruption treatment they were always significantly higher than in the standard treatment. Corylophidae and Lathridiidae do not have direct effects on pear pest population, they feed on decaying vegetation and moldy materials (Borror et al.,



Standard treatment



Figure 18. Mean non-parasitic Hymenoptera numbers in suction samples in mating disruption and standard treatments



Mating disruption treatment

Standard treatment



Figure 19. Mean Coleoptera numbers in suction samples in mating disruption and standard treatments

1989). Surprisingly lady beetles, cited as an important predators on psylla (Riedl, 1991) and other pests, were found infrequently.

An overall view of the Diptera (Fig. 20 and 21) shows relatively similar variation pattern in both treatments, but with slightly higher populations in the mating disruption treatment. However, during August and September, Brachycera became significantly higher in the mating disruption treatment, due to the increase of Drosophilidae. Fruit overripening without insecticide spray during all the season was probably the main reason of this increase.

Araneae was another order with important differences between the two treatments (Fig.22). Mating disruption treatment always had significantly higher populations of spiders, frequently more than 10 fold differences, with the highest peak at the end of July. Araneae seems to be very susceptible to pesticides. Specifically amitraz is a very toxic material for spiders (Staubli, 1984). The role of spiders as biological control agents is not clearly understood. Riedl (1991) pointed out for the conditions of Northern Oregon that spiders are commonly found on unsprayed pear trees, but their role as predators is still not well Gut et al., (1991) examined the arthropod understood. communities on pear. The most abundant species of general predators were several species of spiders (e.g. Theridion <u>differens</u> (Emerton), <u>Gnathantes ferosa</u> (Chamberlin & Ivie),





Standard treatment



Figure 20. Mean Nematocera numbers in suction samples in mating disruption and standard treatments





Standard treatment

Figure 21. Mean Brachycera numbers in suction samples in mating disruption and standard treatments



Standard treatment



Figure 22. Mean Araneae numbers in suction samples in mating disruption and standard treatments

<u>Metaphidippus mannii</u> (G.& E.Peckham), and <u>Misumenops</u> sp; <u>Chrysoperla carnea</u> (Stephens), <u>Podabrus</u> sp; <u>Deraecoris brevis</u> <u>piceatus</u> (Knight) and <u>Forficula auricularia</u> (L). Their maximum population density occurred during the summer.

As a general observation on the overall orders, phytophagous orders like Homoptera were always higher in the standard treatment. Orders with potential predators such as Hemiptera and non-parasitic Hymenoptera were higher in the standard treatment at the end of the growing season. While parasitic Hymenoptera and Araneae were always higher in the mating disruption treatment. For these two orders, azinphosmethyl and amitraz are considered very harmful pesticides (Staubli, 1984).

Assessment of pear psylla and pear rust mite populations.

In the standard treatment pear psylla nymphs and eggs had relatively constant levels until early July, but then increased rapidly with the higher populations at the end of August (Fig.23). Burts (1988) estimated an action threshold of 0.3 nymphs per leaf for pear psylla populations. This threshold was reached from the beginning of July when amitraz sprays were suspended. As a standard commercial practice, the two sprays of amitraz were applied on May 29 and June 24. In the mating disruption block (Fig.24), the population was near the action threshold level only at the end of the season. It is important to note that probably the main factor that





Figure 23. Mean (\pm SE) pear psylla eggs and nymphs per leaf sampled with leaf sampling in standard treatment





Figure 24. Mean (<u>+</u>SE) pear psylla eggs and nymphs per leaf sampled with leaf sampling in mating disruption treatment

allowed this situation was the spray of avermectin on May 14. Control of codling moth with mating disruption plus only one spray of avermectin at petal fall was sufficient to keep psylla populations below the economic injury level.

In the standard treatment, pear rust mites on leaves were most abundant at the beginning of August (Fig. 25). There were no pear rust mites found in the mating disruption treatment.

Assessment of fruit damage.

Harvest evaluation (Table 7) showed that plum curculio and apple maggot caused a relative damage in the mating disruption treatment, while in the standard block damage was almost 0. This situation could be an important disadvantage for the development of the mating disruption technique. These pests will become economically important if no insecticide sprays are used.

Pear rust mite produced high percentage of fruit damage in both treatments. However, in the mating disruption treatment, there were no pear rust mite populations found by leaf evaluation. This situation could be due to the relatively late spray of avermectin (May 14). Early control of this pest is very important to avoid fruit damage.

The standard treatment had a high percentage of fruit damaged by pear psylla, while it was almost 0 in the mating disruption treatment. This evaluation was coincident with the

Table 7. Fruit damage by non target pests, at harvest, in disrupted and standard treatments.

PESTS	<pre>% fruit damage in mating disruption treatment</pre>	<pre>% fruit dama in standard treatment</pre>			
Plum curculio	6	0.4	*		
Tarnish plant bug	0.4	0.8	NG		
Leaf rollers	1	0	NG		
Green fruitworm	0.4	0.2	NG		
Apple maggot	3	0	*		
Pear psylla	0.2	43.6	*		
Pear rust mite	52.2	94.6	*		

*: Student T-test (P>0.05), significantly different between treatments.



Figure 25. Mean (\pm SE) numbers of pear rust mites per leaf sampled with leaf sampling in the standard treatment

leaf sampling evaluation.

Besides the effectiveness of mating disruption to control codling moth, results showed a promising effect of the reduction of insecticides by increasing species diversity, with a very remarkable effect in the population increase in parasitic Hymenoptera and Araneae. This could play an important role in the pear ecosystem stability. On the other hand, non-target pests like plum curculio and apple maggot, must be carefully considered to avoid potential economic loss under mating disruption conditions. SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

The overall objectives of this research were to determine the feasibility of mating disruption technique for commercial use on pear and to evaluate its effects on arthropod populations.

Based on pheromone trap captures, virgin female traps captures, fruit damage, overwintering larvae and suction sampling of arthropod populations we make the following conclusions:

The evaluation of mating disruption with pheromone traps showed very different results depending on the location of the pheromone traps. If they are located in the middle of the tree, disruption of mating appeared to work very well, but if they are located near the top of the trees, complete disruption of mating did not occur. Pheromone molecules behavior and moth behavior at the top of the trees and near border areas are two factors involved in these results. More research will be necessary to clarify the effect of these factors.

Traps baited with virgin females showed similar results to pheromone traps, but variability of captures was high.

Fruit damage at harvest in the mating disruption

treatment while lower than 1990, was not commercially acceptable, with 9.2% of fruit damage.

Evaluation of the overwintering larvae population through corrugated cardboard bands on the trees trunk showed important differences between the standard and the mating disruption treatment (0.26 larvae/tree and 8.47 larvae/tree, respectively). This evaluation was highly correlated with the fruit damage evaluation.

The diversity index of arthropod families was consistently higher in the pheromone treated orchard, indicating a more stable condition for this system.

The groups of arthropods that showed more dramatic differences between the two treatments were pear psylla, parasitic Hymenoptera and Araneae. Pear psylla populations in the standard treatment were always much higher, while the beneficial arthropods, parasitic Hymenoptera and Araneae, were always higher in the mating disruption treatment.

Fruit damage produced by non-target pests like plum curculio and apple maggot were higher in the mating disruption treatment, showing a potential danger if no insecticides are used.

It is still necessary to clarify and modify some factors that decrease the effectiveness of mating disruption, but the potential for improving pest management on pear is high. The most interesting feature of this technique, besides the codling moth control, is the possible increase of the long

term stability of the pear system, through more balanced arthropod community. The dramatic increase of beneficials in mating disruption trials could control many phytophagous pest organisms below the economic injury level, but constant monitoring of potential damaging pests is crucial to avoid unexpected crop damage.

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APPENDIX

APPENDIX

Family numbers per order in suction samples.

FAMILIES TREAT. 6\5 6\19 7\2 7\16 7\31 8\20 9\3 9\20 Psylli-ST 110 94 72 297 371 393 287 30 dae MD 22 8 9 7.8 12 11.5 31 5.2 ST Cerco-0.4 0.6 0.2 0 0 0 0 0 pidae MD 0.2 5.6 3.4 3 2 0 0.6 0 Cicade-ST 0 0 1.2 3.4 2.6 0.6 0.4 0 llidae MD 26 27 35.4 13.4 24.8 3.2 4.2 0 Aphididae ST 0.2 0 0.6 0 0.4 0 1.4 4.2 MD 0 1 0.8 0.2 1.6 0 1 0

Table A 1. Mean Homoptera numbers in standard and mating disruption treatments.

Table A 2. Mean Neuroptera numbers in standard and mating disruption treatments.

FAMILIES	TREAT	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Chryso- pidae	ST MD	0 0	0 0	0 0	0 0	0 1	0,2 0.8	0 1.2	0.6
Hemero- biidae	ST MD	0	0 0.2	0 0	0.2	0 0.2	00.4	0.2	0 . 4
Lacewing larvae	ST MD	0.2	0.2	0.4	1.2 2.6	0.2 1	0.2	0.2 0.4	0 0

FAMILIES	TREAT	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Antho- coridae	ST MD	0 0	0.2	0 0	0 0	0.4	19.8 0.2	30 8.8	0.2
Nabidae	ST MD	0 0	0 0.6	0 0	0 0	0.6 0.6	0 0	0 0.2	0 0.2
Miridae	ST MD	0.2	0.8 1	0 1	0.4 1.2	0.4 1.4	0.6 0.75	4.5 0.4	0 0
Reduviidae	ST MD	0.2 1.2	0.6 1.2	0 1.4	0.4 1.2	0.2	0 0	0 0	0 0.2
Pentato- midae	ST MD	0 0	0 0	0 0	0.2	0 0.2	0.2	0.4	0.6
Tingidae	ST MD	0.5	0 0	0 0	0 0	0.4	0 0	0 0	0 0
Piesma- tidae	ST MD	0.5	00.2	00.2	0 0	0 0	0 0	0 0	0 0

Table A 3. Mean Hemiptera numbers in standard and mating disruption treatments.

FAMILIES	TREAT.	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Chalci- doidea	ST MD	10.4 9.5	4 10.4	2.4 13.8	4.4 19.6	2 24.8	3.6 9.5	2.6 14.8	0 0.4
Ichneu- monidae	ST MD	0.5	0.2	0.4	0.2	0.8	0.6	0.6	0.2
Braco- nidae	ST MD	0.6	0 0.4	0 2.6	0.2	0 2.2	0 1	0.2	0 0
Procto- trupidae	ST MD	0	0 0.2	0.2	0	0	0 0	0.2	0
Eucoi- lidae	ST MD	0	0	0 2	0 0.8	0.4	0	0.4	0.2
Figi- tidae	ST MD	0	0	0	0	0	0	0.2	0
Ceraph- ronidae	ST MD	0 1	0	0 0	0	0	0	0 0	0 0
Diaprii- dae	ST MD	0	0	0 0	0.2	0	0 0	0 0	0 0

Table A 4. Mean parasitic Hymenoptera numbers in standard and mating disruption treatments.

FAMILIES	TREAT.	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Formi- cidae	ST MD	0.4 2.8	0.8	0.4	1.4 0.4	0.2	0.4	19 0.4	5.6
Vespidae	ST MD	0 0	0 0	0	0 0	0 0	0 0	1.2 0	0.2
Halic- tidae	ST MD	0 0	0 0	0 0	0 0.2	0 0.2	0 0	0 0	0 0

Table A 5. Mean non-parasitic Hymenoptera numbers in standard and mating disruption treatments.

FAMILIES	TREAT.	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Lathri- diidae	ST MD	1.2 3.5	3.8	5.8 7.2	12.2 17	1.6 15.4	2.8 9.7	0.2 3.2	0.2
Corylo- phidae	ST MD	1.2 1.75	1 4.4	2.2	0.8	0.2 3.8	0.6	0.4	0 0
Curculio- nidae	ST MD	0 0	0.4	0.6 2.6	0.6	0.4	0	0	0 0
Chrysome- lidae	ST MD	0 0	0.2	0 0	0.2	0.4	0.4	00.2	0 0
Elate- ridae	ST MD	0.2	0.2	0.4	0 0	0.2	0	0	0 0
Lampy- ridae	ST MD	0 0	0.4	0 0	0 0	0 0	0 0	0	0 0
Cantha- ridae	ST MD	0.2	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Coccine- llidae	ST MD	0 0	0 0	0 0	0 0	0	0 0	0	0 0
Cleridae	ST MD	0	0 0.4	0 0	0	0 0	0 0	0 0	0 0
Anobiidae	ST MD	0 0	0	0 0.4	0	0.2	0	0 0.2	0 0
Carabidae	ST MD	0	0	0 0	0	0	0 0	0.2	0 0
Scoliti- dae	ST MD	0 0	0 0	00.2	0 0	0 0	0 0	0 0	0 0

Table A 6. Mean Coleoptera numbers in standard and mating disruption treatments.

FAMILIES	TREAT.	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Sciaridae	ST MD	36.4 3.2	4 3.8	00.6	0.6	0.6 2.2	0.8 3.25	0 1	0 0
Chirono- midae	ST MD	0.2 2.25	0.2 2.2	0 0	00.2	0.8 3.2	0.6	0.4 2.2	0
Cecido- myiidae	ST MD	0.2 1.75	0.2	0 0.2	0.6	0 0.2	0 0.2	0 0	0
Tipulidae	ST MD	0 1.75	0 0	0 0	0 0	0 0	0 0	0.6	0 0
Myceto- philidae	ST MD	0.2	0.4	0 0	0 0	0 0	0 0	0 0	0 0
Culicidae	ST MD	0 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Cerato- pogonidae	ST MD	0.4 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0
Scatop- sidae	ST MD	0 2.2	0 0	0 0	0	0	0	0	0 0
Unidenti- fied	ST MD	0.2	0 1.4	0 0	0 0	0 0	0 0	0.2	0 0

Table A 7. Mean Nematocera numbers in standard and mating disruption treatments.

FAMILIES	TREAT.	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Chloro- pidae	ST MD	2.2	2 5	4.2 2.8	5.6	3.4	3 2.25	1.2 0.6	0.4
Tephri- tidae	ST MD	0 0	0.4	0.2	4 0.6	0.4	0.6	0 0	0 0
Drosophi- lidae	ST MD	1	0.2 3.4	0 2	0.6	0.8 0.6	1.87.7	1.8	1.2
Dolicho- podidae	ST MD	2.4 3.5	4.6 6.6	3.2 2	1.2 2.8	1.2	0.4	0.6 0.2	0.2
Phoridae	ST MD	0	0.8	0.4	0.2	0.4	0 0.2	0 0.2	0 0
Empididae	ST MD	0.4	0.2	0.2	0 0.2	0 0.4	0.2	0.8	0 0
Tabani- dae	ST MD	0 0.25	0 0	0	0 0	0	0 0	0 0	0
Asilidae	ST MD	0 0.25	0 0	0 0	0 0	0 0	0 0	0 0	0
There- vidae	ST MD	0.2	0 0	0 0	0.2	0 0	0 0	0.2	0
Syrphi- dae	ST MD	0 0	0.2 0.4	0 0	0 0	0 0	0.4	0 0	0 0
Muscidae	ST MD	0.4	0.6	0.6 0.2	0 0	0 0	0 0	0 0	0.2
Sarco- phagidae	ST MD	0 0	0 0.2	0.4 0.2	0.2 0	0 0	0.2	0.2	0.2
Callipho- ridae	ST MD	0 0	0 0	0 0	0 0.2	0.2	0 0	0 0	0 0
Tachi- nidae	ST MD	0.4	0 0	0 0	0 0	0.2	0.2	0.2	0
Unident. Acal.mus.	ST MD	0.2 1.2	1.4 2	2 1.6	1.4 1	0.2	0.2	0.4	0.6 0.2

Table A 8. Mean Brachycera numbers in standard and mating disruption treatments.
ORDERS	TREAT.	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Trichop- tera	ST MD	0 0	0 0	0 0	0 0	0 0	0 0	0.2	0 0
Orthop- tera	ST MD	0 3	00.4	0 0	0	0 0	0 0	0 0.2	0 0
Thysanop- tera	ST MD	0 1	0.2	0 0	0.8	0 0	00.2	0.4	0 0
Lepidop- tera	ST MD	0 0	0 1	0.6	0.2 1.4	0.8	0 0	0 0	0 0
Psocop- tera	ST MD	0.25	0 0	0.2	0.6	1 1	0 0	0 0	0 0
Unident. larvae	ST MD	0 0	0 0	0 0	0 0.2	0 0.6	0 1.4	0.2	0 0.2

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Table A 9. Mean other insect orders numbers in standard and mating disruption treatments.

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ORDER	TREAT	6\5	6\19	7\2	7\16	7\31	8\20	9\3	9\20
Araneae	ST MD	0.4 1.5	0.6 2.8	0.4 10.6	3 13.2	1.2 16	1.2 11.8	1 8.2	0.2
Opiliones	ST MD	0 0.75	0 0	0 0	0 0	0 0	00.4	0 0.4	0
Acari	ST MD	0 0	1 1.4	0 0	00.8	0 0.4	0 0	0 0	0 0

Table A 10. Mean non-insect orders numbers in standard and mating disruption treatments.

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