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Mating disruption of codling moth: a perspective from the Western United States

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Abstract: An historical perspective is provided of pest management programs in western apple orchards using the Washington situation as an example. The adoption of mating disruption as a key pest management tactic in western pome fruit orchards has resulted from the availability of new technology, a changing regulatory environment, concerns about food safety, and large-scale demonstration projects. Organization of the Codling moth Areawide Management Project (CAMP) is discussed. Results from a specific case study of one CAMP site, Howard Flat, are discussed in detail with comparisons made to other CAMP sites. The future of pheromone-based pest management programs is discussed relative to their long-term stability, research needs, and continuing changes in the US pesticide regulatory environment.

Key words: mating disruption, codling moth, codling moth areawide management project

Historical perspective

History can be a great teacher. By understanding the past we may be better able to understand the present and anticipate the future. A brief history of Pacific Northwest apple pest control is presented in order to place in perspective recent changes in programs. This history provides the foundation on which the current program has been built and now becomes the new basis for assessing future change.

In the 1960s, a crisis was developing in Washington's apple production system. Reliance on chlorinated hydrocarbon insecticides for control of the region's key pest, the codling moth, *Cydia pomonella* L., resulted in increased problems with spider mites, specifically the McDaniel spider mite, *Tetranychus mcdanieli* McGregor, and European red mite, *Panonychus ulmi* (Koch). Specific miticides were employed to control spider mites, but resistance to these products developed rapidly. It was common in late summer for apple orchards to take on a brownish cast due to injury by spider mites, even after several miticides had been applied. Growers were facing a crisis and, as so often happens, this was the environment in which a radical shift in pest control could occur. Dr. Stan Hoyt (WSU-TFREC) observed that in some orchards where lower rates of organophosphate (OP) insecticides were used spider mites were less of a problem. His detailed research in integrated mite management culminated in what is still recognized as a breakthrough in pest management (Hoyt 1969). He showed that the western predatory mite, *Galandromus occidentalis* (Nesbitt), could tolerate low rates of certain OP insecticides and provide biological control of spider mites and that these low rates of OP insecticides provided adequate control of the key pest, codling moth. Growers rapidly adopted the principles of integrated mite management, and by the end of the 1960s most Washington growers had stopped applying specific miticides in apple orchards.

The apple pest management program was stable throughout the 1970s. Codling moth was controlled using below maximum label rates of OP insecticides, with an average of about two applications per hectare per year. Biological control suppressed spider mites below damaging levels in most orchards. Resistance to OP insecticides began to appear in some secondary pest insects such as the white apple leafhopper, *Typhlocyba pomaria* (McAtee), and apple aphid, *Aphis pomi* (De Geer); however, these pests could be controlled with selective insecticides at relatively low rates in a manner that did not disrupt biological control of spider mites.

In the 1980s, there was an erosion in stability of the apple pest management program. Leafrollers, *Pandemis pyrusana* Kearfott and *Choristoneura rosaceana* (Harris), appeared as serious problems in some orchards (Brunner 1984). The increased problems with leafrollers were tied to reduced efficacy of certain OP insecticides, especially chlorpyrifos (Brunner 1991). A new pest appeared, the western tentiform leafminer (WTLM), *Phyllonorycter elmaella* Doganlar & Mutuura. The increase in pest status of the leafminer was thought to be associated with the development of resistance to OP and most carbamate insecticides. The only effective insecticide against WTLM was oxamyl, a carbamate insecticide that was highly toxic to the western predatory mite. Thus, the WTLM problem caused an erosion in integrated mite management programs in some orchards. Some stability was returned to the apple pest management system when research showed that a small parasitoid, *Pnigalio flavipes* (Ashmead), was an effective biological control of WTLM (Barrett and Brunner 1990). Codling moth control using OP insecticides was still effective; however, by the end of the 1980s the average number of insecticide applications for this pest had risen to almost three per year (Table 1). There was interest in introducing synthetic pyrethroids into the apple pest management system during the 1980s, but recognition of the detrimental impact on integrated mite management (Croft et al. 1987), and pest management in general, resulted in growers rejecting use of these products for pest control.

In the early 1990s, growers were facing increasing difficulties controlling codling moth, and resistance to certain OP insecticides, especially azinphosmethyl, was reported (Dunley and Welter 2000, Knight et al. 1994, Varela et al. 1993). In Washington, the increased problem controlling codling moth were reflected in the gradual increase in the average number of applications per hectare per year (Table 1). Leafrollers problems occurred in more orchards (Brunner 1994b), and growers were seeking ways to control this pest without disrupting biological control of other pests (Brunner 1994a), especially spider mites and WTLM. The concern about the impact of agricultural chemicals on the environment and residues on food fueled public debate and scientific inquiry (NAS 1993). Research on mating disruption as a viable alternative for controlling pests in fruit crops was stimulated by success against the oriental fruit moth, *Grapholitha molesta* (Busck), (Rothschild 1975, Weakley et al. 1987) and promising evaluations against the codling moth (Knight 1996, Gut and Brunner 1998).

Table 1. Average number of insecticides applied per acre and the percent of acres treated at least one time to apple in Washington from 1989 to 1999.

Insecticide treatment	Average number of applications per acre (% total acres treated)					
	1989[a]	1991[b]	1993[b]	1995[b]	1997[b]	1999[b]
azinphosmethyl	2.9 (98)	2.8 (90)	3.3 (81)	3.3 (94)	2.9 (91)	2.3 (78)
phosmet	2.4 (4)	2.1 (9)	1.1 (19)	2.4 (2)	1.2 (<1)	2.0 (7)
methyl parathion	1.1 (17)	1.5 (28)	1.2 (24)	1.2 (19)	2.0 (33)	1.1 (5)
ethyl parathion	1.2 (42)	1.0 (32)	1.0 (8)	nr [c]	nr	nr
chlorpyrifos	1.3 (56)	1.4 (65)	1.3 (85)	1.3 (80)	1.4 (91)	1.3 (78)
Bacillus thuringiensis	-	-	1.9 (24)	2.2 (21)	1.5 (26)	2.0 (19)
esfenvalerate	-	-	-	-	-	-
spinosad	nr	nr	nr	nr	nr	1.4 (39)

a Survey of pesticide use in Washington – (Beers and Brunner 1991)
b NASS (National Agriculture Statistics Service) survey of pesticide use in tree fruit.
c not registered

Changing regulatory environment

The Food Quality Protection Act of 1996 (FQPA) set the stage for radical change in pest management programs in US agriculture. This law established a new standard for determining risk of a pesticide, that there would be "a reasonable certainty that no harm will result from aggregate exposure." This law required all pesticides to be evaluated within 10 years starting with those deemed of greatest risk to humans, i.e. the OP insecticides. The result of FQPA has been elimination or restriction in the use of most broad-spectrum pesticides, especially on crops that are important foods for infants and children. Apple, pear and peach are all important foods for infants and children in the United States. While there remains a great deal of uncertainty about the final effect of FQPA on tree fruit production, it is not too difficult to realize that yesterday's pest management programs will look much different than tomorrow's.

Codling moth mating disruption

Codling moth is the "key" pest in western apple and pear orchards. It is primarily controlled by summer applications of three to four broad-spectrum insecticides per year (Beers and Brunner 1991, NASS 1994, 1998, 2000). Insecticides used to control codling moth constitute over half of all insecticides applied to apple during the summer months. Toxicity of these broad-spectrum insecticides to most natural enemies has severely limited opportunities for biological control of many pests in western apple orchards.

The use of sex pheromones has been investigated as a selective control for codling moth since the early 1980s, but it was not until the early 1990s that reliable commercial products were available to growers in the United States. Initial studies demonstrated the potential of using pheromones to control codling moth (Knight 1996, Gut and Brunner 1998), but they also pointed to areas of concern. For example, under conditions of high codling moth densities, mating disruption was not an adequate "stand-alone" tactic. In addition, orchard borders had consistently higher levels of fruit injury than orchard interiors, and leafrollers increased as a problem where mating disruption was used for codling moth and broad-spectrum insecticide use was reduced. Even with these limitations, growers began adopting codling moth mating disruption (CM-MD), and by 1994 an estimated 4,800 hectares in Washington were being treated (Figure 1).

Codling moth areawide management

In 1994 a proposal was submitted to federal agencies for funding of a Codling Moth Areawide Management Project (CAMP). The goals of CAMP were: (1) to control codling moth using mating disruption as the primary tactic over large contiguous areas; (2) to reduce the use of broad-spectrum insecticides by 80% over five years; (3) to assess changes in pests and natural enemies in "areawide" sites over time; and (4) to enhance the biological control of secondary pests.

CAMP was funded by a special allocation from the Agricultural Research Service of the United States Department of Agriculture (USDA-ARS) for the implementation of an areawide pheromone-based codling moth management program in the western United States. The project involved scientists at the USDA-ARS laboratory in Wapato, Washington; Washington State University; Oregon State University; and the University of California, Berkeley. Five CAMP sites were selected, three in Washington and one each in Oregon and California. Each CAMP site had its own unique character representing different combinations of fruit crops, farming practices, codling moth populations, and resistance levels, and ecological settings (Calkins 1998).

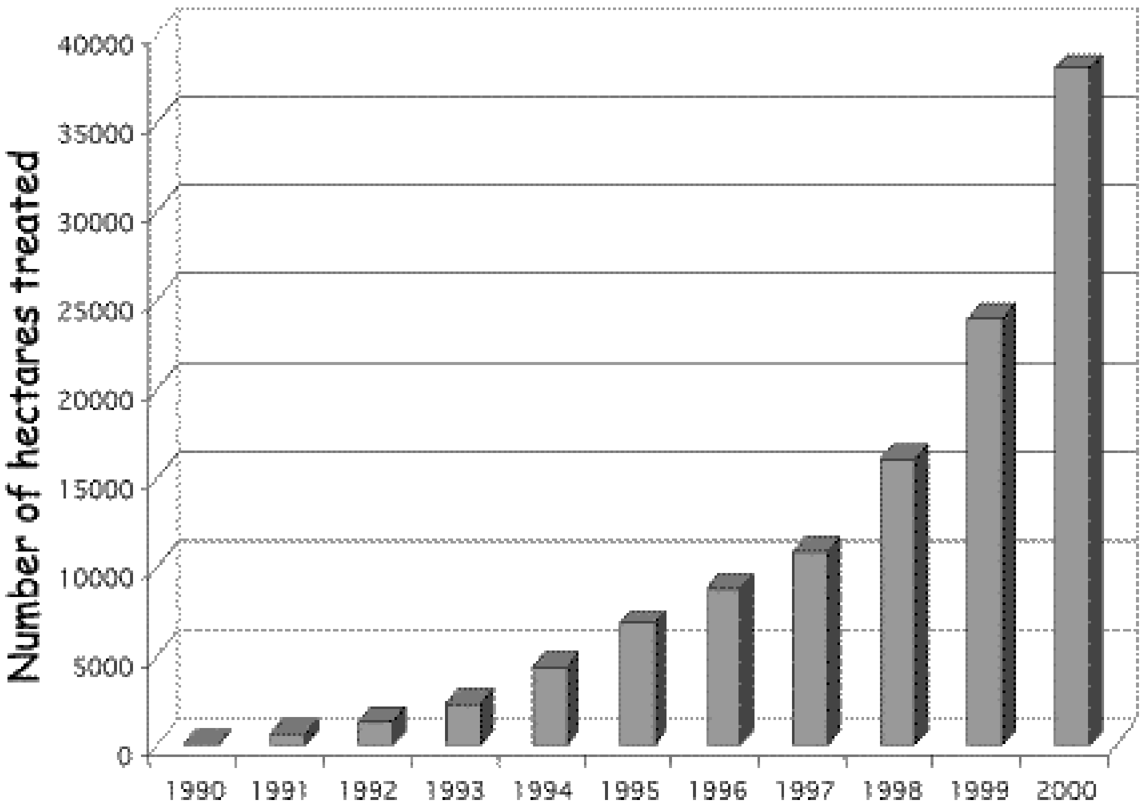

Figure 1. Area treated with mating disruption products for management of codling moth in Washington State from 1990 to 2000.

Pear was the predominant crop grown at the two CAMP sites in Oregon and California. The Randall Island CAMP site (300 hectares) in California had actually been initiated in 1993 in response to high levels of codling moth resistance to OP insecticides. In this crisis situation, CM-MD was seen as an alternative that could be used to reduce the number of insecticide sprays and as a possible resistance management tactic. The Carpenter Hill CAMP site located in southern Oregon near Medford (180 hectares) used CM-MD to reduce broad-spectrum insecticide use in summer as a strategy to encourage biological control of another serious pest, pear psylla, *Cacopsylla pyricola* (Foerster).

The three CAMP sites in Washington represented a mix of orchard production practices found throughout the state. The Parker Heights CAMP site near Yakima was a mixture of apple, pear and stone fruits (160 hectares). The Lake Osoyoos CAMP site was located in the Okanogan valley and bordered Canada. This site was primarily apple (160 hectares) and used a novel approach of combining CM-MD, reduced insecticide applications and release of sterilized codling moth. Sterile codling moths were provided by a Canadian program as part of a cooperative effort to seek new technologies for pest control in orchards. The Howard Flat CAMP site was primarily an apple production area (440 hectares) located near Chelan.

To encourage participation in CAMP and to reduce the economic risk to growers of using CM-MD, CAMP provided $125/hectare ($50/acre) to growers as a means of subsidizing the cost of the pheromone that at full rate was $275/hectare ($110/acre). This subsidy was only provided for the first three years of the project, and in the last two years growers paid all the pheromone costs. Growers at most sites decided to use the Isomate-C mating disruption product (Pacific Biocontrol) but at some sites, at least in the initial years, growers also used the CheckMate-CM product (Consep, Inc.).

Standard protocols were adopted for monitoring codling moth and other pests across all CAMP sites as a means of comparing project results. Codling moth were monitored using “high-load” (10 mg codlemone) lures changed every three weeks in the spring and every two weeks in the summer. Wing-type traps were used and these were placed in the upper 1/3 of the canopy or just below the placement of the pheromone. In addition, orchards outside the CAMP sites within each region were monitored for pest and natural enemy populations and crop damage using the same methods employed in CAMP sites. These orchards used conventional methods of pest control and provided a means of contrasting results with CAMP sites.

Howard Flat CAMP site - a case study

A detailed discussion of the Howard Flat CAMP site provides an insight into the experiences encountered in CAMP. Thirty-six growers produced fruit at the Howard Flat site, and in various ways these growers received guidance from 16 crop consultants in the production of their crop. Growers and crop consultants met to elect a Management Board consisting of three growers and five crop consultants. The Management Board hired a Project Coordinator who was responsible for the intensive monitoring of codling moth and leafrollers. Crop consultants or growers were responsible for monitoring other pests. Information collected by the Project Coordinator was shared weekly with all participants through a newsletter and by posting the data on a bulletin board located within the project boundaries. Decisions to apply pest controls were the responsibility of the grower based on recommendations of crop consultants. Scientists associated with CAMP provided technical support to the Howard Flat Management Board, assisting them in making decisions and setting direction for the project.

Data from 1994 on pesticide use, codling moth damage and moth captures in pheromone traps were obtained as a baseline for the Howard Flat CAMP site. An average of 2.9 insecticides per hectare was applied for codling moth control in 1994 with an average crop loss of 0.8%. In the spring of 1995, CM-MD products were applied to orchards of 34 growers at Howard Flat. Two growers had decided not to participate in the project, underscoring the point that participation was totally voluntary. In the first three weeks of codling moth flight over 3,000 moths were captured in 450 traps. However, following application of the first insecticide, moth captures declined to low levels where they remained the remainder of the summer. In the second codling moth flight, pheromone trap capture was 80% lower compared to the first flight. Fruit damage at harvest averaged 0.55% for the entire project, and the average number of control sprays applied for codling moth declined slightly more than one per hectare, from 2.9 (1994) to 1.7. Growers and crop consultants considered the first year of CAMP a success. Damage by codling moth had been reduced in most orchards and no serious problems with secondary pests were observed. One large grower who decided not to join CAMP in 1995 applied four insecticides against codling moth and still suffered more than 2.5% damage. He decided to join CAMP in 1996 after seeing the results his neighbors had achieved.

In 1996, the average number of codling moths captured in pheromone traps over the entire season was 83% lower than in 1995, 1.5 moths/trap versus 8.8 moths/trap. Growers responded to the reduced moth captures by reducing the number of supplemental insecticide applications. An average of only 1.1applications were made for codling moth control in 1996, and fruit damage at harvest was only 0.2%. Most (80%) of the damage experienced by growers in Howard Flat occurred in only five blocks of fruit surrounding the one grower who did not participate in CAMP both years. Unfortunately, this grower did not follow good pest control practices, and codling moth damage in his orchard (3 hectares) was so high (estimated to be at least 25% damage) that it could not be harvested for fresh market. This experience demonstrates the vulnerability of an areawide CM-MD management project to growers who do not follow good pest control practices. Growers at Howard Flat solved their own problem when they convinced the one grower not participating in CAMP to lease his orchard to another CAMP participant, and in 1997 the orchard was not a contamination source for neighboring growers.

From 1997 through 1999, codling moth captures in pheromone traps at Howard Flat remained low, with 80-90% of the traps catching no moths the entire season. The average number of insecticides applied to control codling moth continued to decline from 0.7 (1997) to less than 0.5 (1999) applications per hectare, and crop damage at harvest ranged from 0.01 to 0.03%. As growers at Howard Flat saw codling moth pressure decline, they reduced the number of mating disruption dispensers from 1000 (Isomate-C plus) to an average of 560 per hectare.

Other CAMP sites

A story similar to Howard Flat could be told for each of the other CAMP sites. At all CAMP sites codling moth populations were reduced, and damage associated with codling moth declined over the duration of the project. In years four and five of CAMP, fruit injury levels were 60 to 97% lower than in the first year of the project at all but one site. At the Parker CAMP site codling moth injury in the fourth year was equal to damage in the first year of the project (0.18%) and was substantially higher in the final year (0.68%) of the project compared to the first. The increased fruit injury by codling moth at Parker was most likely the result of a too aggressive reduction in number of dispensers per hectare, 1000 to 500, coupled with a reduction in the number of supplemental insecticide sprays, an average of 1.0 to 0.2 per hectare. Although the CAMP project did not reach the 80% reduction target for broad-spectrum insecticides three of the five sites showed a significant reduction over time. However, by the end of the project CAMP sites were applying about 75% fewer broad-spectrum insecticides relative to the comparison orchards or to other conventionally managed orchards.

Other pests and natural enemies

During the five years of CAMP no consistent or unexpected pest problems arose in apple orchards. Leafrollers were present in most CAMP sites after year one, but this was anticipated and growers employed control programs that maintained them at acceptable levels without disrupting biological controls for other pests. Actually, leafroller densities were consistently higher in comparison orchards than in CAMP site orchards, and fruit damage was about two fold higher. Damage from true bugs, Pentatomidae or Miridae, tended to be slightly higher in CAMP site orchards than in comparison orchards although in the final year of the project this trend was reversed. There were no outbreaks of secondary pests due to reductions in broad-spectrum insecticide use in CAMP site orchards.

Populations of some secondary pests were lower in CAMP site orchards than in comparison orchards, and this was associated with higher densities of the natural enemies of these pests. For example, densities of the western tentiform leafminer were consistently higher in comparison orchards and parasitism, at least in the second generation, lower than in the CAMP site orchards over the duration of the project. Spider mites were not a serious problem in CAMP site or comparison orchards, but their densities were consistently higher and predatory mite densities consistently lower in the latter. Densities of white apple leafhopper nymphs were similar in CAMP site orchards and comparison orchards, but parasitism of overwintering leafhopper eggs was consistently higher in the CAMP site orchards. Aphid densities, primarily *Aphis pomi*, were slightly higher in CAMP site than in comparison orchards; however, the density of general predators associated with the aphids was similar in these orchards (Beers et al. 1999).

The key secondary pest in pear orchards was the pear psylla. In CAMP site orchards pear psylla densities and fruit injury were substantially lower than in comparison orchards in most years of the study. Spider mites were consistently higher in comparison than in CAMP site orchards, but predatory mite densities were low in both. Leafrollers, which are not considered a serious problem in pear, caused higher fruit injury in CAMP site orchards than comparison orchards.

Adoption of mating disruption

The adoption of CM-MD was influenced strongly by CAMP in two ways. First, CAMP sites offered demonstration and educational opportunities for growers, helping them to understand and consider implementing CM-MD as an integral part of their orchard management program. Second, the CAMP supported the establishment of new areawide projects with one-year grants at several locations from 1997 through 1999. In Washington 1995, approximately 8,800 hectares of pome fruit were treated with mating disruption products and the three CAMP sites accounted for less than 10% of this acreage (Figure 1). The In 1999, there were 24,000 hectares of orchards treated in Washington, or about 30% of apple and pear acreage. In 2000, the area treated with CM-MD continued to increase to an estimated 38,000 hectares (Figure 1).

Pheromone-based pest management: what is the future?

It seems likely that apple and pear growers will continue to seize the opportunity to move towards a pheromone-based pest management system in their orchards. Factors that will continue to promote the adoption of mating disruption include long-term benefits associated with increased biological control of secondary pests, threats of losing traditional broad-spectrum pesticides because of FQPA implementation, and continued concern about safe food by the public. Factors that are most likely to slow adoption of mating disruption include low prices growers are receiving for apples and pears, the relatively high cost of mating disruption and a perception of higher risk of crop loss compared to a conventional pest control approach.

While CAMP was a highly successful project it exposed weakness in the pheromone-based pest management approach that must be dealt with to promote long-term stability. Pheromone-based monitoring systems are not optimal for use in pheromone treated orchards. Non-pheromone monitoring systems, especially for Lepidoptera, would provide a better means of estimating pest densities in mating disruption treated orchards and reduce the incidence of unanticipated crop loss. Use of OP insecticides as supplemental controls for CM-MD limits the full expression of biological controls in many orchards. Adopting the use of more selective insecticides to supplement control of codling moth, as well as for other pests such as leafrollers, in CM-MD orchards would enhance biological control of many secondary pests. However, a more complete understanding of the impact of new insecticides on biological control agents is required.

Federal dollars have recently been provided through two grants supporting projects that address many of the issues discussed above. These grants fall under the umbrella title of “Building a multi-tactic pheromone-based pest management system in western orchards” and keeps together the team of scientists that had been involved in CAMP.

Objectives of these projects are to: (1) promote the adoption of CM-MD through development of new pheromone delivery technology, mating disruption approaches for other Lepidoptera, non-pheromone monitoring systems, and feeding stimulants or baits to enhance selective insecticides; (2) double the impact of biological control agents in orchards through the use of selective control tactics; (3) stabilize the management of specific pest populations through manipulation of orchard ecosystems, including groundcovers and surrounding habitats; (4) create an integrated educational plan to support the implementation and sustainability of a pheromone-based IPM system for western orchards.

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