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Chapter 9

Building a Multi-Tactic Biologically Intensive Pest Management System for Washington Orchards

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Tree fruit production has historically used more "high risk" insecticides than other agricultural systems and therefore has been significantly impacted by implementation of the Food Quality Protection Act of 1996. The key to transforming an agricultural system lies in developing alternative management approaches for key pests. The codling moth (CM), *Cydia pomonella* L., is a key pest in western apple and pear orchards. In the early 1990s, research demonstrated that pheromones could be used to manage CM. This knowledge led to the establishment of a USDA sponsored project known as the Codling Moth Areawide Management Program (CAMP). CAMP reduced crop losses and use of broad-spectrum pesticides while speeding the adoption of pheromones as a control tactic. Since that time, scientists that were associated with CAMP have been evaluating new technologies for pheromone delivery and other tactics, including soft insecticides, which strive to stabilize pest management systems in orchards. The goal is to maximize biological controls while minimizing impacts on human health and the environment.

The western United States produces most of the nation's fresh market deciduous tree fruits. For example, Washington State is the number one producer of fresh market apple, sweet cherry, and either number one or two for pear (*1*). The management of tree fruit pests in the western United States is simplified relative to fruit production in eastern regions because of habitat and climate. The relatively cold winters, especially in the Pacific Northwest, help synchronize pest development by eliminating all but the most hardy overwintering life stage. In addition, most western tree fruit crops are grown in areas with low summer precipitation (less than 30 cm per year). The lack of summer precipitation reduces problems from plant diseases that must be dealt with annually in eastern fruit producing states. The habitat surrounding most western orchards is primarily a semi-arid shrub-steppe. As a result suitable host plants for most insect pests are lacking, reducing the problems associated with their immigration into orchards. Because orchards are irrigated and incident solar radiation levels are high, trees can be managed intensively and production levels are high. The combination of climate, habitat, and intensive management offers a unique advantage to the western states for producing fruit organically or in a "biologically intensive" manner. Since most of our experience is with the Washington State fruit industry we will use examples from this production system, primarily from apple, to tell the story of how pest management programs have changed over time, what they are like at present, and where they are most likely heading.

Changes in Pest Management Programs

History of apple production in Washington State illustrates the evolution of a system dependent on synthetic organic insecticides to one that is now implementing a multi-tactic biologically based approach and supports the highest level of organic tree fruit production in the United States. Crisis often precipitates changes in management systems, and such was the case in Washington State in the 1960s. Reliance on chlorinated hydrocarbon insecticides (e.g., DDT) following World War II 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 the miticides developed rapidly. It was common in mid- to late summer for foliage in apple orchards to take on a brownish cast due to injury by spider mites, despite the applications of several miticides. The crisis faced by the growers provided the environment allowing a paradigm shift in pest control tactics. Dr. Stan Hoyt (Washington State University, Tree Fruit Research and Extension Center) observed that spider mite problems were reduced or eliminated in certain orchards that used

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lowered rates of organophosphate (OP) insecticides. His research 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 further, that these low rates of OP insecticides provided adequate control of the codling moth (*2*). The research in integrated mite management culminated in what is still recognized as a major breakthrough in pest management. 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, relying instead on biological control of spider mites (*2*).

In the 1970s, the concepts of pest management were being elucidated and adopted in several cropping systems, including tree fruit (*3, 4*). Integrated mite management produced a stable apple pest management program with successful biological control of spider mites occurring in most Washington orchards. Codling moth was controlled with an average of about two applications per year using rates below the maximum allowed on OP insecticide labels (personal communication, S. C. Hoyt). Resistance to OP insecticides began to develop in some secondary insect pests such as the white apple leafhopper, *Typhlocyba pomaria* (McAtee), and apple aphid, *Aphis pomi* (De Geer); however, these pests were controlled with insecticides at relatively low rates and in a manner that did not disrupt biological control of spider mites.

In the 1980s, there was erosion in stability of the apple pest management program. Two leafroller species, *Pandemis pyrusana* Kearfott and *Choristoneura rosaceana* (Harris), appeared as serious problems in some orchards (*5*). The increased problem with leafroller pests was tied to a reduced efficacy of certain OP insecticides, especially chlorpyrifos (*6*). Also, a new pest appeared, the western tentiform leafminer (WTLM), *Phyllonorycter elmaella* Doganlar & Mutuura. The increase in pest status of the WTLM was most likely associated with the development of populations resistant to OP and most carbamate insecticides. The only effective insecticide against WTLM was found to be oxamyl, a carbamate insecticide that was also highly toxic to the western predatory mite. Thus, the WTLM problem added to the erosion of integrated mite management in some orchards. Stability returned to apple pest management programs when research showed that a small parasitic wasp, *Pnigalio flavipes* (Ashmead), was an effective biological control agent of WTLM and that it was tolerant of certain OP insecticides (*7, 8*). Codling moth control using OP insecticides was still effective; however, by the end of the 1980s the average number of insecticide applications used to control this pest had risen to almost three per year (Table I). There was interest in introducing synthetic pyrethroid insecticides into the apple pest management system during the 1980s, but recognition of their detrimental impact on integrated mite management (*13*), and pest management in general, resulted in growers rejecting use of these products for pest control.

Table I. The average number of times an insecticide was applied per year and percent area treated ( ) in Washington apple orchards 1989-2001

Pesticide	*1989*[1]	*1991*[2]	*1993*[2]	*1995*[2]	*1997*[2]	*1999*[2]	*2001*[2]
azinphos-methyl	2.9 (98)	2.8 (90)	3.3 (81)	3.3 (94)	2.9 (91)	2.3 (78)	2.0 (73)
chlorpyrifos	1.3 (56)	1.4 (65)	1.3 (85)	1.3 (80)	1.4 (91)	1.3 (65)	1.1 (68)
ethyl parathion	1.2 (42)	1.0 (32)	0	0	0	0	0
methyl parathion	1.1 (17)	1.5 (28)	1.2 (24)	1.2 (19)	2.0 (33)	1.1 (5)	0
phosmet	2.4 (4)	2.1 (9)	1.1 (19)	2.4 (2)	1.2 (1)	2.0 (7)	1.5 (18)
petroleum oil	1.1 (90)	1.1 (88)	1.1 (88)	1.0 (77)	1.2 (87)	1.8 (69)	1.6 (79)
phosphamidon	1.8 (74)	1.2 (72)	1.4 (67)	1.4 (9)	1.4 (2)	0	0
imidacloprid					1.4 (65)	1.2 (50)	1.2 (38)
Bacillus thuringiensis	5.0 (<1)	0	1.9 (24)	2.2 (21)	1.5 (26)	2.0 (19)	1.2 (12)
spinosad						1.4 (39)	1.3 (50)

[1] Data from pesticide use survey conducted in Washington State (*9*).

[2] Insecticide usage data for Washington apple orchards from biennial surveys conducted by the USDA-NASS (*10, 11, 12*).

In the early 1990s, growers were facing increasing difficulties controlling codling moth, and resistance to certain OP insecticides, especially azinphosmethyl, was reported (*14, 15, 16*). The increased problem controlling codling moth was reflected in the gradual increase in the average number of azinphos-methyl applications per year (Table I). Problems with leafrollers occurred in more orchards (*17*). Research provided growers with control alternatives for these pests that would not disrupt biological control of spider mites, WTLM and other pests (*18*).

Concern about the impact of agricultural chemicals on infants and children (*19*), the environment, and residues on food fueled public debate and scientific inquiry. Regulatory action soon followed when the United States Congress passed the Food Quality Protection Act of 1996. This legislation required that all registered insecticides, and those proposed for new registration, be reviewed using criteria based only on the risks they posed to human health. Higher standards for risk assessments were used, including considerations of non-food uses of pesticides and additional safety factors for the assumed higher sensitivity of children and infants to pesticides in food. The Environmental Protection Agency established a priority to review those pesticides deemed most toxic to humans, the OP and carbamate insecticides. Because these products still formed the majority of insecticides used on tree fruit crops in the 1990s, increased interest was generated in finding alternatives for pest control.

Research on the use of mating disruption (pheromones) as a viable alternative for controlling pests in fruit crops was stimulated by success against the oriental fruit moth, *Grapholita molesta* (Busck) (*20. 21*) and promising results against the codling moth (*22, 23*). In 1995, the Codling Moth Areawide Management Project (CAMP) was initiated in three states. This was a cooperative effort between the USDA-ARS and three land grant institutions: Washington State University, Oregon State University, and the University of California at Berkeley. CAMP established five demonstration sites in three states. CAMP documented substantial reductions in the use of OP insecticides directed at codling moth control while at the same time reducing crop losses (*24, 25*).

Howard Flat, located near Lake Chelan in Washington, is a good example of how the use of mating disruption at a CAMP site improved management of codling moth. Codling moth losses at Howard Flat were estimated to be about 0.9% in 1994, one year prior to the beginning of CAMP, with an average of nearly 30 codling moths per pheromone trap and 2.7 insecticide applications per year used for its control (Figure 1). As the areawide use of mating disruption plus supplemental insecticides took effect, the average number of codling moths per trap declined dramatically, as did the average percent crop loss. By the end of the third year (1997), the average crop loss due to codling moth was only 0.01% (Figure 1). The low level of crop loss was maintained during the following two years even while the average number of insecticides applied per year dropped to less than 0.5 (Figure 1). By the end of CAMP, the pheromone use by Washington apple growers had increased from 6,500 to almost 24,300 hectares treated. Implementing a pheromone-based pest management approach in CAMP initially resulted in increased problems with leafrollers, which were managed with less hazardous, non-OP insectcicides ("soft" pesticides), but not with other secondary pests (*26*).

The primary means of delivering pheromones for mating disruption of codling moth control has been via hand-applied dispensers. These dispensers are applied at densities from 500-1,000 per hectare. Pheromone evaporates from the surface of dispensers, and most last the entire season. Over a three-year period (2001-2003) we evaluated different hand-applied dispensers to characterize how they released pheromone. Dr. Vincent Hebert reviews this work in a chapter in this book (*27*).

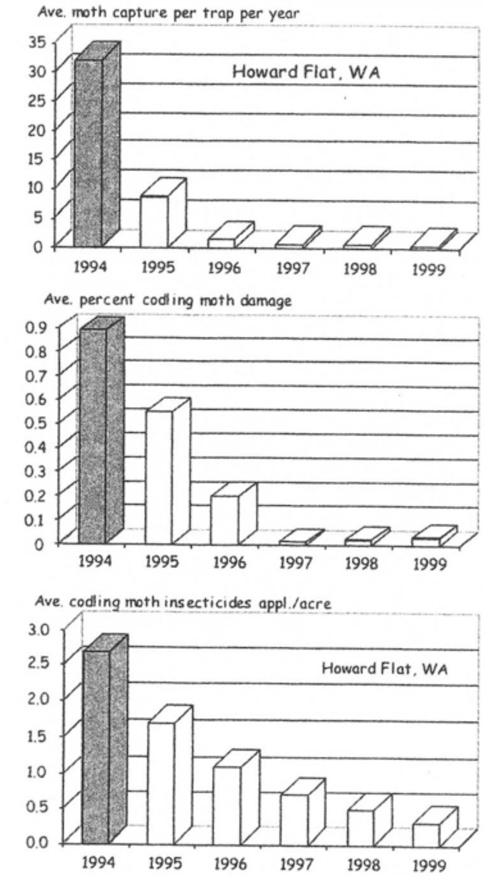

Figure 1. Results from the Howard Flat CAMP site showing data on levels of codling moth adult activity, fruit injury and insecticide applications to control this pest prior to (1994) and throughout the project duration (1995-1999).

In 2000, many members of the research and extension team who worked together in CAMP joined in two federally funded projects (*28, 29*). The goal of these projects was to refine and extend the benefits of a pheromone-based IPM system to additional apple and pear acreage and to extend this technology into walnut production in the western states. Scientists associated with these projects, (dubbed "Areawide II") are conducting research on new ways to deliver pheromones that would make them either less expensive to use or more effective. Efforts include using high-emission release devices, referred to as "puffers" or "misters." These devices release massive amounts of pheromone from a very few sites per area. Puffers have shown promise in apple orchards and walnut groves where in the latter, tree height is a challenge for more traditional pheromone delivery systems, i.e., the hand-applied dispensers (*30, 31*). Researchers are also evaluating methods of pheromone delivery such as sprayable (*32*) and hollow fiber formulations (*32, 33*). These formulations are the opposite of the "puffer" approach in that they release pheromone from thousands of sources per area, and they have the possible added advantage of being applied by air.

Research has clearly demonstrated that the use of mating disruption can reduce reliance on insecticides to control codling moth; however, they have not eliminated the need for insecticides as part of a pest management program. Growers are currently combining the tactics of mating disruption and insecticides to achieve acceptable levels of crop protection in apple and pear. This approach remains a barrier to a more robust biologically intensive pest management program because even the use of one OP insecticide can disrupt biological control of certain pests. The "Areawide II" team has demonstrated that alternatives to OP insecticides can be used for control of codling moth and other apple and pear pests without reducing high standards of crop protection. A recently completed three-year implementation project in 15 Washington apple orchards demonstrated that pheromones supplemented with only "soft" insecticides (those that do not negatively impact biological control agents) provided crop protection as good as pheromones supplemented with broad-spectrum insecticides. This efficacy was achieved at no increased cost to the grower (*34*). Results of this project suggest that many Washington apple and pear orchards could move away from use of OP insecticides, thus enhancing the opportunity for biological control of pests in their orchards.

Organic Fruit Production in Washington

The pest management continuum continues to an "organic" production end point. Organic production, while being holistic in including more than just insect pest management, is also highly legalistic. Only certain kinds of products and

practices can be used in organic production, and growers must become certified to market their fruit with an organic label. The western US produces more organic apple, pear, and sweet cherry than any other region of the country (*35*). While as a percentage of the total apple acres in Washington State, production of organic and transition organic fruit remains small (≈5%), its growth over the last decade has been dramatic. Granatstein and Kirby (*35*) reported that in Washington State organic apple production (certified acres) increased from 1,200 in 1991 to 6,540 in 2001; plus, there were an additional 3,411 transition organic acres that year. Organic pear and sweet cherry production has also increased dramatically over this same period. There is a potential for a much greater increase in organic apple, pear and cherry production in western states with the registration of two new insecticides that will control codling moth and a key pest of cherry, *Rhagoletis indifferens* Curran. The greatest barrier to increased organic fruit production is the lack of a consumer demand that will support higher retail prices to offset the higher production costs of organic fruit.

Conclusions

The historical perspective presented in this article shows that western apple orchards are moving along a pest management continuum from what can be referred to as a "conventional" approach that relies almost exclusively on synthetic organic insecticides towards a more "biologically intensive" system (Figure 2). Calls for more biologically intensive pest management programs arose from a symposium on Food, Crop Pests and the Environment sponsored by the USDA and EPA and held in Washington, D.C. in June of 2002 (*36*). The "biologically intensive" phrase added to pest management was an attempt to place more emphasis on developing multi-tactic approaches to crop protection that would allow a greater role of biological control in agricultural systems. Apple pest management programs in Washington have steadily moved from a traditionally conventional approach towards a more biologically intensive approach. Integrated mite management showed that there was a different way to think about apple pest management, but progress was slow. By the 1980s, more examples integrating biological and chemical control had been developed, and growers and crop consultants were using population monitoring and thresholds to make pest control decisions (*37*). Shifts in the apple pest management program are documented in pesticide use survey results over the last 12 years (Table I). Uses of some broad-spectrum insecticides, ethyl parathion and methyl parathion, have been eliminated because of regulatory action. An OP insecticide, phosphamidon, used primarily to control aphid pests, was replaced with a more

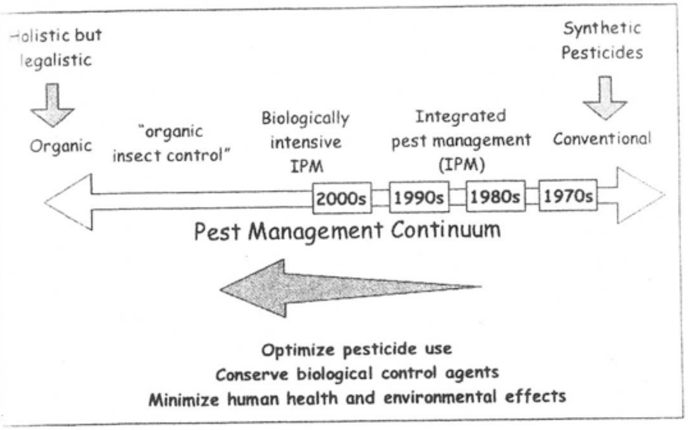

Figure 2. A conceptual pest management continuum from programs relying only on synthetic insecticides as a control tactic (conventional) to ones that are holistic but highly legalistic (organic).

selective insecticide, imidacloprid, in the late 1990s. The use of *Bacillus thuringiensis* (*Bt*) increased in the mid-1990s as a "soft" insecticide solution to increased leafroller problems. In the late 1990s, spinosad, a new selective insecticide, was introduced for management of leafrollers (*38*). In the 1990s, the use of mating disruption was introduced, and adoption of this technology reached nearly 50% of apple acreage by the end of the decade. The use of mating disruption has remained fairly constant in Washington, even through very difficult economic conditions of the late 1990s and early years of the new millennium (Figure 3). The reduction in azinphosmethyl use for codling moth control between 1995 and 2001 (Table I) coincided with an increased adoption of mating disruption (Figure 3).

In the current decade, new insecticides are being introduced that will help replace or further reduce broad-spectrum insecticide use (*34*), and new ways of delivering pheromones promise to reduce the costs of this technology. A new areawide organic insect pest management program in pear has demonstrated not only protection of sensitive freshwater habitats from potential broad-spectrum insecticides, but also the added value of products grown in environmentally sensitive ways (*39*). In addition, scientists are examining the design of orchards and manipulating surrounding habitats to create refugia for natural enemies. For example, Dr. Thomas Unruh is working with growers to establish gardens of

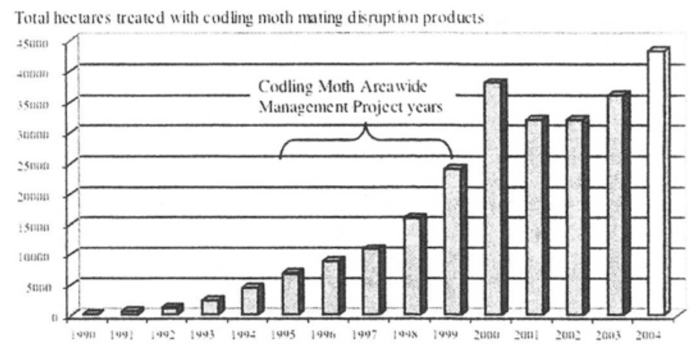

Figure 3. Estimates of the hectares treated with codling moth mating disruption products as part of a pheromone-based management effort in Washington apple and pear orchards from 1990 through 2004.

wild rose and strawberry that harbor a leafroller species, *Ancylis comptana* (Foelich), that provides an overwintering host for a key parasitoid, *Colpoclypeus florus* Walker, which is an important natural enemy of pestiferous leafroller species that inhabit orchards (*40*). Dr. David Horton has identified key plants in native habitats that harbor natural enemies that are important in suppressing pests in pear orchards (*41*). We are also developing new information on the seasonal occurrence of parasite species attacking leafroller pests, providing a means of more accurately determining their impact and identifying times of the year to avoid use of insecticides that would disrupt their activities (*42*).

Understanding how various biological components fit together into an interactive matrix can be daunting. To help us understand these interactions, Dr. Vincent Jones has developed a novel marking methodology that is being employed to assess movements of insect pests and their natural enemies between various components of the orchard ecosystem (*43*). Progress in developing and implementing biologically intensive pest management programs for apple and pear, and even walnut production, in the western United States is being made through the research and education efforts of many people (*28, 29*). As new technologies are developed, they are being evaluated and integrated into pest management programs that have high standards for crop protection. As we understand how complex biological systems interact on a spatial scale that is larger than an individual orchard, new approaches for managing pests as well as their natural enemies will be possible.

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