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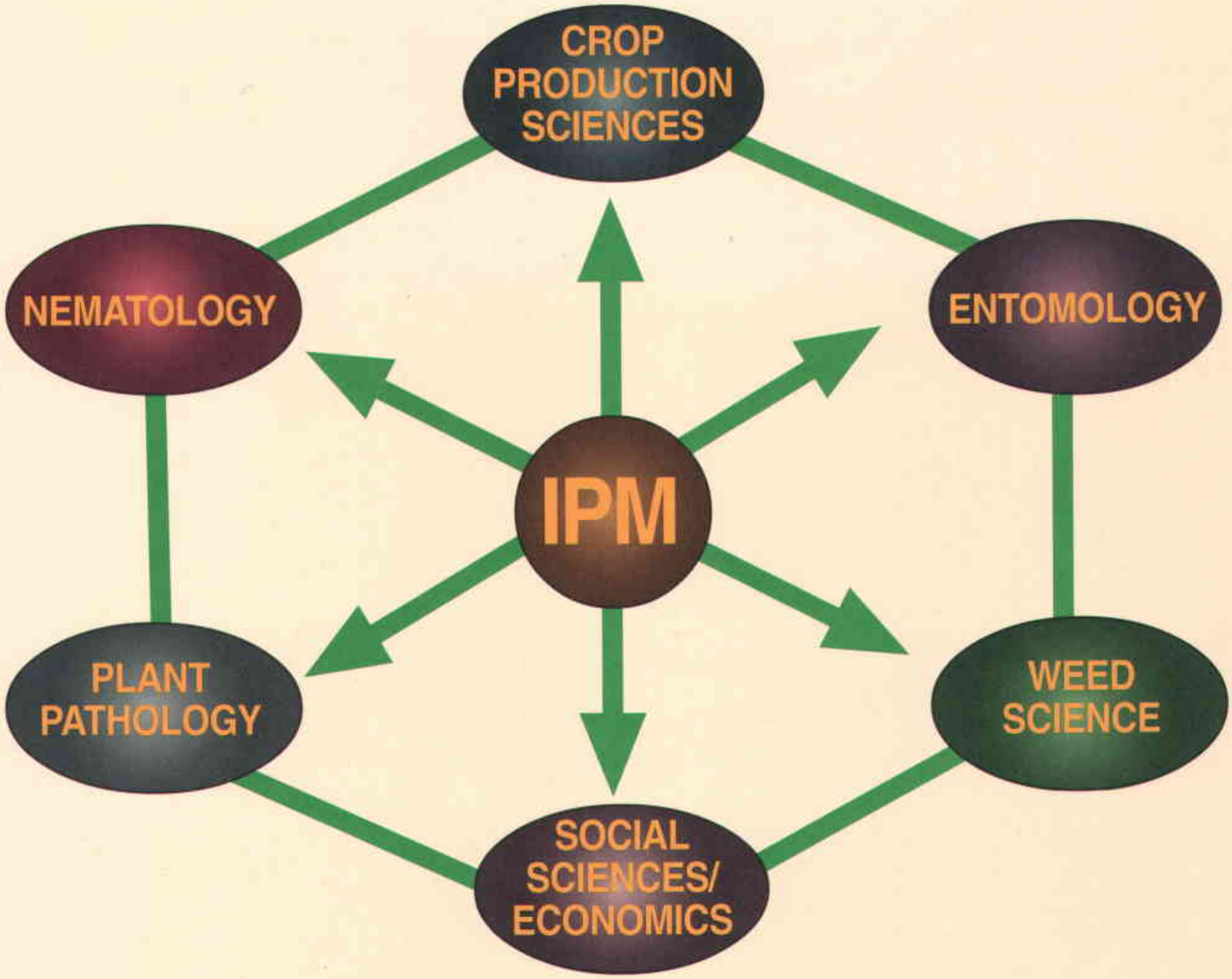
IPM in Oregon: Achievements and Future Directions



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IPM in Oregon: Achievements and Future Directions

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and

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Acknowledgments

This Conference was made possible through the combined efforts of Integrated Plant Protection Center (IPPC) staff members in collaboration with Oregon State University (OSU) research and Extension faculty and students dedicated to the advancement of integrated pest management in Oregon and the Pacific Northwest. The participation of representatives of the Oregon Department of Agriculture reaffirmed the commonality of our goals in plant protection. Although few growers participated in the Conference, their presence was particularly significant, as they provided a unique perspective based on their experience in the production fields. The U.S. Department of Agriculture, CSREES, Pest Management (Smith-Lever 3(d)) program through IPPC provided funding for the Conference. Technical editing of the proceedings was under the direction of IPPC staff, with final copy editing and design by the OSU Department of Extension and Experiment Station Communications. To all of the people who made this Conference possible, our deepest appreciation.

Marcos Kogan
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Oregon has had a long and distinguished history of accomplishments in crop protection. F.L. Washburn, first entomology department head at State Agricultural College of Oregon, also taught the first course in economic entomology in 1889. Both Washburn and A.B. Cordley were Station entomologists and published on codling moth and San Jose scale in the late 1800s. Until 1911-12, little attention was given to pests of field crops; but soon after, work started on vetch, clover, alfalfa, field peas for seed, and hay. The department expanded with new faculty added and research focusing on all major fruit, vegetable, and field crops in the state (Richter, 1966). The first head of Botany and Horticulture was E.R. Lake (1888-1891), and the first publication in plant pathology, "Investigations of Plant Diseases," was issued in 1889. In 1894, Moses Craig published "Cause and Prevention of Plant Diseases" (Station Bull. No. 27). The name of the department was changed to Botany and Plant Pathology in 1909. Both entomology and plant pathology research and outreach at the College of Agricultural Sciences have contributed since then to solve insect pest and disease problems in agricultural and horticultural crops and in forestry. We are following in the steps of men and women who pioneered creative approaches to pest control when few control options were at their disposal. They compensated with keen observation of pest biology and resourcefulness. Much can be learned from these early professionals.

This conference was conceived to offer a forum for all of us within the Oregon State University system, our counterparts and collaborators in other state agencies, and producers, commodity commissioners, NGOs, and private consultants to assess where we are and where we should be going in IPM. We often are asked, "What is Oregon doing in integrated pest management?" We hope that as an outcome of this conference, we will be in a better position to answer this question.

Nearly 30 years after first enunciated, the concept of IPM is undergoing severe scrutiny. The Federal administration established a goal to implement IPM on 75 percent of the land under agriculture in the U.S. by the year 2000. Critics complain that, depending on how one looks at IPM, either we already have exceeded that target, or in no way are we going to meet it. It all depends on how we define IPM and how we measure progress in IPM adoption. It would be useful to achieve consensus on a definition of IPM, but this is not easy. On the IPPC web site there is a compendium of IPM definitions (Bajwa and Kogan, 1997). At last count, the compendium included 67 published definitions. I would not be surprised if by the end of this conference, we did not hear of three or four new ones.

Definitions usually are selected to suit one's perspective or vested interests. I personally favor one that considers IPM primarily as a decision-making system for crop protection. I feel that IPM success hinges on the quality of the information that is available to support pest control decisions. A traditional pest control program becomes IPM when control (or management) decisions are based on the clear understanding of crop/pest ecological interactions and take into account not only the short term economic benefits to the producer, but also the long term benefits to the environment and to society.

> **"IPM is a decision support system for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment." (Kogan, 1998).**

Through the course of this conference, we will have a chance to hear five guest speakers discuss some key issues that are being debated nationally and that may have a profound effect on the directions of agriculture in general, and IPM in particular, for many years to come. We will hear about the role of Extension in advancing IPM adoption, the impact of the Food Quality Protection Act of 1996 on pesticide use, the approaches being used to measure IPM adoption, and what we can expect from the Federal and State governments to bring IPM closer to a global reality. We also will learn about some very creative and cutting edge IPM work being done here in Oregon. We hope that this conference will reaffirm our confidence in the soundness of the IPM concept and our commitment to make IPM a reality for the benefit of future generations.

I would like to thank the University high administration for its genuine support for IPM, as demonstrated by the presence at this opening session of President Paul Risser and Dean Lyla Houglum, who will be offering welcoming addresses on behalf of Oregon State University. Thanks also to our guest speakers for their willingness to share with us their experience and expertise in IPM and to the participants in the program and members of the audience for the good work they are doing in IPM around the state. Finally, I want to express my appreciation to my IPPC colleagues for the hard work in helping organize this conference: Myron Shenk, Allan Deutsch, Waheed Bajwa, Len Coop, and Linda Parks. Thank you all very much.

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President Paul Risser
Oregon State University

I welcome you to this conference and to Oregon State University. The chance to do that is more than just a casual opportunity for me. I have had a keen interest in IPM for many years, and preparing these remarks led me to think about integrated pest management and its trajectory over the last 20 or 30 years. It seems to me that this particular conference is quite timely, mainly because it draws together in a kind of microcosm way much of what is happening at this university, and, I think, at other universities around the country as well. The program of this conference reflects the integrated nature of plant protection, bringing disciplines together to solve a common problem. This is also a goal for Oregon State University, and I want to extend my congratulations to the organizers—not only for putting on the conference, but for the work they do in promoting interdisciplinary cooperation in crop protection.

Thinking about integrated pest management over the weekend, I reflected on its ecological foundations. I have the honor and the responsibility to lead a group entitled the Willamette Restoration Initiative, which looks at the Willamette Valley as a complex ecological and sociological unit. One major concern results from the fact that a number of fish species now have been listed as endangered; e.g., some runs of salmon and steelhead. Those two listings have enormous potential impacts on the economy of the Valley, and since about 70 percent of the population of Oregon lives in the Willamette Valley, it has large implications for how we plan its future. Often in the past, we have focused on water quality measures when evaluating watersheds such as the Willamette Valley. We measured variables such as turbidity and dissolved oxygen, as well as chemicals in the water and in the sediments. Pesticides always were a major concern. But to understand what happens in the river, it is essential to assess what happens on the landscape. Much of the water quality is defined by what happens in the riparian zones and the adjacent lands. So, as I think about the future of the Valley, I think that much of the success will depend on the degree to which we manage our pests in ways that protect the river, as well as protect the landscape. Our long-term success in the endeavor to restore the Willamette Valley will depend upon broad public participation. I think, also, that it will depend to a large extent on how successful we are in integrated pest management. There are particularly sensitive issues related to potential conflicts between urban areas and agricultural areas. The finger frequently is pointed first at agriculture in terms of sources of nitrates and pesticide pollutants, for example. But as we look at the Valley, it is clear that the issue arises not only in agriculture but also in urban areas.

One of the challenges for integrated pest management is not just the solution of pest problems in field crops, horticultural crops, or fruit orchards, but of becoming a much more conspicuous part of the way we manage urban systems as well. So, I think there is a challenge for us, and I hope that this conference also will set the stage for expanding integrated pest management in urban settings. As I said, integrated pest management, in some ways, mimics what is happening at this university in a number of ways. We at Oregon State essentially are turning the university inside out—that is, making the whole state of Oregon our university campus, beyond the limits of Corvallis, the network of Experiment Stations, and the Extension offices around the state. We are taking the university to become partners in communities and to build capacity in those communities. That is a sort of new way of thinking about the land-grant mission, but it is one that I think represents the future.

As I think about this goal in all its details, I recognize that what is happening in this organization is what has happened in integrated pest management. IPM began by looking largely at individual pests and their biology, the physiology of crops, impacts of weather and climate conditions, and the influence of soils and below ground processes. Then, over the last decades, we have moved far beyond that, so that environmental as well as economic and sociological considerations become part of the equation. In considering the sociology of IPM, we must reflect more carefully on the role of the university and particularly of our Extension Service, and the way in which we cultivate partnerships with the private sector, both individual consultants and corporations. So, IPM has become an ever-more complicated topic, one which seeks to integrate—in new levels—both the economics and the ecology of how we manage pests. I am not surprised that there are so many definitions of IPM, because integrated pest management brings so many dimensions together under a single umbrella. This is also why we need to have such a conference. As I said at the outset, it is timely because it looks at the past accomplishments, then it tries to look at future directions. And, as we do that, those of us here in Oregon have an extraordinary opportunity to provide leadership. The program is rich and varied, and it should provide the necessary stimulus for fruitful discussions. So, on behalf of Oregon State University, let me welcome you. I hope you can infer from my comments my fervent desire for us to think hard about IPM, and also my recognition of just how important it has been, and that it will be more important in the future. Thanks very much and welcome.

Opening Remarks for the Conference "IPM in Oregon"

Lyla Houglum
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On the front cover of the Conference's program, I see this wonderful representation of the integrated and interdisciplinary nature of IPM. It reminds me that the people we work with don't really care what department or discipline they get the information from; they care that they get the information they need in order to help deal with the issues they are struggling with. It also is an illustration of the especial opportunity that we have here to integrate not only multiple disciplines, but also the research and Extension functions of the university. IPM has provided the perfect test for the research and Extension working group model. This model was implemented to help bring diverse fields together in a way that can deal with the complex multidisciplinary problems of producers. Not only are the linkages internal to the university, they also are external.

Let me read a sentence from the 1998 Oregon Extension Annual Report that goes to the Federal Government. I suspect that many of you feel that we just ask you for reports that don't really go anywhere. Well, they do, and they serve very important functions in our communication with legislators and Washington administrators. This particular report talks about the interdisciplinary nature of IPM. It also talks about external linkages that are established through IPM program activities. The report states that "External linkages include collaborators in the private sector—crop consultants, farm advisors, field personnel of commercial firms, as well as professionals in other state government agencies, environmental concern groups, and commodity commissions."

So, IPM really is much more than just an internal, multidisciplinary effort. External connections are essential, as well. The Federal Government has a goal that 75 percent of all agricultural acreage will be under IPM management by the year 2000. This is a very important goal, and it is something that we do, in fact, need to work toward as we look to the future.

One of the things that you will see in this Federal report is that IPM is not only multidisciplinary, but it is also multi-state. For Extension, this is becoming increasingly important also, in that we are mandated by the Federal Government to spend an amount equivalent to 25 percent of the Federal funds that we receive, in projects that are multi-state. IPM is a good example of how we do this.

When I talk with legislators about the Extension Service, I often talk about interdisciplinary projects and multi-state projects. I don't know how many of you have seen this briefing booklet that we put together for our legislative budget hearings. In this briefing booklet, there is much information, including brief success statements and descriptions of some successful programs. One of the items in this booklet is, "Extension teaches new approaches to control insect pests in pears and cherries. Growers in Jackson and Hood River counties save up to $800,000 a year on pesticides and apply fewer chemicals in the environment." One of the legislators on our budget hearing committee picked up on this and asked a question specifically about it during our hearing. He wanted to know how we did it. How we went about actually saving growers $800,000. This provided an opportunity to talk a bit about the basic principles upon which IPM is based. This is just one illustration of how the programming you do not only benefits the grower, but also is of interest to legislators and helps us in the budget process, as well.

When I travel across the state I get comments about Extension from growers. A few years ago, I was traveling down in southern Oregon and talked with different growers about Extension and what they value about Extension. One of the growers came up to me and said, "You know, I don't think we need Extension anymore." Usually when I hear this kind of comment, I say, "Tell me more." I like to get a sense for where the person is coming from. Well, what this particular grower said to me was, "I don't go to Extension for agricultural production information anymore." So we talked about that a little and I asked him where he did go. "Well," he said, "I go to the field reps." Now, how many of you have included field reps in your audience? Yeah, lots of you. How many field reps do we have in the audience right here? Several of you. In fact, when I ask field reps around the state, "How do you feel about Extension?" Their comment is, "Oh, my gosh, we need Extension. That is where we get our information." So, we are both an important part of the whole system. It is a system, however, that we need to help people understand as we think about Extension and how Extension operates.

When I looked at the IPPC Web page, I also found a number of different definitions of IPM, but one of the things that I was curious about was the history of IPM. The thing that was most interesting to me was that I didn't realize IPM had such a lengthy history. This particular paragraph intrigued me. "Dwight Isely provided the earliest record of IPM concepts as a formal agricultural practice." Isely's work began in the 1920s. How many of you knew that it was that long ago that IPM work began? He "pioneered modern pest control using principles of scouting, economic thresholds, and trap crops, along with insecticides, to control boll weevil in Arkansas cotton." It also goes on to say, "IPM really did not gain momentum until the late 60s in the United States." If you continue to go through some of the history, one of the things you will find is that IPM Extension programs sponsored by the Federal Government weren't introduced until 1971. This is where you begin to see the introduction of Federal monies into IPM. Then, if you continue, you will find that there is a fairly big gap until the Federal IPM Initiative was established in 1994. So, it really has been a fairly lengthy history. It also has been a controversial history over the years.

Now, we have a Federal mandate to include up to 75 percent of the acreage under IPM by the year 2000. According to the information I was able to access, we are about two-thirds of the way there. We probably have about 50 percent of the acreage under IPM right now. But the level obviously depends on how one defines IPM. It was interesting to see on the IPPC the web page the different definitions of IPM over the years.

I was interested in the definition that was presented at the introduction. If you look back at the definitions in the 1960s, what you will find is a focus on economic development—on making sure a crop was economically feasible for a producer. That was the primary goal. Profitability was a primary IPM goal in the early 1960s. If you look at how the definitions have changed over the years, though, in the 90s you will see other key factors, such as social welfare and environmental sustainability, beginning to creep into the definitions of IPM. Let me give you a couple of examples of this. Here is a definition from 1966. It says, "Integrated pest control is a pest population management system that utilizes all suitable techniques in a compatible manner to reduce pest populations and maintain them at levels below those causing economic injury." If you go through the definitions from the 60s and 70s, the issue of economic injury shows up over and over.

If you look at some of the definitions from the 90s, though, you will see definitions that sound like this: "Integrated pest management or IPM is a systematic approach to crop production that uses increased information and improved decision-making paradigms to reduce purchase inputs and improve economic, social, and environmental conditions on the farm and in society." See how the words begin to change? Another one from 1997 says, "The management of pests by integrating host-resistant, cultural, biological, and chemical controls in a manner that minimizes economic, health, and environmental risks." Those kinds of words didn't show up in the definitions in the early 60s.

IPM also has become increasingly political and increasingly a part of public issues. Even popular TV programs highlight IPM related issues. For example, the OPB show Oregon Field Guide recently talked about controlling nonnative species of plants in watersheds by introducing insects from the plant's original country.

You now can go to garden stores and buy bags of ladybugs or other "good" bugs to put in your garden. I'm not sure how effective this is, but it is a very common practice. The one that I see probably most often is the cinnabar moth that is used on tansy ragwort in this part of the state.

IPM is going to become increasingly important in the future. As we look at climate change, climatologists are telling us that we are beginning a 25-year cooler and wetter cycle. That is going to change how we deal with diseases and insect populations among various crops. This is going to make Extension and research in this area increasingly important in the future. It also is going to take a significant amount of work to meet the Federal mandate to have 75 percent of all agricultural acreage under IPM by the year 2000. This really is a huge charge and a very important charge for the university (see also Harold Coble's paper).

So, I wish you well with the conference. As I look at the program, I see many, many, many interesting workshops planned. Again, along with President Risser, welcome to Oregon State University. Thank you very much.

IPM on the National Scene

Harold Coble
National IPM Program Coordinator
USDA/ARS/OPMP

Oregon State is one of the two land-grant universities that I had not visited before, but I am impressed with what I have seen and heard so far. The fact that President Risser and Dean Houglum could display such a high level of understanding of IPM tells me a lot about this institution. I also am pleased that the program of this workshop includes growers, whose input at all levels, from planning through implementation, is essential for progress in IPM.

National IPM Coordinator and the 75 percent Goal

The role of the IPM Coordinator in the USDA today is to resolve what we facetiously call the "real Y2K bug." That has nothing to do with computers; but, rather, how to achieve the goal of 75 percent of the agricultural area in the U.S. under an IPM program by the year 2000, and to do the assessment appropriately. The first order of business to do this assessment was to reach a consensus on what is IPM. We needed to find a working definition of IPM for growers, without trying to create yet another definition. When I arrived in Washington and started thinking about how we were going to measure the 75 percent goal, no operational definition was found that provided a good basis for measuring adoption. So, I will discuss our attempt to define what is a baseline for IPM and how to measure adoption, although this topic will be addressed in greater detail by others in this workshop. My main concern, however, is the direction of IPM beyond 2000 and the 75 percent goal. I will give you some reasons why this is critical as well as talk about funding mechanisms for IPM, because nothing gets done without appropriate funding.

Most current IPM definitions provide mainly a vision for IPM—what IPM will do for us. We aren't really using the over 60 definitions that show up on IPPC's website—except to the extent that they provide a vision of what IPM is or should be. To measure IPM adoption, we needed a practical definition that would give us measurable parameters to assess the 75 percent adoption objective.

First, though, let me give the background for this 75 percent goal. Back in September of 1993, the USDA, EPA, and FDA, in joint testimony before Congress, decided that to promote adoption of IPM, it was more desirable to use as a target the area under IPM rather than a percentage of pesticide use reduction. EPA and USDA signed a memorandum of understanding to work together to try to reach this goal. In December 1994, USDA launched the National IPM Initiative with several objectives. The USDA had some funding to go along with that initiative, but to the present time, additional funding has been in the President's budget, but Congress always throws it out. This is a problem that we have to deal with. The goal was to implement IPM on 75 percent of U.S. cropland acres by the year 2000; i.e., planted cropland acres, not including rangeland or forests. The objectives that the USDA had were primarily to ensure availability of information and technology, to measure the adoption by growers, and to promote biologically intensive IPM.

It was up to us to come to some understanding of what is IPM in order to measure it. There are several ways to approach the problem based mainly on the vision set forth as the basis of the current definitions. Essentially, those definitions establish that IPM is a system based on the understanding of pest population dynamics, the relationships between pests and hosts, natural enemies, and long term impacts of suppression strategies, with a goal of stabilizing pest populations below economically damaging levels. Most of us involved in teaching and research in IPM for many years understand what that means, but it is difficult to communicate to growers what all of these definitions really mean. The key issue for growers is what they are actually supposed to be doing in order to practice IPM. If we are to measure IPM, we must measure what growers are practicing. And make no mistake, growers are the ones who in the end turn IPM from a vision to a reality. We in Research and Extension can do all we want to get IPM technologies out in the field, but unless growers adopt them, it doesn't really make any difference. We have to deal with it from the growers' perspective. We must tell growers what it is they are supposed to be doing to practice IPM.

The practice of IPM comes down to a strategic approach to managing pests, including prevention, avoidance, monitoring, and suppression with a goal of minimizing economic, health, and environmental risks.

Now, what is the real practical meaning of those four basic components? *Prevention* refers to the actions that keep a potential pest (disease, insect, or weed) from ever infesting a crop field or an orchard. There are practices that growers can use. If we tell them, "Use pest-free seeds or transplants, remove alternate hosts, clean your equipment between fields when you are tilling or mowing, use field sanitation measures such as removing old fruit from the orchards," we are identifying preventive tactics. There also can be quarantine measures imposed by the government. Growers understand these measures and will support them. These are tactics that growers can put on the ground, things that they can use. These are the kinds of definitions we have to have in order for the growers to implement or to adopt IPM.

Avoidance is the approach taken if you already have a pest infestation in the field or the orchard. What can you do to avoid the full economic impact of the infestation? Tactics that avoid, or attenuate, pest impact include crop rotations, using host plant resistance, trap crops, even fallowing parts of fields. Again, growers understand that these are practices that they can put on the ground.

Monitoring involves the practices that allow us to know what is in the field and when; this knowledge is essential to allow us to chose the best method to deal with the pest. Monitoring includes surveys, scouting, and access to local weather information. Record keeping is an essential component of monitoring. New approaches of precision agriculture aid in defining where pest problems are: data from the monitoring component help make intelligent decisions. It always amazes me how many growers make the effort to get good information from the field and then don't use that information. They just go out and spray the whole field even if they know that the infestation is localized only in one corner of it.

Suppression refers to the actions taken after you have used prevention practices and still have a pest problem that you cannot avoid. You know there is a problem because you have done the monitoring. Actions now are needed to suppress the pest. Cultural controls, physical controls, biological controls, and chemical controls, in that order, are the suppressive actions that may be taken. This is the way we present integrated pest management to growers. And these are the elements or definitions that we will measure against to determine whether we have reached the 75 percent goal.

We think that we are at about 50 percent of the agricultural acres under IPM. Many of the minor crops—fruits and vegetables—are already at 75 percent. That may not be good enough. Many growers may have the impression that IPM means organic agriculture. That is not what it means. Pesticide use in IPM is appropriate if used according to the definitions that we proposed. Prevention and avoidance strategies, we know, are seldom sufficient, particularly in bad pest years. Cultural, physical, and biological controls may fail, so pesticides that are effective and economical may be needed to supplement the effect of the other control tactics. We may not have any broad scale viable alternatives in most situations in the near future, particularly for weed control. If we are trying to reach 75 percent implementation of IPM on cropland acres, what shall we use to replace pesticides in the immediate future? And, on a broad scale? So, pesticides will continue to be used in IPM for a number of years.

When we state that we are at about 50 percent of acres under IPM, this is mostly low to medium IPM in terms of a continuum. The level depends on the crop. It is higher on fruit and vegetable crops; i.e., in the high value crops. Pest management is still chemically intensive, but the risks associated with pesticide use are being reduced gradually. If we consider the history of insect management, not too many years ago we still were using products such as lead arsenate. At that time, the introduction of DDT was received as an improvement. Organochlorine insecticides gradually were replaced by more effective organophosphates and carbamates. Each new chemical family opened new opportunities, but also brought about new problems. Today, new products are coming with opportunities to reduce the risks associated with their use. Are we where we need to be? Probably not, but we are reducing risks to the environment and to human health.

When considering the 75 percent IPM adoption, we must ask, Where are the acres? We have about 335 million planted acres in the United States. Seventy percent of that acreage is in four crops: corn, soybean, cotton, and wheat. Less than 2 percent of the acreage is in all vegetable and fruit crops. So, if the goal is acreage based, where do we put our efforts? Obviously, we must focus on the major crops. But, even in these major crops, where are the pest problems? In 1996, 201 million of the 234 million acres in corn, soybean, cotton, and wheat were treated with herbicides, 44 million were treated with insecticides (up to about 60 million acres in 1997), and 1.7 million with fungicides, excluding seed treatments. Ninety percent of all the pesticide use in these field crops are in herbicides. Except for cotton, insecticide use in most other crops is not that large. In the past few years, insecticide use in corn is growing because of greater severity of root worm attacks. So, to reach the 75 percent goal, we must concentrate in the major acreage crops and we must stress weed management. We must accomplish that by developing strategies that include cultural, physical, and chemical controls. We emphasize detection of weed problems, definition of what the weed problems are, and then we should try to measure the results of the implementation of this strategy.

Whether we will reach the 75 percent goal by the end of 2000 is questionable. What is certain is that we must approach achievement of the goal in an appropriate manner. We must measure the 75 percent adoption against a definition based on those four strategies and the tactics within those strategies. If it comes out to be short of the 75 percent goal, so be it.

Regardless of the outcome, the important issue is: What do we do next? Obviously, we need to encourage movement along the IPM continuum. We want people on the continuum, but we want them to move along the continuum. That is more important than simply being on it. We need to encourage the use of multiple pest-type thresholds. It's fine to know the threshold for the European corn borer or for cocklebur, or for some disease, but these pests occur together and they interact. Establishment of multiple pest thresholds for interacting pests is a critical area for IPM to advance to higher levels of integration. Another critical issue is minor acreage crops. In fact, targeting these crops is probably more important than achieving the 75 percent goal in the major field crops. These minor acreage crops make up our basic food supply. We need to measure the sustainability of our IPM systems. Are they strong? Are they resilient? For the immediate future, we must concentrate on the four major crops, and the reason is not just the 75 percent goal—it is mainly water quality. Water quality is a major issue, and the four major crops contribute the most to water quality degradation. We then should focus on the 10 or so fruit and vegetable crops that are most important in human diet, particularly the diets of infants and children.

The Role of the USDA

Several USDA programs are oriented to promote IPM through targeted funding. PMAP is the Pest Management Alternatives Program. PMAP is, in a sense, our short term—what we call our "plug-and-play"—approach to replacing undesirable IPM technologies. If particular tactics need to be replaced in an IPM program (an organophosphate insecticide, for instance, that may be at risk because of Food Quality Protection Act (FQPA) implementation), PMAP supports studies that will allow removal of that OP from the program without reducing program efficacy. It is a short-term, 1- or 2-year research and implementation program, a first step in the replacement of tactical components of an IPM system.

The second step for FQPA implementation is supported by the Crops at Risk Program (CAR). Under CAR, an entire crop (e.g., peaches) will be targeted. Problems with peaches in California probably stem from the excessive use of OP insecticides and B2 carcinogens that are coming next in the Food Quality Protection Act. Under this program, scientists consider the entire crop, tear the IPM program apart, put it back together in a sustainable manner, and test it in the field. So, PMAP operates at the tactical level to the crop, and CAR deals with the crop as a system.

The third step, then, is to consider the entire cropping system. The program is known as Risk Avoidance and Mitigation Program (RAMP). We are asking for $10 million for RAMP. You might consider the entire Willamette Valley with the major crops that are grown here, consider which pest management programs are in place, how they need to be improved in terms of environmental quality, food quality, sustainability; this is a long term program. We are looking at 4- to 6-year projects, and we also are looking at maybe 20 of these across the country.

We also have requested some increase in Extension formula funds, and in special grants. The Regional Competitive Grants Program is staying the same at $2.7 million. In addition, there is the Methyl Bromide Alternatives Program coming out to the states through CSREES for $5 million. These are the major IPM funding efforts at this time. These are in the President's budget. The objective, obviously, is to get this through the appropriations process.

A key feature of both the PMAP and the CAR programs will be the requirement for early stakeholder input. The RAMP program, focusing on a cropping system, is a long term approach involving the strategic concept of PAMS. We should be able to define the systems with suspected risk, define what the pest management systems are and which ones need to be improved, focusing on productivity, profitability, and environmental quality. This may be the first program to incorporate the idea of regional pest management centers.

An idea that has been floating in Washington probably for 4 or 5 years, is the establishment of virtual IPM centers in various regions of the country. We're not considering new buildings and money put into brick and mortar, but to identify places where cropping systems or cropping approaches can be defined—maybe considering agroecological zones or cropping system zones. EPA has done a reasonably good job, for instance, of developing 12 or 13 of what they call field trial regions in the United States. These regions were based on cropping system zones. There may be some overlap because of different zones that we will develop. We probably will try to follow a model that was developed by the National Science Foundation. It is an industry/university cooperative research center model. The reason is that it allows centers to bring in a board of advisors that represents the stakeholder groups that have an interest in the region. It also allows the center to bring in grant funds from various sources: from commodity groups, from industry, from foundations interested in funding projects at a regional center.

The primary goal of developing regional centers is decentralization from Washington. Pest management is not something that can be decided inside the Beltway. The decisions on pest management should be based on the cropping system regions. That is where they are used. EPA may join in this approach to the regional centers, and it has even suggested that it would be willing to have some regulatory decisions based within the regions. An example, cited by the EPA, is the work on insect resistance management programs with respect to Bt crops. These IRM programs are very different in the Midwestern corn growing area than they are in the Southern cotton growing area, for instance. So it would make sense for the people in the Midwest and the North Central region to make decisions on corn, and it makes sense for people down in the Southern region to make decisions on cotton. Centers also may participate in the development and evaluation of new technologies, because suitability of these technologies will differ from region to region. Management and dissemination of information is probably one of the key roles that the centers would play. There are times, for instance, that the Office of Pest Management Policy in USDA needs information rapidly on a particular crop or from a particular region. If the expertise had been organized and identified within regions, it might be easier to go to a regional office and get that information than to go to each state individually.

I mentioned input on policy and regulatory decisions and the ability to fund and manage research projects. There are many things that can be accomplished through regional centers that could take some of the burden off of states to do repetitive tasks, such things as a Section 18 request going into EPA. If five states need a Section 18 on a particular pesticide, all five states have to do the application individually. Regional centers could do that application, instead of all individual states having to be involved in it. It definitely would speed things along when it got into EPA. The Regional Center concept is now in the developemental stage.

Question (C. Benbrook): I can't resist the temptation to ask you how, given the importance of weeds in IPM on major row crops like soybean, for example, how would you envision the Roundup® Ready soybeans scoring under the USDA PAMS concept?

Answer: It depends on how it is used. If a grower goes out and plants Roundup® Ready soybeans, then automatically sprays, that is obviously not good IPM. But if he uses Roundup® Ready soybeans with the idea that he is going to look at that crop and determine whether he really needs to use a herbicide or not, then use it only where it needs to be used, that is a good concept. Roundup® has better environmental characteristics in terms of water quality than most other herbicides that are being used in soybeans right now. So, it is simply a matter of how it is used. It goes back to the decision making process. One of the problems is the cost involved in buying Roundup® Ready seed, and a lot of growers are understanding that now and are taking a closer look at that convenient approach to weed management on their crop. So, if they realize that they have a weed spectrum that Roundup® does a good job on, if they buy the seed and plant it in narrow rows, which is another one of the real critical things in terms of making Roundup® successful, if they do field monitoring and use Roundup® where it is needed, that is a good approach. If they just plant and spray without concern for where they are spraying or why they are spraying, that is not a good approach, and that's why the monitoring is essential.

Question (?):You talked about the big picture and the long term sustainability of IPM systems. We are looking at genetically engineered seed and consolidation of the gene pool by international corporations. At issue here is the sustainability of the small system and what is, in the long run, the impact of a few large multi-national corporations controlling the seed that is being planted. Where does that fit into the big picture in the long term sustainability of farming systems?
Answer: It's a very serious question. I certainly don't have the answer but I can tell you that there are a lot of people all over the country who are interested in that and there is a lot of attention being paid to it. It does concern us in terms of the IPM situation. Are we going to have access to all of the variability we need in terms of genetics down the road represents a very critical question.

Question (?): In the GMO debate with EPA there has been considerable emphasis given to the establishment of refugia for resistance management. Some of the large corporations that were mentioned before lobbied heavily to get that resistance management part taken out of the rules. The requirement to leave 20 percent refugia in corn, cotton, or potatoes was accepted initially by the large corporations, but as more of them got into the game, that 20 percent margin share became quite important. All at once now, resistance management is taking a back seat to a policy process rather than the profit probability of these large crops. What do you think about this?
Answer: Well, I happen to have a draft of the IRM approach that came from the combined industry group and it's back at 20 percent. I think they realize they were going to lose the fight with EPA if they didn't get on the bandwagon, so there is some "give" occurring within the industry.

The Role of Extension in Promoting IPM Programs

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By 1977, the Cooperative Extension Service had supported the implementation of 52 (3-year) pilot IPM (integrated pest management) programs across 33 states in a variety of cropping systems (Good, 1977). Evaluations of these pilot efforts were conducted by Federal agencies and external groups, and these conclusions were drawn:

- *Pesticide usage can be reduced 30 to 70 percent in situations where unwarranted or poorly timed applications are made.*
- *In many situations, nonchemical means of pest control can be substituted for or augment pesticides.*
- *Use of certain pesticides may increase where farmers are unaware of losses caused by pests and where use of a pesticide is the most feasible control method.*
- *Situations develop where no combinations of available pest suppression methods can prevent serious crop losses.*
- *Economic benefits to farmers and society occur from savings in costs of pesticides and their application, as well as increases in yield andlor quality.*
- *Energy savings occur in both fuel and petrochemical products used.*
- *Increased employment opportunities are provided for youth who scout fields, as well as for private sector professionals who advise farmers.*
- *Fewer pesticides enter the environment and residues of pesticides in food products are minimized. Many farmers increasingly are willing to pay for improved advisory services when they are available.*

The overall success of these pilot IPM Extension projects quickly led to the annual Federal support of Cooperative Extension Service IPM programs in most states by the mid- to late 1970s. In 1977, at a National Pest Management Workshop in Kansas City, Missouri, Joseph Good, Extension Service, USDA, Washington, DC, offered the following thoughts on the future role of the Extension Service in promoting integrated pest management practices: *"Future implementation of Integrated Pest Management will depend on advanced research technology and availability of trained personnel in both the public and private sectors. To be effective, the State Cooperative Extension Service must acquire the necessary expertise and resources to conduct programs at the state, area, and county levels. Without continuing Extension participation on a permanent basis, the program cannot advance. If not adequately developed, it will falter or fail completely. The objective will be education rather than providing services. Training must be provided to farmers, field scouts, county Extension personnel, and others who advise farmers. In the future, large farmers are most likely to secure advisory services from private pest management consultants and firms."*

With the hindsight of nearly a quarter century, it's safe to say that Joseph Good's remarks were on target. Indeed, most state Extension IPM programs no longer provide field-level services directly to growers. A survey of Extension IPM coordinators (Gray, 1995) revealed that 29 states no longer provide direct scouting services for growers. In fact, 41 Extension IPM coordinators indicated that they primarily conduct educational programs and prepare IPM resource materials. As Good predicted, many large-scale farmers and growers currently are securing much of their direct pest management information from the private sector. The private sector has stepped into the one-on-one pest management advisory breach with producers. Increasingly, the private sector has become Extension's direct audience. Ultimately, producers benefit indirectly through the dissemination of pest management information from private consultants, certified crop advisers, and others in the seed and agrichemical industries.

The potential for conflicts of interest is obvious and frequently is mentioned by critics of this system. In addition, producers often fail to see the advantage of supporting Extension IPM programs, because pest management recommendations made to growers most often are delivered from the private sector. In certain instances, industry has attempted to alert their customers to the importance of university Extension programs in providing educational materials and programs for their employees. However, this message frequently is lost or forgotten among producers.

Why can't Extension programs provide as much direct contact with producers today? During the past decade, the number of Extension specialists has continued to decline, or at best has remained constant among the pest management disciplines. For instance, the number of Extension entomologists decreased in 21 states and remained unchanged in 18 others. Thus, by factoring inflation into the equation, Extension entomology programs have lost ground in 39 states (Gray & Steffey, 1998). Quite simply, there aren't enough Extension specialists to provide the one-on-one contacts with farmers and growers compared with the private sector.

The traditional land-grant model, that of disseminating research-based information to clientele, continues to be the envy of those throughout the world who struggle with supplying abundant, healthy food to their growing populations. The standard components of this model consist of Extension specialists interacting with producers to better understand their pest management challenges; Extension specialists conveying this information to researchers on campuses; researchers solving these applied pest management problems; Extension specialists disseminating the results of these scientific investigations back to farmers; farmers finally implementing solutions on their farms. The magnitude of this success story has not been duplicated anywhere else. Yet, despite nearly 85 years of cooperation among Extension specialists and researchers, this remarkable track record of impressive achievements is undergoing a rapid transition. Producers increasingly are becoming more interested in participating as full partners in the research process. This includes not only the identification of pest management problems, but also may involve cooperation in the design of experiments conducted on their farms and eventually the implementation of the findings.

The increase in the popularity of participatory on-farm research programs in many states is a testament to the growing interest in this new model. Those producers who continue to prosper increasingly are more sophisticated, very well educated, computer-savvy, and looking for new partnerships with Extension specialists at universities. As the number of producers continues to decline nationally, so does the number of IPM Extension specialists on many campuses. The complexion of research conducted by campus scientists also has shifted considerably during the past 10 years in the direction of molecular biology and away from field-level experiments. This development has placed much of the applied pest management research in the arena of the Extension specialist. In fact, many tenure-track Extension specialists clearly have identified research responsibilities in their official appointments. Consequently, it is becoming less common in many departments to find specialists with 100 percent Extension appointments, especially for recently hired Extension faculty. With these many changes to the traditional land-grant model, new challenges as well as opportunities must be recognized. In 1992, in response to these developments, Steffey and Gray (1992) offered the following recommendation: *"We suggest that a continuum in which researchers, Extension specialists, and farmers are intimately involved in all phases of problem identification and resolution is more appropriate today than the traditional linear model..... We should build on the strengths of our tradition and change our model to meet today's new challenges. Although the rules of the game have not changed, the game has."*

The results from a survey of Extension IPM coordinators (Gray, 1995) reflected the reality of this changing land-grant model in the Federally supported Extension IPM programs across the nation by the mid-1990s. Results revealed that Extension IPM programs typically invested the Federal allocation into salary lines of employees, most often in the direction of nontenure track appointments. However, 22 respondents indicated that, in their state, some tenure-track faculty derived full or partial support from the Federal allotment. Because of stable Federal funding for

Extension IPM programs in the 1980s (actually decreases in real dollars due to inflation), and marginal increases in the 1990s, reduced program flexibility at the state level remains a reality. Despite the erosion in Federal support for Extension IPM programs since the early 1970s, IPM coordinators (44 of 45 of whom responded to this question) indicated that they anticipated IPM gaining support from the general public throughout the 1990s.

Unfortunately, this anticipation has not translated into significant increases in funding from the Federal Government. In September of 1993 (House testimony), the Clinton administration challenged the IPM community to implement IPM on 75 percent of the nation's managed acres by the year 2000. In an effort to respond to this lofty challenge, the U.S. Department of Agriculture launched (December, 1994) the so-called "IPM Initiative" which pleaded for the strengthening of existing partnerships and creation of new cooperative ventures between IPM research and Extension programs with other governmental agencies, other universities, and, most importantly, with user groups in the private sector. During the second National IPM Symposium/Workshop (Las Vegas, Nevada, April 1994), T.L. Nipp, AESOP, offered a warning regarding the renewed interest during that time in IPM: *"During the past 30 years, there have been repeated waves of support for IPM. Somehow, each time, we managed to fragment our interests and our coalitions, only to lose momentum and support and fade to the background again. Frankly, I am surprised that IPM is going to have one more chance. I don't think that there will be another chance if we repeat the mistakes of the past."* Five years after Nipp offered his stern warning, I believe it is accurate to conclude that considerable momentum has been lost for increasing support of our Extension IPM programs.

Why did the momentum of the mid-1990s for Extension IPM programs erode? Are the supporters of IPM so diverse and fragmented that we couldn't all "hitch up to the IPM wagon"? There may be significant truth to this suggestion. The IPM community is a diverse group with urban and rural sectors, 99 field crop and fruit and vegetable components, and multiple disciplines within university IPM leadership structure. For instance, even among Extension IPM coordinators, there are considerable differences in academic backgrounds (as of 1995): 31 entomologists, 6 plant pathologists, 4 weed scientists, and 4 others in horticulture, nematology, chemistry, and invertebrate ecology. A divergence of opinions always has existed among Extension IPM coordinators regarding the primary goal of Extension IPM programs.

In 1989, at the National IPM Symposium/Workshop in Las Vegas, Nevada, F.L. Poston, Director of the Cooperative Extension Service at Washington State University, offered the following thoughts regarding priorities for Extension through the 1990s: *"Clearly, Extension must take a leadership role in moving away from pesticide use. If the scenario I have described is correct, farmers will eventually be driven away from reliance on pesticides. This position may initially be unpopular with farmers. If, however, my assessment of the future is correct, Extension will benefit greatly from its leadership role."*

Did Extension embrace or reject this Extension role outlined by Dr. Poston through the 1990s? The following question was directed at Extension IPM coordinators (Gray, 1995) and may help at least to provide some insight regarding how Extension responded to Poston's 1989 challenge: *Do you believe that the chief goal of an IPM* Cooperative *Extension Service Program should be to reduce pesticide use?* Twenty Extension IPM coordinators answered "yes," while 23 indicated "no" to this question (2 remained undecided). I suggest that many segments of the general public would maintain that if the primary goal of an Extension IPM program is not to reduce pesticide use, it should be (Cuperus et al., 1996; Hamilton et al., 1997; Potter and Bessin, 1998). A slim majority of Extension IPM coordinators, as of 1995, believed otherwise.

Integrated pest management coordinators also were asked (Gray, 1995): *Would you agree with some critics that IPM has not delivered upon many of the expectations of the early 1970s (most principally that pesticide use would decline if IPM practices were followed)?* Eleven IPM coordinators answered "yes" and 34 responded "no." Yet, this is despite the fact that herbicides are applied to 98, 94, and 98 percent of the corn, cotton, and soybean acres, respectively, within the United States (USDA-NASS-ERS, 1995), and insecticide use in nonrotated corn remains significant (Pike and Gray, 1992). Pesticide use by U.S. homeowners also is pervasive (69 million U.S.

households), with 2,4-D and chlorpyrifos commonly used (Pesticide and Toxic Chemical News, 1994). Cate and Hinkle (1994) suggested *"there is an understandable cynicism about IPM as a paradigm for pesticide use reduction."* Without the general agreement even among Extension IPM coordinators regarding what the primary goal of an Extension IPM program should be, it's no wonder that the momentum of the mid-1990s largely has been lost.

Looking back, the early 1990s started off in the right direction regarding our efforts to increase IPM adoption among producers. In June, 1992 (Arlington, Virginia) the USDA and the U.S. Environmental Protection Agency sponsored a national IPM forum. More than 600 participants, largely from the university and Federal sectors, sought to identify constraints and solutions regarding the adoption of IPM practices by growers. The top constraints agreed upon by those who attended the forum included (Sorensen,1994):

- *Lack of a national commitment to IPM.*
- *Insufficient funding and support for IPM implementation, demonstration, and fundamental infrastructure.*
- *Lack of funding and support for long-term interdisciplinary research and Extension education.*
- *Burdensome, expensive, time-consuming, unclear regulatory processes.*
- *Lack of funding for applied research, lack of regulatory personnel to expedite product registration, and lack of education promotion for growers.*
- *The shortage of independent, trained IPM practitioners.*
- *Inability of USDA and EPA effectively to address cross-cutting agricultural and environmental concerns.*
- *Insufficient education of the public about IPM and its benefits.*
- *Agricultural policies that were developed without considering IPM.*
- *Lack of common and specific goals for IPM.*

The **primary solutions** to overcome these constraints were as follows (Sorensen, 1994):

- *Make a national commitment to IPM.*
- *Increase public and private funding for IPM research and Extension.*
- *Increase funding to the Cooperative Extension Service to provide long-term stability for IPM education.*
- *Combine research and Extension programs.*
- *Implement EPA's safer pesticide policy.*
- *Include social science and marketing strategies in IPM development.*
- *Reevaluate agricultural policies with IPM in mind.*
- *Establish an EPA ombudsman or problem solver.*
- *Establish a formal interagency IPM taskforce.*

Because relatively few producers attended that national forum, a series of regional workshops subsequently were conducted to "get the pulse" of growers regarding IPM constraints and potential solutions. In 1993, the National Foundation for IPM Education, with the assistance of land-grant scientists at selected universities, organized regional workshops for producers, who were asked to identify constraints to the adoption of IPM as well as potential solutions to overcome the constraints (Sorensen, 1993). The production systems featured at the regional workshops included: (1) fruits and vegetables in California, (2) corn and soybeans in Illinois, Iowa, and Indiana, (3) apples in Pennsylvania, and (4) cotton in Texas and Oklahoma. The EPA provided partial support for the workshops. The objective of these workshops was stated succinctly: *to identify constraints producers face in using IPM and in moving away from chemically based pest control to information based pest control.* The following constraints were mentioned by producers in at least three of the regional workshops (Sorensen, 1993):

- *A lack of incentives to use IPM or a perception that the economic benefits of IPM programs did not justify the increased demands on management*
- *Differing agendas and conflicting messages from governmental agencies*
- *Loss of funding for applied research*
- *Lack of funding for IPM education and research programs*
- *Slowness of the EPA pesticide registration system*
- *Lack of availability of pesticides, thereby limiting control options for growers and*

reducing the flexibility that IPM programs need to respond quickly to pest outbreaks
- *Commodity programs that discourage crop rotations, a key IPM tactic*
- *The need to market IPM more effectively*
- *Problems with Delaney Clause restrictions, which may limit pesticide availability*
- *Lack of understanding by producers about the total production system approach to IPM*

The similarity is striking between those constraints identified by participants at the national IPM forum and growers at regional workshops. The road map for increasing IPM implementation was laid out clearly several years ago by growers, researchers, Extension specialists, and other leaders in IPM. Although progress surely has been made toward overcoming some of the constraints identified by growers and those who attended the national IPM forum, it is my assessment that many of the same problems that plagued the IPM establishment in the early 1990s remain today. Most notable of these constraints are: (1) an acute and persistent lack of funding for Extension IPM educational programs, (2) shrinking resources for applied pest management research, (3) chronic confusion regarding the pesticide reregistration process, (4) uncertainty regarding the future of many pesticides, (5) incongruity of many agricultural practices and policies with sound pest management strategies, (6) failure of "IPM" supporters to market IPM success stories effectively to the general public (most members of the general public still do not recognize what IPM stands for), (7) a general lack of agreement within the IPM establishment regarding the primary goal and direction for Extension IPM programming, and (8) failure of IPM supporters to carve out an "identity" for IPM programs that is understood clearly by policy makers and legislators. These will remain daunting challenges into the next century.

How can the Extension Service provide more effective leadership in the promotion of IPM educational programs? Doing so requires paying closer attention to the many constraints and solutions for increasing IPM adoption that were articulated very clearly by producers at regional workshops throughout the U.S. (Sorensen, 1993). Ultimately, Extension has been asked to do more with less for many years. Strategic alliances among IPM Extension specialists across state lines will become imperative. Providing pest management expertise across all commodities in each state was abandoned many years ago. Extension entomologists in 36 states routinely rely upon management recommendations from specialists in other states (Gray and Steffey, 1998). Rapid progress is occurring in the more effective use of web-based technology for the delivery of pest management information. However, I believe we have hit the brick wall in terms of stretching Extension IPM resources. New political support for IPM must be generated at Federal and state levels if we are to continue delivering world-class pest management information to our clientele. This will not be easy. Fred Poston (1989) at the National IPM Symposium/Workshop offered the following remarks on the importance of political support: *"One of the greatest criticisms of IPM stems from the fact that pesticide use has increased dramatically during the IPM era. Although many reasons exist for this phenomenon, it is a fact which has not escaped its detractors. Perhaps IPM's greatest liability, however, rests with its age. There is nothing more politically impotent than an old program. Legislators sell new programs as "fixes" for the future. Reemphasis of an old program offers little hope for the future."*

Extension IPM coordinators must become stronger advocates for their educational programs at all political levels. As scientists, many coordinators are not comfortable in the role of an advocate. In fact, in some states, advocacy by a scientist for a speific program is discouraged due to many competing interests for a limited pot of resources. The reality is that program priorities at land-grant institutions generally are not established through the lobbying efforts of small collections of individual scientists with vested interests. If Extension pest management programs are to expand and thrive into the next century, increased political support ultimately will be required of the clientele we serve through our pest management programs. In order to generate this renewed political support, the IPM leadership at Federal and state levels must articulate a unified, easily understood, and crystal-clear mission to legislators, policy makers, and citizens of an urban society.

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Performance Criteria for Measuring IPM Results

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Introduction

I believe that most people at this meeting accept the notion that the best way to reduce pesticide use, reliance, and risks on a sustainable basis is to promote adoption of biologically based Integrated Pest Management (IPM) systems. This surely is the take-home message from progress made on farms across Oregon and the western U.S. in recent years.

The bottom line is clear: it is more cost-effective in the long run to manage pests with a heavy dose of information and biology than it is to try to crush them with chemistry. There also is, of course, much less collateral damage with biointensive IPM than chemical-dependent control strategies.

Still, many barriers persist, slowing progress toward biointensive IPM. Some relate to the pest management knowledge base and others to the tool kit accessible to pest managers. On both fronts, major progress is being made. It's a good thing, too, since challenges on American farms and ranches also keep evolving.

Farmers want to change for a host of reasons. The multiple shortcomings of chemical-based management systems are increasingly difficult to ignore, and the range and effectiveness of options continue to grow. Resistance and secondary pest problems are common. Regulators will continue to drive change, despite the ability of the agricultural sector generally to slow the pace of implementation of new laws such as the Food Quality Protection Act (FQPA). And a growing percentage of consumers is seeking green options in the marketplace. One might expect, as a result, a golden era of innovation on the farm, a period when farmers have little reason or need to look back upon a past era of pest management that left much to be desired.

Still, change in agricultural pest management is not happening very fast, especially compared to other information- and technology-based activities. In parts of Oregon agriculture, it is happening hardly at all. Some wonder why.

The Crux of the Challenge on the Farm

Biobased IPM systems are fundamentally and functionally different from chemical-dependent IPM systems. Pest management systems are composites of decisions and actions made by busy people in a very dynamic industry managing dynamic biological processes. To change IPM systems, farmers and pest managers first must change the organisms that thrive within farming systems. The second step is managing the interactions among organisms and in relation to the crop. Pest managers and farmers must learn to manage interactions across a dizzying, unpredictable array of conditions, while also meeting the quality demands of the marketplace and making an acceptable profit.

This ability depends on definitive knowledge of the ecology of farming systems. It takes a new set of tools and attitudes and a willingness to spend time in the field. It takes the ability to identify effective, affordable, and nondisruptive courses of action when populations approach economic threshold levels. Time is money, and both are stretched. Plus, the ecological sciences have been withering on the vine, especially field based systems research. And most of the pesticide industry's investment capital has been flowing into biotech, buying seed and other companies, and defending old, high-risk pesticides.

Momentum for change in the world of pest management is growing from new roots, particularly ongoing problems with chemical-based systems and the pent-up demand among consumers looking to exercise freedom of choice in the marketplace. The "new green mainstream," to borrow Harvey Hartman's term (Hartman, 1996), is looking for ways to support ecologically committed farmers and food companies. Ecolabels have emerged as a promising bridge linking consumers with farmers and food companies that place a premium on safer production systems, resource stewardship, and enhancing quality of life. In the Pacific Northwest, the Food Alliance is making steady progress in offering consumers value-added choices (for more information, see www.thefoodalliance.org/).

Reducing Pesticide Risks and Promoting IPM

Many organizations and government agencies have adopted as their mantra the twin goals of reducing reliance on high-risk pesticides and promotion of biointensive IPM. The former goal is designed to draw the interest and support of consumers and environmentalists, the latter to draw the participation and cooperation of innovative farmers, farm organizations, food companies, and marketers.

Each of the programs I know of deals differently with the inevitable tensions between consumer-environmental and farmer-ag industry goals, agendas, and world views. In many cases, the setting of concrete goals, coupled with the development of a measurement system to monitor progress, has proven the decisive steps that have given growers, environmentalists, consumers, and the ag industry reason enough to stay at the table looking for solutions rather than complaining about problems.

A Credible Measurement System and Transparency

In many respects, agreeing on goals is the easy part. The hard part is translating goals into concrete, real-world actions that can be monitored over time.

Everyone supports progress along the IPM continuum, but opinions differ on what this really means and whether such progress will, in fact, reduce use of high-risk pesticides. In 1993, I was hired by the Consumers Union to carry out a project on IPM with the goal of trying to come up with a well-grounded definition and IPM measurement system. The 1996 book *Pest Management at the Crossroads* (PMAC) (Benbrook et al., 1996) sets out the basic framework of the IPM measurement system I have been working with and refining for the past 5 years. Those interested in the latest large-scale application of the measurement system can go to the June 1999 draft papers posted on the PMAC web site at http://www.pmac.net/potatipm.htm. These papers present the 1998 IPM baseline for the Wisconsin potato industry: a major analytical accomplishment of the World Wildlife Fund–Wisconsin Potato and Vegetable Growers Association collaboration.

Why Measure?

The best way to reduce pesticide use, reliance, and risks on a sustainable basis, while also cost-effectively managing pests, is to promote adoption of biologically based IPM systems.

IPM systems exist in almost limitless variety along what can be thought of as an IPM continuum. Biointensive IPM systems—the kind most people are willing to support—strive to lessen pest pressure through management of ecological and biological processes and interactions. When pests do emerge as a threat to crop production and quality, such systems rely principally on biological and ecological means to reduce pest populations below economic thresholds.

Monitor Trends

American Vegetable Grower has been compiling data on the "Top 100 vegetable growers" for 11 years. Two decades of incorporation of IPM practices has changed greatly the way these growers have managed their farms. "Crop quality should be the biggest motivation of IPM. When you're out there every day, you know what's going on in the field." (Rick Melnick, "Shedding Light on IPM," *American Vegetable Grower,* October 1998, pages 9-19).

Stemilt Growers, a company organized in the 1960s, has been a pioneer in this area. In the early 1990s, Stemilt Growers developed a point system linked to pesticide properties and hazards, helping growers understand the environmental consequences of various changes in IPM systems. Given the stated goals of the Stemilt program, its measurement system is one of the best in the country.

Recognize Changes in Efficacy and "Trade-offs"

Over the next decade, the FQPA is likely to precipitate important changes in pesticide use patterns and pest management systems. As regulation and the availability of better alternatives drive high-risk pesticides off the market, farmers and pest managers will seek new ways to manage both old and new pests.

Most will draw upon three basic options in crafting new IPM systems: switching to different pesticides; reducing reliance on pesticides by moving toward the biointensive end of the IPM continuum; and adopting emerging "high-tech" approaches, such as crops genetically engineered to express bacterial endotoxins or tolerate certain herbicides.

Each option will have a range of impacts—some positive, others possibly negative—on diets, pesticide exposure, farmers, and rural communities. A reduction in one kind of risk may be accompanied by a rise in other risks. To make wise choices, both the U.S. Environmental Protection Agency and pest managers need careful analyses of the consequences of alternative courses of action.

The need for better information to guide choices is acute. EPA faces dozens of key strategic choices both in the biotech and conventional pesticide arenas. The biotechnology industry aggressively is marketing new transgenic plants that may well increase pesticide reliance and heighten the risk of resistance. Reliable data on the long term economic and ecological consequences of these choices and decisions generally do not exist. New risk assessment tools are needed to keep pace with changing technology and to assure that the FQPA and biotech decisions and policies reduce risks across the board.

A major part of the work of Benbrook Consulting Services aims to generate new, data- and science-based analyses of risk trade-offs, a necessary step in getting at the consequences of regulatory choices and policies. We are examining alternative pest management systems that are available to fill in for high-risk pesticides targeted for phase-out under the FQPA. The "FQPA Impact Simulation Model" we have created also projects changes in risk levels and economic impacts.

Applications of this model to the apple and pear industries in the West show, for example, that reductions in miticide expenditures as a result of progress toward soft, mating-disruption-based insect pest management systems can more than make up for the increased costs associated with adoption of mating disruption technology. I am aware that some innovative Oregon fruit growers have made the transition successfully to bio-based IPM and have been pleasantly surprised by reduced late-season problems with mites.

Evaluate Programs and/or Return on Investment

Practice-based programs are a good first step, but they will, over time, face questions regarding actual accomplishments in terms of reducing pesticide use and risks. My sense is that 5 years down the road, most ecolabel programs will incorporate a way to document credibly their impacts on pesticide use and risks and on water quality, where that issue is on consumers' radar screen. One reason is that these are the issues the majority of consumers care about most deeply. Another reason is the growing presence of the organic industry in the marketplace. Those with the clearest and most compelling message will compete successfully for the dollars of the green shopper. They will thrive and others are likely to fall by the wayside.

A strong case can be made for an increase in public and private-sector investments in biointensive IPM systems, because of the many benefits that will accrue to society as a result of their adoption. But the same case cannot be made at the other end of the IPM continuum. Pesticide manufacturers and others who profit from pesticide sales should bear most of the burden in developing and sustaining chemical-dependent systems. Indeed, society is likely to ask manufacturers and farmers to cover more of the social and regulatory costs stemming from pesticide-based systems through fees, taxes, and other financial instruments.

Rewarding Progress is Key

Creating and capturing value in the marketplace will, in the end, determine whether ecolabeling becomes a stable part of the country's food marketing system. Those willing to pay for biointensive IPM adoption in the marketplace, or with tax dollars, will need to be convinced that they are getting what they are willing to pay for: reduced reliance on risky pesticides, along with improvements in water quality and worker and food safety. This is why the ability to distinguish between pest management systems along the IPM continuum in terms of reliance on high-risk pesticides will be critical in establishing IPM adoption baselines and then in measuring progress.

Considerable effort is underway to develop ways to distinguish between various levels of IPM adoption. An example is the four zones of adoption described in *Pest Management at the Crossroads:* no IPM, low-level IPM, medium IPM, and biointensive IPM. Another key step is to capture differences in pesticide reliance, use, and risks across farms at various stages along the IPM continuum and over time as progress is made toward biointensive IPM.

A common strategy is emerging that entails focus on the information and knowledge relied on in reaching a decision to use certain seminal pest management practices, rather than counting the total number of practices used. This approach is under development within IPM-labeling efforts carried out by WWF-WPVGA, The Food Alliance, and the Core Values apple program in New England. (For details on these programs, see the "Measuring IPM Adoption" portion of the *PMAC* web page, http://www.pmac.net).

Knowledge-based strategies rest upon recording and verifying grower responses to a set of questions linked to key pest management system choices. The questions are designed to identify the completeness of the information growers had when deciding what practices to adopt, as well as how they used the information in structuring and carrying out field interventions—whether applying a pesticide, using a cultural practice, releasing beneficials, or doing nothing.

An example might help demonstrate this concept. Consider a common dilemma: whether to spray a broad-spectrum insecticide in the face of an early-season leafminer, thrip, or aphid infestation, knowing that the application will set off a number of other secondary pests because of impacts on their natural enemies. Sometimes such applications, or other costly interventions, simply cannot be avoided; but in other cases, they can and should be. Distinguishing the information a grower should have and use in determining what to do in such situations is the focus of knowledge-based certification. Questions an annual program application, survey, or farm plan might explore are:

1. The scouting information the grower had and considered in making a decision to spray or not spray
2. Specific field information used in conjunction with a forecasting model or expert system, such as the University of Wisconsin's WISDOM program for potato pest and nutrient management
3. Information and knowledge relied upon in carrying out interventions, and steps taken to minimize future problems and maximize the chances of success

Knowledge-based systems are promising for many reasons beyond their simplicity and focus. Measuring IPM adoption is going to take effort and cost money, particularly if it is used to support IPM-labeling programs. Those designing and implementing such systems should do everything possible to keep system costs down and to design approaches that serve as many useful ends as possible.

Knowledge-based systems can do just that by also fostering grower-scientist-practitioner dialogue on the cutting edge of IPM implementation in the field. This approach can hasten refinement of scouting techniques, identifiy ecological interactions to monitor and manage, enhance the effectiveness of emerging tools and biopesticides, and create better ways to use decision-support tools and other sources of information.

At the end of each season during grower meetings, the results of the past season should be reviewed routinely, as most programs do now. Growers or consultants who feel they have found a better way to deal with a common pest problem will be free to make their case. The resulting exchanges among growers, consultants, and researchers will highlight where there is consensus and where further research and experimentation are needed. In this way, knowledge-based IPM measurement systems can serve both as a verification tool and a way to foster dialogue and creative problem solving.

Set Priorities: R&D, Education, Policy Change

Much of my work now is focused on developing and applying methods to measure progress toward biointensive IPM—a common challenge facing government agencies, grower groups, the food industry, researchers hoping to win and/or defend larger budgets, and private foundations supporting cooperative IPM projects.

People recognize that managing pests is like dealing with diabetes or computer software. Science and technology are driving rapid change in what is possible. At the same time, Mother Nature is throwing her share of curve balls at farmers. Pest challenges are not static. Progress made in one year can evaporate in a flush of whiteflies or be swamped by the pathogens that thrive in a wet fall.

Ecolabel programs must build this reality into their goals, performance standards, and monitoring systems. Progress will not be made in every year in reducing pesticide use and risks. Ecolabel programs must accommodate slippage when it truly is unavoidable. In return, the programs should ask growers and pest managers to make a commitment to steady progress whenever and however it can be achieved.

Most ecolabel programs really have yet to deal with this challenge, at least in a way consumers understand. They need a way to accept slippage (limited pesticide use) when unavoidable, but without opening the door to an endless series of "justified" setbacks. Successful programs will achieve incremental change yet accept periodic setbacks through adherence to a common set of principles, criteria, and decision processes.

First Steps in Measuring Pesticide Impacts and IPM

1. *Cornell University scientists propose the "Environmental Impact Quotient (EIQ)."*

Filling what many saw as a key need, a team of researchers at Cornell University developed a way to assess the relative risks of pesticides (Kovach et al., 1992). The team developed what has been called the Environmental Impact Quotient (EIQ), a model that integrates various environmental impacts into a single value based on the rule "environmental impact is equal to toxicity times exposure."

2. *The Clinton Administration sets a 75 percent adoption IPM goal.*

In June, 1993, the Clinton administration embraced IPM as a national goal, although Congress has still not made achieving the goal a priority. The Administration captured the attention of farmers, food processors, environmentalists, and the academic community with its pledge to get 75 percent of cropland acreage under IPM by the year 2000. The timing of this pledge was no accident. On June 28, the National Academy of Sciences released a long-awaited report, *Pesticides in the Diets of Infants and Children* (NRC, 1993a). Heavy coverage of the NRC report and reaction to it and the Administration's pledge continued for months.

3. *ERS/USDA release the first national assessment of IPM adoption and conclude that approximately 50 percent of acres are under IPM using "count the practices" criteria.*

Between the June, 1993 IPM pledge and spring 1994, senior USDA officials were grilled several times on Capitol Hill about where the nation stood in terms of IPM adoption. They had no basis to answer even simple questions and so directed the Economic Research Service (ERS) to develop a method as quickly as possible for estimating current IPM adoption, based on data available in early 1994. A September, 1994 report, *Adoption of Integrated Pest Management in U.S. Agriculture*, was released, the first of its kind (Vandeman et al., 1994). Analysts from the ERS acknowledged that further work was needed in order to refine their IPM adoption criteria and measurement methods. In releasing the report, though, the USDA embraced the importance of measuring IPM and started an ongoing process toward better measurement methods.

Measuring IPM Adoption in Corn and Soybean Systems in 1994

In a 1994 project (Benbrook, 1996), I used farm-level data on herbicide use patterns and prevention-oriented weed management practices in the USDA's cropping practices survey to divide surveyed soybean and corn acreage into four zones along what is called the "integrated weed management" (IWM) continuum: "No," "Low," "Medium," and "High" levels of integrated weed management. These levels of adoption correlate roughly to those reported in the ERS report (Vandeman et al., 1994). Results are accessible at **http://www.pmac.net/wssa.htm** and demonstrate the potential for reducing herbicide application rates, pounds applied, and acre-treatments as progress is made along the IWM continuum.

Ongoing Efforts and Current Challenges

GPRA and AREERA compliance

The USDA's Cooperative State Research, Extension, and Education Service (CSREES) has initiated discussions with land-grant partners on how to respond to IPM measurement challenges in the context of both Government Performance and Results Act (GPRA) and Agricultural Research Extension and Education Act (AREERA). A set of IPM program evaluation "indicators" has gone through several drafts and is nearly ready for implementation (see http://www.reeusda.gov/ipm/planning.htm).

EPA's Pesticide Environmental Stewardship Program (PESP)

EPA and USDA held a stakeholder workshop in February, 1994 to gather ideas, suggestions, and concerns about reducing pesticide use. A set of principles emerged that were used to guide development of a new voluntary program, the Pesticide Environmental Stewardship Program (PESP). PESP encourages progress along the IPM continuum through cooperative effort. (For a list of current partners and an overview, see www.pesp.org/)

"Green Labeling" Programs

Several groups and programs are embracing the principles of IPM in the context of ecolabel programs. Environmental and consumer groups, including the World Wildlife Fund, are exploring ways to promote and reward IPM adoption through marketplace initiatives. (For a review of the genesis of WWF's involvement, see Hoppin, 1996 at http://www.pmac.net/pollyipm.htm; for recent WWF activities, see http://www.pmac.net/potatipm.htm). Yet, questions remain and views differ regarding what constitutes "IPM," as made clear in Marcos Kogan's introductory remarks.

Some Arizona farmers enthusiastically are supporting the principles of IPM and their application in IPM-labeling. David Kerns, a University of Arizona IPM specialist, explained why in a recent issue of *California Farmer:*

> "...to market crops certified as IPM grown would be a boon for the Arizona vegetable industry. The reason I want us as a state to go ahead and develop this program is then it can be designed to fit what works best for us, instead of possibly in the future having a system forced upon us that doesn't work in Arizona. I don't believe the government will be able to effectively mandate specific IPM practices from a national set of standards because pest populations, cropping patterns and agricultural practices greatly differ from one area to another." ("Assurance Plan," *California Farmer*, Mid-March 1999, pages 12-15.)

New York State and Cornell IPM Labels

New York-based Wegmans Food Markets has developed an Integrated Pest Management program for labeling products in their stores. Wegmans developed crop-specific standards for IPM-labeled products in cooperation with Cornell University. Wegmans first introduced the IPM-labeled sweet corn in one of its stores in 1995. Since then, the program has continued to grow, with 53 of its 56 stores carrying IPM corn in 1998. "Last year, we got up to 40 growers in New York and Pennsylvania. This year, we're getting additional growers into the program," commented Bill Pool, Wegmans' food safety manager. Following a consumer survey, Wegmans discovered that customers are willing to accept blemishes as a tradeoff to reduced pesticide use on food products. The program now is extending its reach to include IPM-labeled canned and frozen vegetables. (For more information, see "IPM Corn Grown in Most Wegmans Food Stores," *IPM SOLUTIONS,* April/May 1999).

Gerber Products Company

For years, the Gerber Products Company has worked to eliminate pesticide residues from their baby food products. Indeed, the company has a clear and straightforward policy that everyone works to achieve: no detectable residues in finished product. Largely, they have succeeded, but it has taken a number of years and initiatives to do so.

One key ingredient is the issuance each year of a list of permitted and prohibited active ingredients. This list has gained a degree of notoriety and has stimulated other companies to develop their own lists. In recent years, the Gerber list has evolved to provide more and more detailed instructions and criteria governing when and how a pesticide can be applied by Gerber's contract growers. These instructions are fine-tuned each year in order to deal with any residues found in finished product. It is a very data-driven process.

The second core component of Gerber's program is supporting grower efforts to develop and adopt biointensive IPM. Gerber accomplishes this through a variety of activities and cooperative projects. They maintain a staff of field agronomists and pest management specialists that assist Gerber growers evaluate IPM needs and implement new technologies. Gerber leadership has proven decisive in increasing research effort on key fruit crops in Michigan and building farmer interest in IPM. Plus, they have shared production risks by helping long-term growers market portions of their crops that had to be treated with prohibited pesticides.

Projecting the Impacts of the FQPA

Many people are working to project—and manage—the impacts of the FQPA. I suspect that relatively few crop-pesticide combinations will be impacted significantly, surely well less than 1 in 10. By "significant impact," we mean label changes substantially affecting 30 percent or more of acre-treatments. If EPA does a good job targeting high-risk uses, FQPA implementation could reduce risks by 98 percent or more from crop year 1996 levels while impacting less than 10 percent of crop use.

A flood of promising new biopesticides and reduced-risk products are well along in the regulatory pipeline, enough to render FQPA implementation a moot point in many crops by the time any FQPA-driven restrictions significantly impact pesticide use in the field. In addition, the pace of novel product discovery is picking up, especially in the area of biofungicides, where alternatives are needed most. (For an overview, see the 1998 ESA-APS meeting paper accessible at http://www.pmac.net/benbrookns.PDF).

The PAMS Concept and the Diversity Index

Ecological theory suggests, and field experience confirms, that IPM systems with a high degree of diversity in control tactics are the most resilient. IPM systems that weave together multiple tactics spread out the burden of control.

In a system where a single tactic is relied on for control, growers are vulnerable when, for whatever reason, the tactic breaks down. Row crop farmers who use cultivation alone for weed management depend on being able to get equipment into fields at the right time to assure no yield loss to weeds. Neighbors relying on pre-emergence herbicides rely on certain weather conditions to activate the chemicals and to maintain season-long control. Regardless of the tactic, there are combinations of weather, technology, and pest pressure that are likely to lead to problems.

The best way to assure cost-effective control across all conditions is to build redundant mechanisms of control into biointensive, prevention-based IPM systems. These insights led to the concept of using a "diversity of control tactics" index as an indicator of IPM adoption. This idea first arose during the 1998 Integrated Pest Management Measurement Systems Workshop held in Chicago, Illinois. The meeting was sponsored by the American Farmland Trust, the U.S. EPA, and the World Wildlife Fund.

IPM systems are comprised of four complimentary strategies: prevention, avoidance, monitoring, and suppression—the PAMS approach. Within each of these strategies, multiple tactics may be identified, some of which may be applicable only to certain cropping systems while others may be broadly applicable. In all crops and circumstances, though, IPM should include at least some tactics within each of these four strategies.

The diversity index measures the extent to which pest management burdens are spread across a number of practices and tactics. Much work is needed to refine the idea and determine how existing and future National Agricultural Statistics Service (NASS) survey data, and other information at varying levels of aggregation, can be used to develop viable empirical measures of IPM system diversity. One approach would be to:

1. Determine the maximum potential diversity of any IPM system by listing all viable tactics within each of the four major components.
2. Develop a method to quantify the diversity of measures within each PAMS component, taking into account the intensity of reliance on each tactic.

3. Use a matrix or equation to combine the diversity of tactics in each of the four PAMS components into a single measure of IPM system diversity.

A key variable in measuring system diversity is the intensity with which certain tactics are relied upon in a given PAMS component. For instance, most 4-year crop rotations should be assigned a higher intensity value than a 2-year rotation. A farmer using cultivation should receive higher intensity scores for more passes with a tillage tool.

Farmers understand the importance of access to many options in managing pest populations. In the past, especially in systems largely reliant on pesticides, farmers generally have applied different pesticide-based options sequentially. When and as the effectiveness of one chemical slips, other materials are chosen and incorporated into management systems. While new options are drawn upon, the system remains largely one-dimensional and vulnerable to future problems.

As reliance shifts from treatment with chemicals to prevention, greater redundancy in control mechanisms often will be needed. Genetic and biological control mechanisms are driven by complex crop and species interactions, which in turn are a function of the competitive balance between different pests, their natural enemies, and the stage and vigor of crop growth. Variable weather and other exogenous factors can and often do impact pest and beneficial organism population dynamics. For this reason, growers who wish to avoid a return to heavy reliance on pesticides must build into systems a greater diversity of preventive control tactics. When problems emerge, they must activate a greater number of control tactics.

In measuring suppression tactics within the PAMS concept, a method will be needed to capture the intensity of pesticide use, measured by pounds applied and the inherent toxicity of active ingredients. The more narrow a farmer's selection of pesticides, the more toxic the materials, and/or the more pounds applied, the higher the estimate of reliance on pesticides as a method of suppression.

Another key measurement goal is finding better ways to track IPM system resiliency. In an ideal world, specialists should be able to predict which IPM systems or parts of systems are at risk of failure before major control failures occur. In addition, measures of system diversity may be an appropriate means to highlight research priorities and measure progress toward the attainment of the Administration's 75 percent IPM adoption goal.

Next Steps in Improving IPM Measurement Tools

Several additional steps are needed to develop more accurate measures of pesticide toxicity and use and IPM adoption. In calculating human chronic risks, much new data will become available as the EPA implements the FQPA. Within the next 5 years, many pesticides are likely to be subjected to detailed screens to assess capacity to impact the endocrine system. New methods will be needed to incorporate new toxicological information into the chronic mammalian toxicity factor.

A critical need is to factor in more effectively a number of physical and chemical properties that impact the likelihood of human exposure occurring as a result of pesticide application.

In the ecotoxicity component of the equation, much effort will be required to improve aquatic and fish toxicity parameters. More work is needed on avian toxicity, focusing on subchronic and chronic effects.

Substantial work is needed to improve the data set supporting estimates of "BioIPM Index" values. This index incorporates pesticide properties and factors affecting the stability and performance of IPM systems, such as impacts on beneficials, persistence, impacts on pollinators and soil microorganisms, and potential to trigger resistance.

Cooperative work is underway with Dr. Paul Jepson, chair of the Department of Entomology at Oregon State University. Dr. Jepson and colleagues are developing an updated and improved set of SIDEFX factor values capturing the impact of pesticides on nontarget beneficial organisms. Again, this is an enormous undertaking. We are focusing now on developing estimates for newly registered compounds, many of which are being marketed as "IPM friendly" because of their more selective mode of action.

A Parting Thought

Continental Airlines Chairman Gordon Bethune has stated, "What gets measured gets managed," especially when tangible rewards are linked to documented progress. He credits this simple insight in explaining how he helped revive Continental Airlines, which teetered on the edge of bankruptcy when Bethune took over as CEO.

The effort to develop improved IPM and pesticide use measurement methods is a step toward developing the capacity to track and reward progress toward lower risk, prevention-based IPM. Hopefully, improved measurement systems will trigger broader recognition among the public and government agencies of the need to invest in the knowledge and human skills that will, in the end, determine whether progress is made and whether it is sustainable.

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FQPA Effects on Integrated Pest Management in the United States

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Introduction

Today, agriculture is undergoing catastrophic change driven by an array of economic, societal, and biological pressures. Over the past 50 years, most of the economic growth in agriculture, as judged by per-unit value, has been associated with processing and the retail/wholesale marketplace. In fact, per unit farmgate receipts have dropped an average of 8 percent since World War II. In the same period, the input portion of agriculture has grown some 460 percent while the retail market sector has grown 627 percent. Profitability is a Gordian knot for most agriculture producers today. For those that can unravel the complex biological, ecological, and sociological challenges of production agriculture, the future may be rosy, but for the vast majority of producers, the future is not an inviting place.

Other dramatic forces driving change in agriculture include the rise in environmentalism and consumerism and their joined effects on production agriculture. These grassroot forces have been predicated on a growing awareness of the impact of human activities on the biophysical and natural systems that all life is dependent upon. Since the early 1970s, these two driving factors have done more to change the face of agriculture than any other factor. They culminate in a proliferation of regulations that demand rapid and potentially catastrophic change in agriculture.

After the underlying societal forces, probably the most significant long-term changes in agriculture have resulted from the biological and ecological features of production systems. New pest species introductions into North American agriculture have increased as the U.S., Canada, and Mexico have catered to a global marketplace that essentially is homogenizing pests globally. Agriculture will continue to experience the introduction of new species and biotypes of disease and insect pests in direct correlation with the degree of international commerce, despite political efforts to curtail these introductions.

Pest resistance also is a rising global challenge to production agriculture. Resistance is the failure of a plant protection tool, tactic, or strategy to control a pest where the failure is due to a genetic change in the pest. This microevolutionary adaptive process, which leads to superpests, is a global phenomenon. Archtype species such as the Colorado potato beetle, diamondback moth, and German cockroach demonstrate the genetic plasticity of the key pests in every food, fiber, and structural system in the world. Without resistance management measures within an Integrated Pest Management (IPM) context, this alarming trend will increase with the increasing intensity of agriculture and trade globally.

The Food Quality Protection Act (FQPA) was passed by the U.S. Congress in August, 1996. FQPA represents the latest product of society's desire to regulate pesticide use in agriculture, industry, public right-of-way management, and human and animal health protection. This legislation will be implemented on a fabric of biological, ecological, economic, and market-driven forces that has many agriculture production systems on the brink of financial collapse.

Pesticide Use History in the U.S.

One of the most significant reductions of agricultural production risk in this century has come about through the use of insecticides, fungicides, and herbicides. These highly efficacious agrichemicals essentially have simplified the biological complexity of production, yet the use of agrichemicals is not a modern phenomenon. Most of U.S. society is surprised to learn that pesticides have been used continuously in recorded history since at least 4000 BC. This use of agrichemicals has progressed from crude animal oils and diatomaceous earth to chlorinated hydrocarbons, organophosphates, and carbonates, to insect growth regulators, pheromone disruption, and genetically engineered plants and animals.

Yet public perception rules the day! Pesticides are not wonder drugs; they are poisons and detrimental to the environment. Any product termed "natural" by the public is safe. Meanwhile, pesticide residues are dangerous and cause cancer, and the agrichemical industry is a bunch of crooks. These general perceptions often dictate modern media coverage of agrichemical use in agriculture, and the ultimate result is the promulgation of more regulations and restrictions on pest management procedures. These regulations in turn force small producers out of business while encouraging large industry-like corporate agricultural production structures.

However, modern maximized industrial agriculture has led to high productivity with many real and perceived ecological, environmental, and human health drawbacks. These highly tuned industrial production systems probably are the most sustainable systems. Sustainability-production systems with economic, environmental, and ecological underpinning, may be agriculture's best hope for the future.

The optimum pest management system under the sustainable rubric would exhibit the following features:

1. A closed pest management system that recycles inputs and outputs
2. Economic returns to producers that assure equitable and sustainable production
3. Minimal environmental impact
4. Optimal ecological diversity
5. Biologically intensive pest supression
6. Sociologically implementable strategies, tactics, and tools for pest management

In short, this idealized pest management system would be a "best practice" system, because it optimally would adopt new sustainable practices as they became available.

Although there have been many different definitions of IPM, I prefer the definition that emphasizes integration, monitoring, and management of pest populations with minimal impacts. In my view, IPM is the integration of strategies, tactics, and tools to manage pest populations below economic injury levels with minimal adverse sociological, environmental, and ecological impacts. Concurrent with this definition is an understanding that IPM is a continuum of integration and management to reduce external inputs into agriculture.

Production Agriculture Sustainability Challenges

Since the late 1960s, U.S. society haltingly has undertaken a process of the societal valuation of different technological paths to more highly sustained agricultural productivity with lower inputs and negative outcomes. This search for an optimum agricultural production system can be illustrated ecologically as in Figure 1.

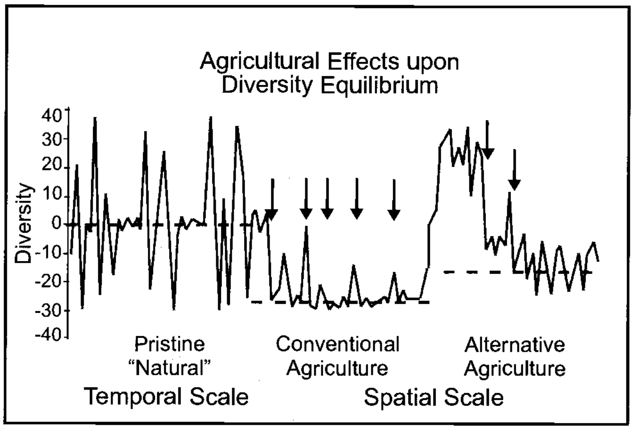

Figure 1. Agricultural pesticide management effects on theoretical species diversity equilibrium for pristine, conventional, and alternative pest management systems.

Essentially, in pristine "natural" ecosystems, species diversity, density, and richness vary across time, often with large fluctuations. In modern agriculture, species diversity has been dampened dramatically by pesticide inputs. As society has mandated alternative, lower pesticide input production systems, greater diversity with increased variation has resulted. Increased variability within the system results when a disproportionate portion of the increased diversity is made up of new, rebound, or facilitated pests. As agriculture moves from pesticide-intensive production systems to these alternative systems, there are numerous challenges and management questions that producers face (Table 1).

Table 1. Challenges of Alternative Pest Management

Conventional	Alternative
Delivery established (1x0)	Delivery requirements increase (6x)
Simple, straightforward	Complex, dynamic (?)
Very effective (too effective)	Less effective (?)
Quality requirements predicated on efficacy	Initially reduced quality/quantity
Known food safety hazards	Wholesomeness (?)
Production system design established	Change of focus (production) to biology
Equipment developed	Equipment unknown - adoption (?)
Economics simple (too simple)	Economics unknown
Consumers conditioned	Consumers willing to pay (?)
Diversity greatly reduced	Diversity increased
Ecosystem simplified	Ecosystem complex
Varieties optimized	Variety development (?)
Proximate ecosystems neutralized	Scale change in management (3x)
Complex Index = 1	**Complexity Index - 10X-20X**

Unfortunately, in these more diverse, biologically intensive IPM systems, the operational and biological complexity of the production system may be increased dramatically. In some minor crop production systems (e.g., perennial tree fruit culture), the transition from conventional pesticide-managed systems to biologically intensive IPM systems results in increased management complexity ranging from 10-20x.

Along with the increased complexity issue, the public sector cost to develop, demonstrate, and implement IPM systems has increased dramatically over the 1960s and '70s pesticide efficacy testing and "spray guide" approach to pest management. For example (Table 2), an economic entomologist employed at a land grant university could carry out efficacy testing in an outlying experiment station or on farms for approximately $1,500 to $3,000.

Table 2. The Cost of Pest Management Research at Michigan State University—Apple Example

	Cost	Support	Delivery	Risk	Recommendations
Pesticide Efficacy Testing	$1,000-6,000/year	Heavily subsidized by public and private sector	Fruit spray calendar	High-risk/Best-guess approach	Simple
Alternative Management Systems at Clarksville	$50,000-100,000/year	Public sector support only	Educational intensive	Current system	Complex

These efficacy trials were supported directly by the agrichemical industry, USDA, and land grant universities. Today, alternative, biologically intensive IPM management systems are much more complex and difficult to carry forward in on-farm research programs. In addition, the agrichemical industry is less inclined to support these programs, since these systems reduce the use of external inputs such as pesticides. Therefore, there is a greater burden on the public sector to fund these multidisciplinary, systems-integration trials. Fewer and fewer land grant universities have the resources to invest, and there is a paucity of public-sector dollars from consumers, environmentalists, and alternative agriculture advocates. This situation has become the modern dilemma of society's valuation of different technological paths to more sustainable agricultural production systems. In short, society says they want these systems, but higher food prices and increased support for IPM have not materialized.

In general, our current land grant system is inadequate to address the scope of the economic, ecological, environmental, and sociological demands for alternative pest management systems in agriculture. Unless society will help in the funding of the development, dissemination, and implementation of these programs, they are certain to fail in the incubation stage.

The Food Quality Protection Act

In August, 1996, the Food Quality Protection Act (FQPA) was passed unanimously by Congress. This legislation had broad support from industry, agriculture, consumers, and environmental activists alike. Although the legislation has many nuances, there are three principal features that will change pesticide-based agricultural production systems fundamentally. These features include: the reregistration of all pesticide uses with new consideration for common mode of action; aggregate exposure in the diet, environment, air, and water; and cumulative exposure over a 70-year lifetime. Finally, the hormonal effects of pesticides must be considered as well. The net effect of these new registration conditions, together with the focus on children safety, will result in dramatic decreases in the use of many current pesticides.

Several recent documents have addressed the general effects of FQPA on agriculture and even on IPM programs. The Director of Biopesticides and Pollution Prevention Division, USEPA, said that "FQPA will push us to biopesticides, we no doubt will lose many pesticide uses." Another significant general effect of FQPA is the new responsibility for developing extensive new data for tolerances establishment in EPA. Much of these new data requirements will fall on agricultural producers, commodity organizations, processors, state departments of agriculture, and land-grant universities.

Political Unification of Agriculture

Probably the most dramatic immediate effect of the FQPA on agriculture is the political unification of minor crop agriculture. In the past, animal and row crop agriculture have been well represented by the American Farm Bureau (AFB), while minor and specialty crop producers have been less vigorously represented. Minor or specialty crops, on the other hand, have been largely fragmented and often congressionally uninformed, politically naive, and underfunded. FQPA galvanized these divergent minor crop industries into a major thrust on Washington, contributing to the Vice President's invoking of the Federal Advisory Committee Act to form the Tolerance Reassessment Advisory Committee (TRAC).

FQPA Impact on IPM

Certainly, economic factors will drive the development of alternative pest management practices in major crops. Minor crops, however, are at great risk because the infrastructure and the economics in the private sector are not sufficient to facilitate the development of pesticide alternatives before FQPA results in losses of these pesticide tools. Therefore, many production scientists and economic entomologist are acknowledging that insecticide costs likely will grow 15 to 40 percent in minor crop agriculture as a result of FQPA. This will occur because product substations for older and more broad spectrum insecticides will cost 10 to 80 percent more per treatment. Many of these alternative tools are less effective and narrow in this pest control spectrum. In addition, more information is necessary to make adequate decisions in the deployment of these newer chemistries. Concurrent with the reduction or elimination of the broad spectrums, agriculture will lose their suppressing effects on secondary and occasional pests. Post-FQPA minor crop production systems will be at least 1 to 2 orders of magnitude more complex biologically due to the greater number of species which will establish or reestablish in these production systems. A good example of these complexities associated with the introduction of more benign and narrower spectrum pest management tools is the use of pheromone disruption products. These chemicals are released by wild-type females to call the male to her for mating purposes. Scientists have isolated these compounds and industry has synthesized and produced them for the commercial market. These pheromones are released in minute quantities over the crop and result in "male confusion" and failure of females to mate. Reduced pest damage results. In apple production, the cost of pheromones currently ranges from $80 to $160 per acre, compared with a conventional insecticide spray program that may cost $40 per acre. These cost increases come along at a very bad time for apple producers, and they have not brought with them any "value added" price increase.

A number of agriculture workers initially may have exaggerated the enhanced environmental and ecological benefits of FQPA on agriculture. However, production systems are dynamic and the long-term effects of WPA may yet yield measurable environmental gains. Will public-sector agriculture research, Extension, and other supports have sufficient resources to meet the challenges of pesticide alternatives under FQPA? The answer will depend on very complex, dynamic private-public sector interaction. FQPA has supported the agrochemical industry's discovery science strategy very effectively, since most companies were investing in safer, more environmentally benign tools. Today, no agrochemical multinational or startup company has a broad spectrum, nerve toxin discovery program underway. Rather, "biorational" strategies are in place at all levels. However, the regulatory environment has disrupted significantly the agrochemical market stability, and sustained new product development is very questionable from the private sector if these regulatory-based uncertainties are not stabilized quickly. Indeed, FQPA has introduced a new dynamic and increased risk into the sector discovery, registration, and marketing situation.

In many instances, unless society steps forward and reevaluates fruit and vegetable grading and quality standards, many producers will not be able to transition the FQPA challenge. In the face of reduced efficacy of alternative products, increased complexity of the information necessary to control pests, and a decreased control-spectrum of pest management products, disrupted IPM programs and changing market demand have resulted in a very unstable picture for minor crop agriculture.

FQPA may have dramatic effects on pesticide resistance development. If FQPA reduces the availability of different modes of mortality (classes of chemistry) in the marketplace, while increasing the reliance on a narrow array of remaining tools, tactics, and strategies, accelerated pest adaptation will result. In the long term, FQPA probably will lead to a broad array of new tools in agriculture. Many of these tools will help to diversify modes of mortality in population suppression. Thus, the short-term consequences may be increased resistance with long term reduction of pesticide resistance.

One of the most significant developments of FQPA may be its impact on agricultural processors. With the increased awareness of the importance of pesticide residues on agronomic and minor crops, processors are moving rapidly to develop their own residue monitoring system. Many are contracting work with the developing residue monitoring service industry, while others are developing their own in-house labs. In addition, there is a push to develop residue management/mitigation systems that reduce pesticide residues on agronomic products. These measures may justify processor mediated product price increases that will be passed on to consumers, but they are unlikely to generate additional revenues for agricultural producers.

Conclusion

Analysis suggests that the passage of FQPA was the result of a societal valuation of different technological pathways in production agriculture. The forces culminating in FQPA resulted primarily in perceived flaws in the Federal Insecticide, Fungicide, Rodenticide Act involving the Delaney Clause, and, more importantly, environmental and consumer fear of pesticide residues in food. The promulgation of this legislation will have profound impacts on the agriculture-input sector and will result in dramatic structural changes within agriculture production, processing, and marketing. The specific impacts of FQPA on Integrated Pest

Management are likely to result in production cost increases and increased complexity of management strategies, tactics, and tools. The increased production system biological dynamics will be brought on by increased arthropod and microbial diversity in production agriculture. Changes in quality standards that produce labeling and processor driven restrictions also will result in the adoption of more complex and biointensive IPM systems. Whether enhanced environmental and ecological benefits actually accrue to the passage of FQPA remains for future measurement. The evolutionary adaptation of pests to reduced pesticide availability in the short-term likely will result in increased pesticide resistance. However, as IPM systems become more biologically intense and more "biorational" tools become available, resistance should decrease.

IPM: Grower Friendly Practices and Cherry Grower Challenges

By Bob Bailey, Cherry Grower
Orchard View Farms, Inc.
The Dalles, Oregon

Orchard View Farms implemented an Integrated Cherry Production program in 1998. This effort was part of the Integrated Fruit Production (IFP) program for the Mid-Columbia region of Oregon. We farm 1,300 acres of fruit, of which 1,100 acres is sweet cherries. We are practicing IFP techniques on all of our cherries.

The IFP program in Wasco County involves all aspects of cherry production, including pest management. I will mention several of our program practices, but I will emphasize our experience with pest management aspects.

Criteria

I used the following criteria to evaluate the value of an IPM program to a cherry grower:

1. *Grower education.* Here, I evaluated the availability, convenience, and clarity of information from the grower's perspective. I found that implementation of an IPM program educates the grower and helps him better understand the various aspects in the production of his product.

2. *Financial Costs and Returns.* Specifically, I evaluated whether IPM practices are financially feasible.

3. *Marketing Opportunities.* I examined the financial incentives of implementing IPM, specifically any marketing opportunities to the grower.

4. *Stewardship.* I evaluated whether IPM practices help cherry growers become better stewards of the environment.

5. *Safety and Health.* I examined the relationship between IPM and the safety and health of the grower, his family, his employees, and the consumer.

6. *Regulatory Compliance.* I evaluated whether IPM practices allow the grower to comply with various regulations with greater ease.

Grower Friendly Practices

I found the following practices to be grower friendly:

1. *Irrigation System and Design.* In my experience, new technology and equipment make it easier to be an efficient and responsible manager of water.

2. *Plant Nutrition.* Plant nutrition is much better understood through the use of soil and leaf analysis, efficient application methods, and an understanding of the soil structure. We found that we can keep our plants healthy without causing harm to the environment.

3. *Orchard Floor Management.* We can control "weeds" in our tree rows without using residual herbicides. To do so, we use mechanical methods or chemicals that do not remain in the soil. Planting cover crops can be of great value to (a) satisfy tree nutrition needs, (b) control dust (dust may increase our trees susceptibility to certain harmful pests), and (c) host beneficial insects.

4. *Calibration of Chemical Application.* Proper calibration of our chemical application equipment is easy to do and saves the grower a lot of money.

5. *Educational Programs.* The grower's support of IPM educational programs is rewarding and makes the grower a better producer. With the leadership of the OSU Extension Service and Agricultural Research Station, the information to carry out a responsible IPM program is readily available.

6. *Record Keeping—Advantages.* There is an increasing incentive to implement IPM

programs because of pressure from our consumers to be more responsible producers. For example, this week I received some forms from one of our larger customers that we needed to sign, certifying that our production practices complied with all regulations, and that we monitored all aspects of our production practices so that we could be sure we would not harm any consumers of our cherries. My IPM records allowed me to make that promise.

Challenges

I found these practices to be challenging:

1. *Investment to Monitor Pests.* Setting up a comprehensive pest monitoring system required a change in our mind-set about how we carry out a pest control program. We no longer schedule pest control measures by the calender or some other arbitrary method. Instead, we find out what is occurring in our orchard relative to (a) target pest populations, (b) predator populations, and (c) life cycle stages of various insects, diseases, or weeds. To do so, we reallocated our resources from pest control materials to manpower and technology. It costs money to put well-trained people in the orchard to monitor the population and stage of growth of our various pests. It is also expensive to purchase monitoring equipment, such as traps, and to invest in weather monitoring stations to build better models for specific pests or diseases in specific locations.

2. *Setting Up and Maintaining Record Keeping Systems.* Setting up an efficient and usable record keeping system has been a challenge for us. We keep records on 65 different blocks at 9 locations. Each block has unique soils, tree ages, varieties, and elevations. Our crop elevations range from 200 to 1,800 feet above sea level. Thus, our IPM record keeping demands keep one person busy.

3. *Regulations Require IPM Violations.* There are regulations that require us to use practices that violate our IPM criteria. For example, to ship fresh cherries into California, we must carry out a cherry fruit fly control program that includes several applications of ULV malathion. It is both expensive and difficult for us as stewards to apply this pesticide, even though we have no cherry fruit fly or larvae in our orchards.

   We need to develop a better monitoring program for the cherry fruit fly so we may, at some point in the future, be able to make the case to friends in California that in most instances, these chemical applications are not necessary. These ULV malathion applications, up to seven per season, disrupt our IPM program in cherries.

4. *Lack of Alternatives to Hard Chemicals.* We need to find effective and economically feasible alternatives to hard chemicals. We need to continue our research in this area.

5. *Tradition.* It is always difficult to change long-term, established practices.

Conclusion

We continually face the question, “How high to set the bar?” for the IPM program. Should we set the criteria to meet our present practices, or challenge ourselves to be more highly responsible producers of quality cherries? As more information and technology is communicated to us as growers, we will be raising the bar. The reason is that we will be challenged by our competitors and our customers constantly to improve our production techniques. In our experience, IPM programs make us better cherry growers.

Areawide Management of Codling Moth in Pears

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Introduction

Several adverse effects of chemicals have been reported in pear grown under southern Oregon conditions, but the search for non-disruptive control options has been slow and at times frustrating to both researcher and grower. However, in the past 4 to 5 years, several materials have received Federal registrations, which have allowed for the implementation of a selective program for the pear pest complex. These materials include the pheromone dispensers used for mating disruption of the codling moth, as well as the acaricides Savey® and Apollo®. Materials previously available, including horticultural spray oils, Bt's, and insecticidal soaps, also can be incorporated into the program.

The focus of the southern Oregon Codling Moth Areawide Project (CAMP) has been on those arthropods which have been perceived as the primary pests in commercial orchards. These include the codling moth, San Jose scale, pear rust mite, pear psylla, and spider mite species, especially the twospotted spider mite. While the development of a selective program for these species may be possible to implement with current control options, it was highly probable that other, so-called minor or sporadic pests would colonize pear and be capable of inflicting significant damage. In the following report we summarize the results from our continuing research and implementation program and assess the strengths and weaknesses of the CAMP.

While the focus has been on the primary pests in commercial orchards, the overall objectives of this 5-year program were: (1) to maintain acceptable levels of crop productivity and quality, (2) to maximize the effects of natural control agents, and (3) to minimize the negative effects of synthetic pesticides. The negative side effects relating to use of synthetic chemicals include the destruction of predators and parasites, rapid development of resistance to pesticides, resurgences in pest densities, as well as risks to farm workers and to environmental quality.

Medford CAMP Program

The CAMP project was initiated on 300 acres, expanded to 400 acres in 1996 and to 500 acres in 1997, where it remained for the duration of the project. The area contained 12 pear and 4 apple varieties in 40 different blocks comprising 12 orchards. Site selection was based on several considerations, including: flat topography, a reported low incidence of codling moth infestation prior to initiating the program, and a predominance of younger trees or those planted on dwarfing rootstocks.

Tables 1 and 2 outline the basic control program in apples and pear recommended for use in the CAMP selective control program. The tables also include a short discussion of the purpose of each treatment and targeted pests. The treatments comprise a "bare bones" program using but one synthetic pesticide, along with the codling moth pheromone, horticultural spray oil, and lime-sulfur. The program also contained optional, supplemental selective controls whose use depended upon results from orchard monitoring.

A listing of chemicals that could be used for suppression of pear pests without causing major disruptions to non-targeted pests and beneficials was presented to growers. This group of compounds included the acaricides Savey® and Apollo®, soaps, and most fungicides. The listing also included chemicals, which we recommended not be used because of their possible disruptive effects (see Appendix A). In general, we attempted to avoid organophosphates, pyrethroids (even in the delayed dormant timing), along with Mitac®, Carzol®, Vydate®, etc.

Horticultural spray oils play a large part in CAMP, both during the pre-bloom and the foliar periods. Not only is the choice of oil important, but also knowledge regarding its compatibility with other compounds is vital in avoiding severe fruit injury. Because our previous trials with the oil program had utilized Orchex 796® base oil, we suggested that growers use this product in the areawide project; however, starting in 1996, not all participants adhered to this recommendation. In addition, we restricted the use of foliar oil treatments to three applications with the last to be applied at the conventional second cover period for codling moth (approx. mid-June in southern Oregon). Oil applications beyond that period were not recommended due to possible negative effects on fruit growth or quality. Additional recommendations regarding the use of oil during the foliar period included:

1. Use in dilute spray application, i.e., minimum 200 gpa.
2. Do not exceed 1% oil concentration.
3. Do not apply when temperatures exceed 80°F.
4. Use a nozzle sprayer to avoid large droplets.
5. Ensure good tank agitation.
6. Make sure oil is emulsified properly.

Within the CAMP program, there were 12 different pear cultivars, which were for the most part planted in separate blocks ranging in size from 3 to 61 acres. Each cultivar exhibits somewhat different degrees of tolerance to injury caused by various pest species; therefore, each cultivar was monitored separately in order to adjust the control program to potential damage for that variety. In mixed plantings where cultivars could not be treated separately, we suggested that the pest monitoring be carried out on the most susceptible variety. The four apple varieties in the CAMP project were sampled individually and treated accordingly.

The monitoring program for pear and apple pests and beneficials consisted of four techniques: beating tray samples; counts from appropriate plant parts (e.g., fruit buds, leaves, etc.); pheromone traps; and field observations. Samplings were to begin prior to the dormant spray treatment for pears and delayed dormant spray treatment for apples and continue to harvest. Codling moth and leafroller pheromone traps were maintained and monitored by Experiment Station personnel while grower participants conducted other sampling.

While sampling protocols have been established for the major pests as found in conventionally treated orchards, there was little experience in assessing densities of species that may be of importance in this selective program. Growers were furnished with sampling protocols for pear extending through the first codling moth generation (approx. mid-July) along with data recording forms. Sampling for apple was restricted to a single leaf sampling and brushing for mites post-bloom and an occasional walk through or visual observation for all other pests. Evaluation of fruit damage was made in mid-July and at normal harvest for all cultivars, a period extending from mid-August through September. Extension and Experiment Station staff primarily carried out this activity.

The experience with mating disruption in southern Oregon largely has been limited to use of Biocontrol's Isomate C and C+ dispensers used at the recommended rate of 400 dispensers per acre. However, in 1998, 17 percent (67.2 acres) of the total acreage utilized the Hercon Environmental Corporation's Disrupt dispenser at a rate of 200 dispensers per acre. The dispensers were placed in the top one-third of the pear tree canopy and applied once during the season. To aid in the control of the second generation of codling moth, a single spray of organophosphate pesticide was recommended in the base program. The efficacy of the pheromone dispensers to prevent mating was evaluated using pheromone-baited traps placed in the upper one-third of the tree canopy. Both the codling moth wing trap (1CP) baited with 10 mg red septa caps, and the new Delta codling moth trap baited with both red septa and the Pherocon bubble cap were used in 1998.

Results

Because of extended cool and rainy spring weather in the Rogue Valley, insect development was delayed, and proper timing of spray applications was difficult. In addition, codling moth, pear psylla, and spider mite levels were higher than in past years, particularly at the end of the season, which is reflected in the increased number of sprays applied and pest damage during 1998.

The percentage of the total pear acreage treated with the basic program in the pre-bloom stage was 31.6 percent (about the same as last year), and 49.3 percent during the foliar period (down from 79.9 percent a year ago). In comparison, 100 percent of the apple acreage received the base program in the pre-bloom (same as last year), and only 10.5 percent received the base program during the foliar season (down from 79 percent in 1997).

Overall fruit damage at harvest attributed to arthropods averaged 3.18 percent in 1998 (an increase of 33 percent over last year) as seen in Table 3. In 1998, all categories of pest damage increased over past years, with the exception of the other pest category, which went down by 48 percent. This reduction most likely was due to our ability to do a better job identifying the damage caused by each of the pests found in the area. Codling moth damage in 1998 was recorded at 0.16 percent. Leafroller damage averaged 0.58 percent, an increase of 150 percent over last year, and was found primarily in blocks where the three foliar season oil sprays were omitted from the program because the owner felt that they had a negative effect on the pear variety within the blocks. Damage attributed to true bugs, 2.25 percent, accounted for over two-thirds of all fruit damage. As noted in 1995-1997 reports, improvements in sampling procedures are needed for the true bugs.

Pear psylla pressure during 1998 was as high or higher than that seen in 1995. For that reason, most conventional orchard blocks recorded increases in sprays applied and pest management cost. Within the CAMP project, areas which did not receive the three oil sprays were four times more likely to have received one or more mite and psylla sprays during the season. As seen in 1996 and again in 1997, spider mite problems generally were restricted to blocks which were new to the program or did not receive the oil sprays. In apples, European red mite and aphids emerged as the predominant pest species, which required treatment with pyridaben, imidacloprid, and soap sprays. As seen in the pears, late pick apple varieties (e.g., Granny Smith) (59 percent of the acreage) required an additional OP application (in addition to the one required in the base program) for control of codling moth.

On pear, the highest levels of pest damage, as in past years, were recorded on red cultivars (Table 4); for instance, compare Red Anjou to green Anjou and Red Comice to green Comice. This increased fruit injury was due mainly to a high incidence of true bug damage as seen in past years. The majority of the apple damage, 97 percent, occurred on two varieties, Braeburn and Granny Smith, which also was attributed to true bugs. On apple, we have found that it is difficult to distinguish true bug injury and the occurrence of bitter pit, which may mean that the incidence of true bug damage reported may be higher than is actually present.

The total number of pesticide applications applied pre-bloom in the conventional Bosc blocks was 4.0, compared to 3.75 in the CAMP blocks. During the foliar season, the total number of applications recorded in conventional blocks were slightly higher than last year at 4.75 applications, compared to 4.25 in the CAMP project. When averaged, the CAMP Bosc blocks received one less pesticide application than the conventional Bosc blocks during the 1998 season.

However, as seen in previous years, there is a large difference between the conventional Bosc blocks and the CAMP blocks in the total number of synthetic pesticides applied (Tables 5 and 6). CAMP Bosc blocks received, on average, seven fewer synthetic pesticides during the 1998 season. That value includes the late season application of azinphosmethyl, which all four CAMP blocks received.

Increased synthetic sprays in the prebloom reflect the use of mancozeb, which does have insecticidal activity and is used for control of pear psylla, but is used primarily for its fungicidal activity to combat pear scab. Many of the applications in the conventional blocks contained tank mixes of two or more chemicals. Also, the application of pheromone dispensers was not included as part of the total in the CAMP blocks.

The CAMP Bosc blocks in 1998 had a higher incidence of codling moth, leafroller, and true bug damage when compared to the conventional Bosc blocks (Table 7). CAMP Bosc blocks in 1998 had the highest fruit damage recorded during the 4 years of the project. Several possible explanations for this increase exist: the slow release of pheromones in the spring due to cool temperatures; the washing off of pre-bloom and oil sprays by spring rains; removal of the foliar oil sprays from the base program (one of four CAMP blocks in the comparison); and, with respect to the increase in codling moth damage, the removal of a highly infested block of pears adjacent to one of the comparison blocks which resulted in significant codling moth damage in that orchard.

Summary

In discussing the CAMP results from the last 4 years, the local coordinator and the grower participants continue to identify the same program strengths and weaknesses. These various points are listed below.

Strengths

1. Has provided on average a 75 percent reduction of synthetic pesticides use
2. Adequate suppression of primary and secondary pear pests
3. Lack of pest resurgences
4. Survival of natural enemies
5. Lowered costs of control (about $179 to $335 per acre)

Weaknesses

1. Prediction of CM damage from pheromone trap catches
2. Protocols for monitoring natural enemies
3. Protocols for monitoring of leafrollers and plant feeding bugs

Table 1. Basic Medford CAMP Spray Program for Pear.

Timing of Application	Target Pest(s)	Material and Rate
Dormant	Pear psylla	Oil, 4 gallons
	Pear psylla	Oil, 4 gallons
	San Jose scale Pear rust mite	Lime sulfur, 10-12 gallons
Just prior to codling moth biofix (ca. 200 DD from January)	Codling moth	Pheromone dispensers
200 DD from codling moth biofix	Codling moth Twospotted mite Pear psylla etc.	Horticultural spray oil 1%
400 DD from codling moth biofix	Codling moth Twospotted mite Pear psylla etc.	Horticultural spray oil 1%
600 DD from codling moth biofix	Codling moth Twospotted mite Pear psylla etc.	Horticultural spray oil 1%
1,250 DD from codling moth biofix (2nd gen. codling moth)	Codling moth	Guthion 50 WP, 2.5 lb or Imidan, 4 lb

Table 2. Basic Medford CAMP Spray Program for Apple.

Timing of Application	Target Pest(s)	Material and Rate
Delayed-dormant	European red mite Leafroller San Jose scale Aphids True bugs	Lorsban, 4 pints PLUS Horticultural spray oil, 6 gallons
Just prior to codling moth biofix (ca. 200 DD from January	Codling moth	Pheromone dispensers
1,250 DD from codling moth biofix (2nd gen. codling moth)	Codling moth	Guthion 50 WP, 2.5 lb **or** Imidan, 4 lb

Table 3. Percent fruit Damage by Pest: Medford CAMP.

Pest	1995	1996	1997	1998
Codling moth	0.26	0.04	0.09	0.16
Leafroller	0.45	0.32	0.23	0.58
Pear psylla	0.06	0.04	0.01	0.06
True bugs	0.38	0.89	1.82	2.25
Other	0.38	0.23	0.25	0.13
Total	**1.53**	**1.53**	**2.40**	**3.18**

Table 4. Overall Fruit Damage by Cultivar.

Cultivar	1995	1996	1997	1998
Pear				
Starkrimson		6.7	6.9	——
Bartlett types	2.8	3.6	3.3	3.0
Seckel	0.6	3.5	0.9	0.4
Green Comice	2.3	1.6	1.9	1.8
Red Comice	——	1.0	4.6	4.1
Green Anjou	——	1.5	1.8	0.6
Red Anjou	1.5	0.7	3.8	1.4
Bosc	0.8	0.4	0.9	1.1
Red Silk				12.5
Forelle	——	1.7	——	——
Apple				
Gala	——	2.9	0.3	0.4
Fuji	——	0.0	0.4	0.1
Braeburn	——	0.2	0.6	6.2
Granny Smith	——	——	0.7	12.3

Table 5. Summary of Prebloom Treatments, Conventional vs. CAMP Blocks: Bosc Cultivar Only.

Management Orchards	# Of Appli.	Total # mancozeb	pyrethroid b	fenoxycarb d	OP rb	Synthetics	Total # cs	Type
1995								
Conventional	15	1.3	—	1.0	—	0.0	1.0	
CAMP	7	2.0	—	0.0		0.0	0.0	
1996								
Conventional	15	2.0	0.5	0.6	0.4	0.0	1.5	
CAMP	7	2.4	0.4	0.0	0.0	0.0	0.4	
1997								
Conventional	4	2.0	0.5	0.0	1.0	0.5	2.0	
CAMP	4	2.5	0.5	0.0	0.0	0.0	0.5	
1998								
Conventional	4	4.00	2.0	1.0	0.5	0.0	3.5	
CAMP	4	3.75	1.5	0.0	0.25	0.0	1.75	

Table 6. Summary of Foliar Treatments, Conventional vs. CAMP Blocks: Bosc Cultivar Only.

Management	# Of	Total #		# Other	Total #
Type	Orchards	Appli.	# OP's	Synthet.	Synthetics
1995					
Conventional	15	5.4	3.2	2.8	6.0
CAMP	7	4.3	0.9	0.4	1.3
1996					
Conventional	10	4.2	3.7	3.0	6.7
CAMP	7	4.9	1.0	0.3	1.3
1997					
Conventional	4	3.8	3.3	2.5	5.8
CAMP	4	3.8	1.0	0.3	1.3
1998					
Conventional	4	4.75	4.25	3.75	8.00
CAMP	4	4.25	1.75	0.75	2.50

Note: Pheromone dispenser installation not included

Table 7. Percent Pest Injury, Conventional vs. CAMP Blocks: Bosc Cultivar Only.

Management Type	# Of Orchards	CM	LR	PP	True Bugs	SJS	GFW	GMB	Surf. Feed.	Total
1995										
Convent.	15	0.10	0.00	3.30	0.00	——	——	——	——	3.40
CAMP	7	0.30	0.10	0.10	0.30	——	——	——	——	0.80
1996										
Convent.	10	0.07	0.00	0.08	0.08	0.05	0.03	0.01	0.01	0.33
CAMP	7	0.30	0.04	0.08	0.06	0.06	0.04	0.00	0.06	0.36
1997										
Convent.	4	0.00	0.00	0.04	0.24	——	0.06	——	0.05	0.39
CAMP	4	0.11	0.04	0.05	0.14	——	0.05	——	0.01	0.40
1998										
Convent.	4	0.03	0.00	0.60	0.05	0.00	0.00	0.00	0.00	0.68C
CAMP	4	1.23	0.43	0.44	0.19	0.00	0.10	0.01	0.00	2.39

Appendix A.

Chemicals Compatible with the Selective Program.

I. Compatibility based on effects on natural enemies		**II. Compatibility of individual compounds with oil, viewed from risk of tree or fruit injury**	
Chemicals compatible with mating disruption	Chemicals not compatible with mating disruption	Chemicals compatible with oil	Chemicals not compatible with oil or unknown
Sun Oil (1)	Ambush (10, C)	Syllit (5, 6)	Soap (C)
Lime Sulfur (8,10, A)	Asana (7)	Savey (5)	Dimethoate (B)
Comply (5)	Imidan	Apollo (5)	Ambush (A, C)
Savey	Guthion	Sulfur (8, A)	Penncap M (B)
Apollo	Mitac (2, B)	Guthion	Diazinon (B)
Morestan (8, 10, B)	Agrimek (4)	Imidan	Vendex (B)
Mancozeb (5)	Sevin (B)	Agrimek (4)	Kelthane (B)
Lorsban (9, A)	Carzol (B)	Comply (5)	Carzol (B)
Bt's (C)	Vydate (B)	Asana (7)	Vydate (B)
Soap (C)	Kelthane (B)	Dimilin	Mitac (B)
Most fungicides (C)	Penncap M (B)	Copper (A)	Thiodan (B)
Bactericides (C)	Diazinon (B)	Terramycin (3, 5)	Karathan (8, B)
Dimilin	Dimethoate (B)	Agri-strep (3, 5)	Morestan (8, 10, B)
Tree nutrients (C)	Karathane (8, B)	Provado (5)	Sulfur products (8, A)
Sulfur Products (8, 10, A)	Provado		Coppers (8, A)
			Mancozeb (B)
			Tree nutrients (C)
			Bt's (C)
			Other fungicides
			Sevin (B)

(1) Is registered, only limited experience with this product.
(2) Not compatible with program after delayed-dormant.
(3) May cause leaf marking; no fruit marking has been observed.
(4) Oil not to exceed 0.25%
(5) Limited testing.
(6) Not Cyprex.
(7) First cover; limited testing.
(8) Highly damaging in combination with oil when pear tissue exposed.
(9) Not registered for foliar use.
(10) Prebloom only.

(A) Compatible with oil dormant and/or delayed dormant only.
(B) Not compatible with oil.
(C) Unknown compatibility with oil during foliar period.

Integrated Fruit Production for Pome Fruit in Hood River: Pest Management in the Integrated Fruit Production (IFP) Program

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Abstract

Integrated fruit production (IFP) offers an alternative to the chemically intensive, conventional pear production system. In 1994, we began a 4-year project supported by the Hood River Grower Shipper Association (HRGSA) together with Oregon's Center for Applied Agricultural Research (CAAR) to demonstrate to the industry how to bring about changes in orchard management practices, particularly as they apply to pest and disease control on pears. Several criteria guided us in designing the pest management programs for the IFP blocks and contrasting them with conventional pest control programs. We emphasized the use of selective control methods to encourage biological control; we avoided toxicity class I pesticides to create a safer orchard environment; and we alternated control tactics with different modes of action as a resistance management strategy. Controls were applied only if needed; for example, when monitoring indicated that pest populations exceeded economic threshold levels. Selective codling moth control was achieved with mating disruption using Isomate-C Plus pheromone dispensers in all four IFP blocks to create an orchard environment that was more conducive to biological control. Pear psylla control consisted of sulfur plus oil and Comply (fenoxycarb) in the pre-bloom period, followed, if needed, by soap sprays or low rates of AgriMek (abamectin) after bloom. A diverse complex of natural enemies was present and helped to regulate pear psylla. Selective acaricides (e.g., low rates of Vendex {fenbutatin}, Savey {hexythiazox}, oil) were applied when mites built up during the foliar season. Control with the IFP program was at least as good as with the conventional program, where broad-spectrum pesticides provided most of the pest control. The pest management program in the IFP blocks was somewhat more expensive, in large part due to the high costs of mating disruption. Fruit from the IFP blocks stored and ripened as well as fruit from the conventional blocks. The project demonstrated that pear growers can switch successfully to pest management programs where organophosphate and other broad-spectrum pesticides are replaced by available alternative controls without loss in yield or quality.

Key Words: Integrated Fruit Production, Integrated Pest Management, pears, selective control, mating disruption, biological control

Oregon is a major producer of pears in the United States and ranks third in the nation in value of pear production. Growers have come to rely on the intensive use of agricultural chemicals (insecticides, disease control agents, chemical thinners, herbicides, fertilizers) to maintain high yields and meet strict quality standards. The production of tree fruits has in many ways become "chemical management." It is doubtful whether this approach is sustainable due to resistance development, a shrinking supply of chemical control agents, secondary pest outbreaks, effects on non-target organisms, leaching of fertilizer and other agricultural chemicals into surface and ground water, and consumer concerns about residues on the fruit.

The pear industry in Oregon will benefit from the adoption of integrated production practices that are less reliant on agricultural chemicals. However, before an IFP program can be implemented on an industry-wide scale, the specifics and economic benefits of such a program must be demonstrated. With funds provided by the local tree fruit industry and the Center for Applied Agricultural Research (CAAR), a project was initiated in 1994 to research, demonstrate, and implement an integrated fruit production (IFP) program as an alternative to the chemically intensive conventional pear production system currently in use. Here we discuss the pest management aspects of the Hood River IFP program and the experiences gained from a 4-year demonstration project as they apply to insect and mite control. The broader goals, direction, and accomplishments to date of the Hood River IFP program are reviewed elsewhere (Niederholzer et al., 1998).

Demonstration Orchards, Monitoring of Pests, and Control Decisions

Four mature Anjou pear orchards that were typical in terms of tree age and horticultural practices for the Hood River fruit-growing district were selected for this study. Blocks were 5 to 10 acres in size and had some Bartlett trees for cross-pollination. Two of the demonstration orchards were located in the lower and two in the upper Hood River Valley. The two demonstration blocks in the lower valley (Hukari, Wells) were surrounded by other sprayed orchards while the IFP blocks in the upper valley (Laurance, McCarthy) were bordered by wooded habitat. At each site, the IFP block was matched by a conventional comparison block that was similar in terms of size, tree age, and orchard practices.

Pest levels were monitored in all IFP and conventional blocks. However, the project provided pest management advice only for the four IFP blocks. Growers made their own pest management decisions and conducted their own control programs in the conventional blocks without input from the project. Established monitoring procedures for the various pest species were followed. Control decisions were based on guidelines and action thresholds used by pest managers in the industry (Westigard et al., 1978; Beers et al., 1991).

Control Programs and Major Pests

The conventional programs used by the four growers were representative of current practice in the Hood River Valley and differed substantially from the control programs in the IFP blocks. Table 1 shows the different control choices used in the conventional and IFP blocks during the 4 project years for control of insects and mites. The pre-bloom programs were similar in the conventional and the IFP blocks. Pre-bloom sulfur plus oil

Table 1. Pest control choices: conventional vs. IFP.

Target	Conventional	IFP
Codling moth	Guthion	Mating disruption Imidan
Pear psylla	*Pre-bloom* Sulfur plus oil Comply Thiodan Morestan Dithane *Post-bloom* AgriMek Mitac	*Pre-bloom* Sulfur plus oil Comply Dithane *Post-bloom* AgriMek Soap Biological control Cultural control
Spider mites	*Pre-bloom* Mineral oil Morestan *Post-bloom* AgriMek	*Pre-bloom* Mineral oil *Post-bloom* Savey/Vendex AgriMek Biological control Cultural control
Pear rust mite	*Post-harvest and/or pre-bloom* Sulfur plus oil *Post-bloom* AgriMek Vendex Sevin	*Post-harvest and/or pre-bloom* Sulfur plus oil *Post-bloom* Vendex AgriMek
San Jose scale	*Pre-bloom* Lorsban plus oil Supracide plus oil *Post-bloom* Guthion	*Pre-bloom* Lorsban plus oil
Leafrollers	*Pre-bloom* Lorsban plus oil *Post-bloom* Guthion	*Pre-bloom* Lorsban plus oil *Post-bloom* Bt *(Bacillus thuringiensis)*

were used in the conventional as well as in the IFP blocks for pear rust mite control. The four growers in this study used primarily Microthiol, a dry sulfur formulation that is easier to handle than liquid lime sulfur.

The majority of the pear growers in the district used Comply (fenoxycarb) for pre-bloom pear psylla control during the 4 years of the study. Growers stopped using Thiodan (endosulfan) or pyrethroids during the pre-bloom period for control of overwintering pear psylla adults due to the effectiveness of a single pre-bloom Comply spray. Morestan (oxythioquinox), for many years a multipurpose material applied just before bloom to control pear psylla nymphs, mites, and mildew, was not used in any of the blocks because of concern about marking fruit. The manufacturer has discontinued marketing Morestan for pears as of 1996. All IFP and conventional blocks were treated with mancozeb (Dithane, Manzate) two or three times before and through bloom (petal fall), primarily to improve fruit finish. At the higher rate (6 lb), mancozeb also aided pear psylla control. AgriMek (abamectin) was used in all conventional blocks for pear psylla and spider mite control during late spring and early summer. The use of a tree wash with high volumes of water (400 GPA) and laundry soap (1 lb/100 gal) was demonstrated in one IFP block to remove excessive pear psylla honeydew. Different mite control programs were used in three of the four IFP blocks as part of a resistance management strategy: low rate of AgriMek; combination of Vendex plus Savey; or 1% oil sprays.

Codling moth control was achieved with organophosphate insecticides, primarily Guthion (azinphosmethyl), in the conventional blocks and with mating disruption using the Isomate-C Plus dispenser (Pacific BioControl, Vancouver, WA) in the IFP blocks. Isomate dispensers were applied once per season at full label rate (400 dispensers/acre). Selective control of codling moth with mating disruption was the key to the implementation of the IFP program. In response to a build-up of obliquebanded leafroller in 1996, Dipel sprays (*Bacillus thuringiensis*) were applied in late August in two IFP blocks. Organophosphates applied against codling moth also provided control of leafrollers in the conventional blocks. Except for pre-bloom Lorsban sprays for San Jose scale control in one IFP block, no other pre- or post-bloom OP sprays were applied in any of the IFP blocks between 1994 and 1997.

Codling moth. The key to the implementation of this program was selective control of codling moth. Mating disruption was the only control applied against codling moth in the IFP blocks and it was not necessary to supplement it with insecticide sprays. This control strategy was successful and none of the IFP blocks had codling moth damage at harvest during the 3 years of the study. The two conventional blocks in the lower valley (Hukari, Wells) where codling moth has two generations were treated twice per season with Guthion. One Guthion spray was applied per season to the conventional blocks in the upper valley (Laurance, McCarthy) since codling moth has only one generation there. Guthion is still a very effective OP insecticide for codling moth control in the Mid-Columbia fruit-growing district, and there is no evidence of resistance development in local populations. Guthion provided complete control in all conventional blocks.

Pear psylla. Pear psylla was a very manageable pest in both IFP and conventional blocks during the 4 years of the study, thanks to Comply, which was available under Section 18 emergency registrations. The widespread use of Comply (used on 70 to 95 percent of the pear acreage in the valley between 1994 and 1997) appeared to have a regional effect on psylla populations and provided excellent control. Levels of overwintering pear psylla adults were very low. Pear psylla declined after bloom and stayed low for the rest of the season. During the foliar season, pear psylla was often difficult to detect. This pattern was the same in the IFP and conventional blocks. Except for AgriMek at Hukari's IFP block, no foliar pear psylla sprays were applied in the other IFP blocks. There was no pear psylla russet on fruit in any of the IFP blocks. Psylla populations stayed low through the fall and produced low numbers of overwintering adults. AgriMek was the summer material of choice in the conventional blocks where it was applied shortly after bloom for pear psylla and mite control. All conventional blocks received AgriMek (in addition to a pre-bloom Comply spray). Control lasted for the remainder of the season and fruit showed no pear psylla russet at harvest.

Spider mites. Spider mite populations on pear in the Hood River Valley usually consist of two species: twospotted and McDaniel spider mites.

Spider mites are generally less severe in the upper valley due to cooler temperatures and a shorter season. They are generally more destructive and also more difficult to manage on pear than on apple. There are several reasons for this: a low economic threshold due to the greater sensitivity of pear leaves to mite feeding; the use of broad-spectrum pesticides for the control of major pear pests which disrupt biological mite control; the lack of an acceptable alternate food source for mite predators; and the intensive use of acaricides leading to resistance problems.

Spider mites were only occasional problems in the IFP blocks due to the absence of broad-spectrum sprays, and they rarely reached levels where chemical interventions were necessary. Different mite control programs were used in the IFP blocks to evaluate their effectiveness and educate growers about resistance avoidance tactics. For instance, a combination of Vendex/Savey (plus a silicone surfactant) was applied in late June against an increasing spider mite population and provided control for the rest of the season. In this combination, Vendex, an organotin acaricide, provides control of the mobile stages and stops mite feeding; while Savey, which is quite persistent and acts primarily as an ovicide, gives long term control. Foliar oil sprays also were effective for mite control. Two 1% oil sprays applied 14 days apart in a spray volume of 200 GPA suppressed twospotted mite at the Laurance IFP block. AgriMek was used only occasionally in two of the four IFP blocks and generally at lower rates than in the conventional blocks. Growers were encouraged to use acaricides sparingly in their IFP blocks and never use the same acaricide twice during the same season or in successive years, in order to keep selection pressure low and avoid resistance development. Predatory mites (phytoseiids) were present in all IFP blocks and contributed to the control of spider mites.

AgriMek was the only acaricide used in the conventional blocks. Although there are indications that the effectiveness of Agrimek has declined somewhat due to low levels of resistance in some orchards (Beers et al., 1998), conventional growers still prefer AgriMek for mite control because of its long lasting effect and its benefit for pear rust mite and pear psylla control.

Pear rust mite. This eriophyid mite was an annual problem and was of particular concern in the IFP blocks due to the lower use of acaricides during the summer. Fruit remains susceptible to pear rust mite feeding damage until harvest. Monitoring of pear rust mite populations on foliage and fruit after bloom is essential for preventing russet damage and planning a seasonal control strategy. As few as five pear rust mites on a fruit may cause russet (Westigard et al., 1978). Successful management requires a control program that includes the use of post-harvest and/or pre-bloom sulfur sprays.

All IFP and conventional blocks were sprayed with sulfur and oil at delayed dormant stage. Growers used liquid lime sulfur as well as dry flowable sulfur formulations with equally good results. Rust mite was lowest in those blocks that received foliar AgriMek sprays in addition to pre-bloom sulfur. AgriMek is probably the most effective rust mite material available. Vendex has activity against pear rust mite. However, the combination of Vendex/ Savey did not prevent rust mite from building up in late summer. Savey only controls spider mites; it has no effect on pear rust mite.

In blocks without foliar acaricides, pear rust mite often peaked in late August and early September at densities ranging from 70 to 200 mites per leaf. When pear rust mite increased on foliage in late summer, fruit was inspected several times to monitor rust mite feeding activity on the fruit surface. However, in spite of high rust mite populations on the foliage in these blocks in late season, no russet damage to the fruit occurred. Even if no russet damage occurs, unchecked build-up of pear rust mite during the summer will result in high overwintering populations, which may pose a threat to next year's crop and cause calyx russet around bloom time. Post-harvest and/or pre-bloom sulfur treatments must be applied to eliminate the threat from overwintering pear rust mite populations. Sulfur treatments were generally more effective in the lower than in the upper valley IFP blocks due to more favorable weather conditions, especially temperature during the time of application.

Obliquebanded leafroller, green fruitworm. Fruit feeding by obliquebanded leafroller and green fruit worm larvae was more common in 1996 than in previous years, particularly in the upper valley. Both pests are present throughout the district. The obliquebanded leafroller is the dominant leafroller species in the Mid-Columbia fruit-growing region. Fruit damage from overwintering leafroller larvae in

the spring is similar to green fruitworm feeding and is difficult to distinguish. One factor that has contributed to the increase of these two pests is the change in the pre-bloom spray program over the last several years. Broad-spectrum sprays (pyrethroids, Thiodan) which were applied previously against overwintering pear psylla adults also helped to suppress these pests.
Another factor, which contributed to an increase of leafroller damage in the upper valley, was the reduced spray program many growers used in 1996. Due to a short crop at the upper elevations caused by winter damage and poor pollination weather, many growers decided not to apply OPs against codling moth. Pear orchards without OP sprays during the summer had decidedly higher leafroller damage at harvest than orchards that were sprayed at least once with an OP. This also suggests that leafrollers still can be suppressed in this area with OP sprays and that resistance has not developed to the point where OPs have become ineffective for leafroller control. Due to the absence of OP sprays, leafroller damage was generally higher in the IFP blocks than in the conventional blocks. In 1996, leafroller damage in the lower valley IFP blocks ranged from 1 to 4 percent damaged fruit at harvest. Damage levels in the two upper valley IFP blocks were even higher (up to 16 percent). Bt sprays were applied too late to effect control. Three of the four conventional blocks received at least one OP spray during the summer and had low leafroller damage. The exception was one conventional block in the upper valley, where the grower decided not to spray Guthion for codling moth control, and fruit damage from leafroller feeding also reached about 16 percent.

San Jose scale. This pest is a chronic problem in the Hood River Valley because of favorable conditions. Many pear orchards in the valley consist of large old trees with rough bark which provide San Jose scale with many protective sites to colonize. San Jose scale has two generations in the lower valley and only one in the upper valley. This pest has been an annual problem in one of the IFP blocks in the lower valley (Hukari). Control was maintained in that block with annual pre-bloom OP (chlorpyrifos) and oil sprays. This was the only IFP block during the 4-year study that was sprayed pre-bloom with an OP insecticide. In the other three IFP blocks, oil sprays applied at dormant/delayed dormant held scale populations in check. Fruit was free from scale damage in all 3 years. However, under high pressure, pre-bloom oil treatments alone may not be enough. Satisfactory scale control only can be achieved with high spray volumes. Therefore, growers were asked to apply pre-bloom San Jose scale sprays dilute (e.g., at least 200 GPA). Pre-bloom applications of chlorpyrifos and oil kept San Jose scale under control in the conventional blocks. Guthion sprays applied against codling moth during the summer provided additional control. These sprays prevented scale crawlers from settling on the fruit.

Secondary Pest Problems

In addition to the major pests discussed above, several sporadic or minor pests were noticed, primarily in the IFP blocks, due to the absence of broad-spectrum sprays. Egg masses of an unknown geometrid moth commonly were found in the IFP blocks close to harvest. Larvae fed gregariously and skeletonized leaves, but did no damage to the fruit. Grape mealybug was present in all blocks with older trees (three of four demonstration sites) which provide more suitable habitat for this pest than young trees with smooth bark. No honeydew marking from mealybug feeding occurred. Pear leafcurling midge infested new growth in one lower valley IFP block, but was not present in any of the other blocks. OP sprays applied against codling moth control this pest in conventional orchards. Green apple aphids were present in the IFP as well as the conventional blocks, but rarely reached high enough levels to require control. No specific controls were applied against aphids in the IFP blocks, and populations usually declined from the effects of high temperatures during July/August and natural enemy activity.

The potential for secondary pests is a negative aspect of selective pest management and can be a cause for concern (Riedl & Niederholzer, 1997). Some pests such as plant bugs, thrips, pear leafcurling midge, pear sawfly, pear slug, and various lepidopterous pests such as redhumped caterpillar and cankerworms actually may increase due to the lack of suppression by broad-spectrum sprays and/or poor regulation by natural enemies. In addition, yet unknown pest problems may appear, or pest problems that were important at one time may reappear. Some secondary pests may show up at first only along orchard borders in the vicinity of natural habitat that harbors wild hosts, or next to cropland which may serve as a source of pests (e.g., lygus bug). Therefore, as growers begin to drop broad-spectrum sprays from their programs, they need to pay particular attention to orchard borders. Careful scouting of the orchard, especially areas which are likely to harbor immigrating pests, is key to guarding against losses from secondary pests.

Selective Control Tactics and Biological Control

One of the immediate benefits of the selective programs in the IFP blocks was that several pests whose pest status normally is elevated under broad-spectrum programs diminished in importance and became easier to manage. Pests that fall into this category are pear psylla, spider mites, tentiform leafminer, aphids, and leafhoppers. Another group of pests which are likely to become more manageable under selective pest management are San Jose scale, grape mealybug, and leafrollers as natural enemies establish themselves and exert their effect.

There were interesting differences in the abundance and make-up of natural enemy assemblages among the four IFP blocks. The two upper valley IFP blocks had higher numbers of natural enemies through the season than the two lower valley blocks. These differences in natural enemy levels were not necessarily related to prey density. More likely, the vegetational setting and the surroundings of a particular block influenced the species pool of natural enemies which colonized each block. Natural vegetation and woodland that serve as a reservoir for natural enemies bordered both upper valley IFP blocks (Laurance, McCarthy). In contrast, the lower valley IFP blocks (Hukari, Wells) were in the middle of a well-sprayed, contiguous orchard area which does not produce large numbers of natural enemies due to low prey levels and use of non-selective broad-spectrum sprays. Therefore, natural enemies were similarly low in the IFP and conventional blocks in the lower valley. As in other pear-growing areas, successful biological pear psylla control in the Hood River Valley relies not on a single natural enemy species, but on a complex of predator species including mirids, anthocorids, lacewings, coccinellids, spiders, and the encyrtid parasitoid *Trechnites insidiosus*.

By comparison, the conventional blocks in the study not only had fewer natural enemy species (lower species diversity), but those which were present occurred only in low numbers. Guthion sprays applied for codling moth control in the conventional blocks prevented natural enemies from building up during the summer and from contributing to the control of pear psylla and other foliage feeders.

A primary consideration in designing the pest management programs for the IFP demonstration blocks was to enhance the role of the biological control component. This was accomplished by using selective controls as much as possible for control of key pests (e.g., codling moth and pear psylla) in order to minimize the impact on natural enemies. We attempted to quantify the overall impact on biological control by rating pesticides used under the two different programs in terms of their toxicity to predators and parasitoids. We relied on a rating system that was developed from field observations and controlled studies by the IOBC (International Organization for Biological Control) Working Group: Pesticides and Natural Enemies (Staeubli et al., 1984). With this rating system, pesticides are rated from “1” to “4,” depending on their toxicity to different natural enemy groups. A “1” means “no toxicity,” and “4” means “very toxic, no survival.” Numbers “2” and “3” represent low to moderate toxicity. By averaging the toxicity ratings for the insecticides and acaricides that were applied during the 1995 season under each program, we calculated an average biological control impact value (BCI) for the IFP and the conventional program at each grower site. This information is summarized in Table 2. The pest management programs in the IFP blocks were considerably more selective to natural enemies compared with the pest management practices in the conventional blocks. During 3 years of the study, no OP or other broad-spectrum sprays were applied after bloom to the IFP blocks. Even during the pre-bloom period, broad-spectrum sprays were excluded as much as possible from the IFP spray programs. Only one grower used an OP insecticide for San Jose scale control at the delayed dormant stage of bud development in the IFP block. The greater selectivity of the IFP pest management programs was reflected by the lower BCI values (Table 2). The average BCI value for the conventional blocks was 30 percent higher than for the IFP blocks. This may not suggest a large difference between the two production systems in terms of biological control impact. However, only one or two broad-spectrum sprays during the early foliar period may exclude natural enemies for much of the season.

Table 2. Average Biological Control Impact (BCI) values for conventional and IFP pest management programs for four grower demonstration orchards; Hood River Valley, 1995.

	Avg. Biological Control Impact (BCI) Value [1]		
Grower	Conventional	IFP	Difference Conv - IFP
Hukari	1.75 (10)	1.49 (10)[2]	0.26
Wells	1.89 (9)	1.46 (5)	0.43
Laurance	1.74 (9)	1.30 (10)	0.44
McCarthy	1.79 (10)	1.30 (7)	0.49
Avg. (all blocks)	1.79 (9.5)	1.39 (8.5)	0.40

[1] For insecticides and acaricides only; on a scale of 1 (low) to 4 (high) using the IOBC toxicity rating system for natural enemies (Staeubli et al., 1984).

[2] Number of applications in parenthesis.

Resistance Problems under Conventional and Selective Pest Management Programs

We expect that resistance will diminish as a problem as growers begin to adopt selective pest management programs (Riedl, 1997). However, experience has shown that IPM programs are by no means immune to resistance development when selective pesticides are used intensively and the number of available control choices are limited. Therefore, a major goal of the project was to encourage growers to employ resistance avoidance tactics (Table 3) to reduce selection pressure and ensure that available control choices remain effective. These tactics included: applying pesticides only when justified and action thresholds were exceeded; using the lowest effective rate of a pesticide; making adjustments in horticultural

Table 3. Use of resistance management tactics under conventional broad-spectrum and selective (IFP) pest management programs.

Resistance Management Tactic	Conventional Pest Management	Selective Pest Management (IFP)
Use pesticides judiciously and only when needed to keep selection pressure low	Control decisions based on cursory observations; sprays often applied prophylactically	Control decisions based on monitoring, use of thresholds
	Higher label rates used as insurance	Lowest effective rates used
Alternate control tactics	Pesticides with similar modes of action used year after year	Control tactics with different modes of action alternated
Encourage biological control	Not effective due to broad-spectrum pesticide use	Possible through selective control of key pests

practices which promote pest populations and increase the need for chemical control; alternating control tactics with different modes of action; and encouraging biological control as much as possible to reduce the need for chemical interventions.

In an IFP program, all production practices are viewed in relationship to each other. Horticultural practices that favor pests and pathogens indirectly affect resistance development since they create a greater need for chemical control. For instance, excessive fertilizer (especially nitrogen) and water use as well as certain pruning regimes will increase tree vigor and vegetative growth. Pests such as pear psylla and aphids thrive on new leaf growth. Under IFP, build-up of these pests should be controlled as much as possible by managing vigor of the host tree with lower fertilizer and water use while still meeting the nutritional needs of the tree.

Alternating pesticides with different modes of action as suggested by Cutright (1959) may be a useful strategy to delay or possibly avoid resistance development. Flexner et al. (1995) demonstrated that alternating acaricides for control of twospotted mite on pear can extend indeed the field life of a product. None of the IFP blocks were treated twice with the same acaricide or pear psylla insecticide during the same season. Different alternations were demonstrated in the four IFP blocks. For instance, AgriMek one year and Vendex/Savey the next year was the alternation for mite control in one of the lower valley IFP blocks where spider mites are usually more serious. In one of the upper valley sites, Vendex was alternated with foliar oil applications to control mites. Few conventional growers alternate the use of pesticides. Short-term economic considerations such as price and the most recent experience with a product (such as spectrum of activity and performance) determine the pesticide choices a grower makes for the season. This leads growers to overuse certain pesticides year after year (e.g., AgriMek for mite and pear psylla control). The costs associated with this practice are accelerated resistance development and a shortened effective field life of the pesticide.

Biological control is a key component of any resistance management strategy. Taking advantage of biological control in orchards under selective pest management reduces the need for chemical intervention. Natural enemies do not distinguish between resistant and susceptible prey, and, over time, they will dilute resistance present in a pest population. Therefore, maximizing naturally ocurring biological control or augmentative releases of natural enemies are very effective ways to deal with insecticide and acaricide resistance. Under IFP, it will be much easier to integrate biological with chemical control and take full advantage of the available biological control potential due to the use of selective controls for key pests (Table 3).

Evaluation of IFP versus Conventional Pear Production

One can apply several approaches to the evaluation of the IFP program when comparing it to the conventional pear production system. Of primary interest to the grower is the cost of the program and its economic benefits. The traditional economic evaluation looks primarily at costs, yield, quality, and price. Grower acceptance of IFP primarily will depend on whether the bottom line of IFP compares favorably to the conventional production system. In addition to the economics of IFP, one also can examine the environmental "costs" of the two production systems, particularly in regard to agricultural chemical use. We will present examples of both analyses below, using data from the 1995 crop year.

Economic Evaluation. Cost-of-production budgets were constructed for each treatment and grower in the study. Cost and price assumptions were made so that treatments and growers could be compared and economic analysis made possible. Some of the major assumptions included in the study were as follows: (1) All labor was hired at a cost of $6.50 per hour, which includes worker's compensation, unemployment insurance, and other labor overhead expenses. (2) The cost to harvest pears was $12.00 per bin. (3) The interest rate charged for all cash and non-cash costs was 10 percent. Annual production and fixed costs not accounted for between treatments were provided from the costs to produce winter pears in the Hood River Valley (Seavert et al., 1996). Therefore, the cost for water assessments, taxes, fixed costs of machinery, etc., was the same across treatments. Enterprise budgets then were constructed to determine the gross incomes and costs to grow Anjou pears under the IFP and conventional programs for the four growers in the study. The main factors that determine gross income are the size of the crop, fruit size, and grade. In most years, larger, better quality fruit results in higher prices. Therefore, packouts from individual growers were very important to this economic analysis. The number of 44 lb boxes of Anjou pears per acre, which represents overall yield, were similar for each treatment (e.g., 1,074 boxes of IFP fruit vs. 1,082 boxes for the conventional blocks). This represents a weighted average between growers for each treatment.

Figure 1 shows almost no difference in fruit size between the IFP and conventional fruit. Both treatments peaked at size 80 fruit, which represents 80 pears in a 44 lb per box (the larger numbers represent few fruit per 44-lb. box.). The overall fruit size distribution was not a bell-shaped curve as demonstrated in past years' production in the valley but was indicative of the 1995 crop year. There seemed to be a large proportion of the total crop between the sizes of 70s and 100s.

Figure 1. Fruit size for all four growers' packouts.

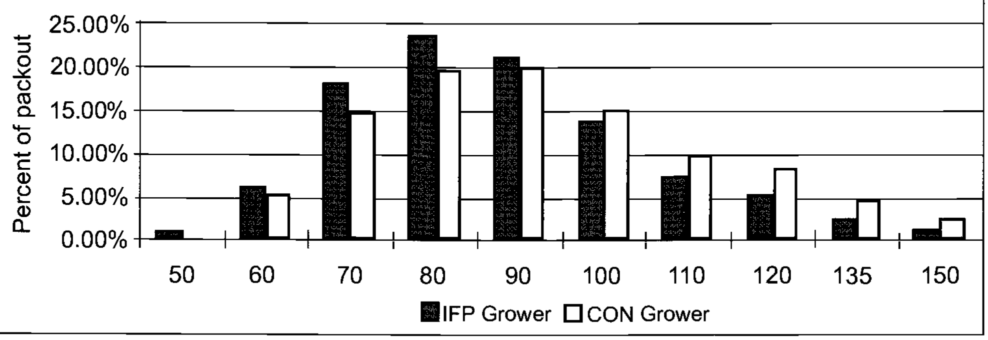


Figure 2. Fruit grades for all four growers' packouts.

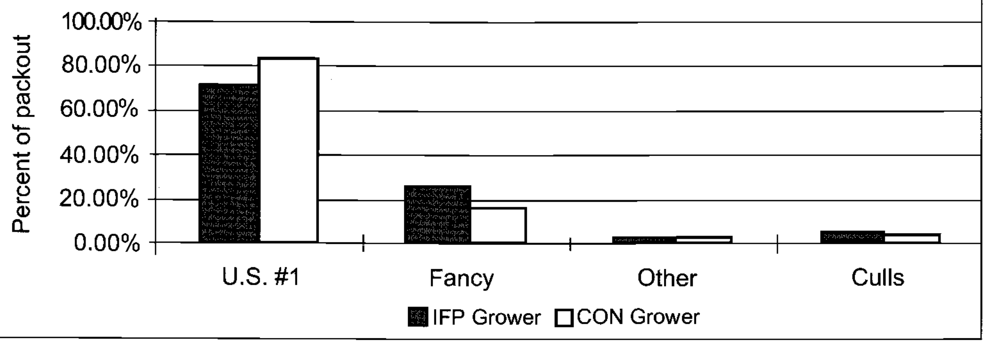
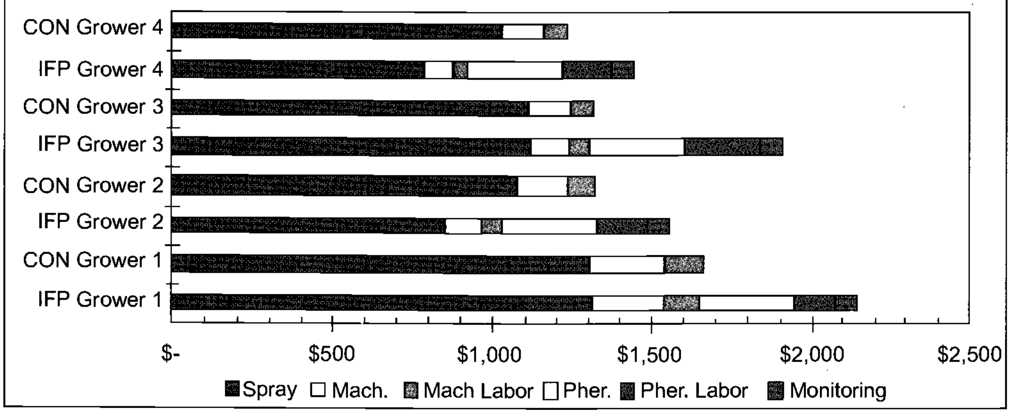


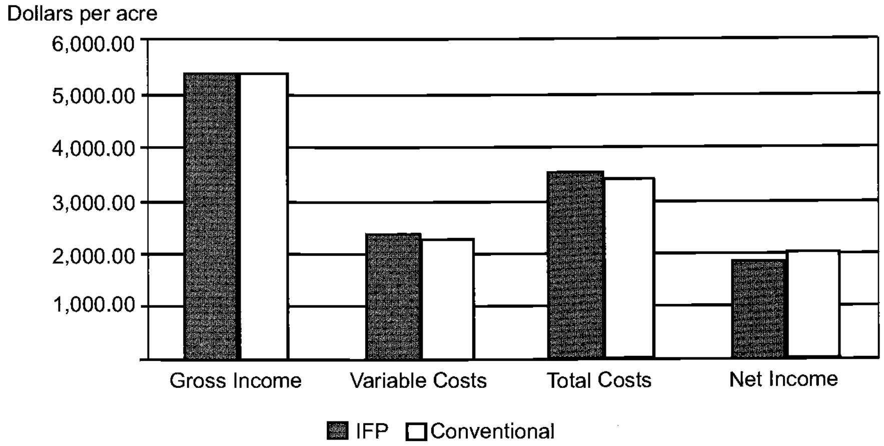
Figure 3. Grower chemical costs, per acre.



The fruit quality differences shown in Figure 2 between the IFP and conventional blocks did not vary much. The majority of the fruit was graded US #1 with 70 percent IFP fruit as compared with 80 percent conventional. Moreover, only 22 percent of the IFP fruit was graded Fancy and 18 percent of the conventional. The percent cullage from each treatment was almost the same. Fruit from the IFP blocks stored and ripened as well and had the same quality characteristics (acidity, soluble solids) as fruit from the conventional blocks.

Figure 3 shows the pest management costs for each of the treatments by grower. The largest cost in each treatment was the cost of the spray materials. For growers #2 and #4, the spray material costs were less for the IFP than for the conventional program. However, it was very apparent that the pheromone installation and materials made the total pest management costs higher for the IFP program than for the conventional. The total pest management costs for growers #1 and #3 were considerably higher, about $450 to $600 per acre, respectively. Costs of machinery and labor to operate it were small relative to the total cost of pest management. The high cost of selective control methods (e.g., mating disruption) makes the IFP program at the present time more expensive than the conventional program.

Figure 4. Gross Income, Costs, and Net Income from All Four Growers



The most important economic information is presented in Figure 4. This figure shows the gross incomes, variable costs, total costs, and net incomes for each treatment. The average price received per box of pears was almost the same for IFP and conventional fruit: $4.98 versus $4.96. The total gross dollars returned for each treatment was about $5,350 per acre. The variable and fixed costs were almost the same as well. The net income for each treatment was similar at $2,000 per acre.

Environmental Impact. We used two methods to compare the environmental impact of IFP with the conventional pear production system, particularly in regards to insecticide, acaricide, and fungicide use. Both methods express the environmental impact of a pesticide as a single value that is calculated from ratings of its ecological impact as well as its farm worker and consumer safety.

The method developed at Cornell University (Kovach et al., 1992) calls this value the environmental impact quotient or EIQ. To calculate the environmental impact of a pesticide application, the EIQ value is adjusted for the active ingredient of the formulation and the rate applied per acre. For instance, Guthion's EIQ value is 43.1. If the grower used a 50WP formulation and applied it at 1.5 lb per acre, the EIQ field use rating is 43.1 x 0.5 x 1.5 = 32.3 for one application. By calculating the EIQ field use ratings for all pesticides applied in a seasonal program and by adding the individual ratings, one can arrive at a total EIQ rating which can be used to compare the environmental impact of different pest management programs. We have done this analysis with the 1995 spray programs. Surprisingly, the total EIQ rating for the IFP was only slightly lower than for the conventional program. This suggests that the environmental impact of the two programs was similar. However, the methodology and the rating system that was used to establish the EIQ values may bias these results. Several products that were used in the conventional as well as IFP blocks have high EIQ field ratings such as mineral oil, mancozeb, and especially sulfurs. These products are used at a high active ingredient (a.i.) per acre that results in a high EIQ field rating compared with AgriMek, Comply, or pyrethroids. Mineral oil and mancozeb generally are considered "soft" products which fit well into selective pest management programs for pears. The other evaluation method we applied to the 1995 spray programs was Stemilt's "Responsible Choice" (RC) rating system (Stemilt Growers Inc., Wenatchee, WA; Reed 1992). Similar to the Cornell method, pesticides are given a value (RC point) which expresses with a single number the environmental impact of the product. RC points are adjusted for the actual rate applied per acre. The total RC points for the IFP and conventional programs were similar, suggesting again that in 1995 the IFP program had little advantage in terms of environmental impact compared with the conventional program. The possible bias of these two methods will be examined more closely with the 1996 and 1997 data.

There is also another reason why the IFP and the conventional programs came out similarly in terms of environmental impact in these evaluations. The pest management programs used by most pear growers in northern Oregon have undergone major changes over the last 3 to 4 years. Today's conventional program is more similar to IFP than it was several years ago due to the availability of new selective products (e.g., Comply) which have replaced broad-spectrum pesticides. If we compare a conventional pest management program from 1990 with today's IFP program (using the EIQ rating system) we see a 20 percent improvement in terms of environmental impact of the pest management practices on pear over the last 5 years. Although these evaluation methodologies have their biases, they give us a way to look at past and present pest management practices more critically and determine where changes need to be made in order to reduce overall environmental impact.

Summary and Future Outlook

The Hood River IFP project successfully demonstrated that pest management on pears is feasible and economical without, or with very limited, use of broad-spectrum pesticides, especially organophosphates. In light of the recent use restrictions (e.g., Guthion) and in some cases cancellations (e.g., methyl-parathion) of organophosphate insecticides imposed by the Food Quality Protection Act (FQPA), it is important to show the industry that control alternatives are available and that they can be molded into a cohesive program. For many years, the lack of registered control choices has been a limitation to the development of such a program on pears. However, with the recent registrations of new insect growth regulators such as Confirm (tebufenozide) and Esteem (pyriproxyfen), new pear psylla insecticides such as Pyramite and Provado, and new acaricides, the situation has improved considerably. Additional registrations of "low risk" pesticides for use on pears are expected in the near future.

During the 4 years of the study, mating disruption was an effective selective control method for codling moth on pears even on hilly terrain and in relatively small orchard blocks (5 to 10 acres). With the registration of mating disruption, pear growers now can control codling moth selectively, which is the centerpiece of the selective pest management strategy for the whole pest complex. Over the last 5 years, the orchard area under grower-financed mating disruption in the Hood River district has increased to over 2,000 acres, which represents about 15 percent of the local pome fruit acreage. New regulatory restrictions on the use of organophosphate insecticides likely will accelerate the adoption of mating disruption and other selective control technologies on tree fruits. A major limitation to the adoption of mating disruption for seasonal control of codling moth has been the expense compared with a conventional full insecticide program. Experience over the last several years has shown that mating disruption can be applied at half the label rate if supplemented by limited insecticide use. This combination program is comparable in cost to a regular insecticide program but has the advantage of being more selective. Most pear growers in the Hood River Valley who have switched to mating disruption for codling moth control supplement it with one OP spray. We expect that recently registered selective insecticides (e.g., Confirm, Esteem) will replace OP insecticides as supplemental controls in mating disruption programs and increase opportunities for biological control.

The project showed that, under selective programs, biological control can make a substantial contribution to the control of a number of primary and secondary pests including pear psylla, spider mites, and aphids. Pear psylla and spider mites became more manageable due to improved biological control and the lack of reproductive stimulation by broad-spectrum pesticides. We expect that with time, the selective pest management program also will have a positive effect on the biological control of San Jose scale and grape mealybug. However, in the short time frame of the project, this could not be assessed. Whether biological control was successful or not at a particular orchard location was dependent on the surroundings and the available species pool of natural enemies. This was evident in two of the four IFP demonstration blocks, where natural enemies were more abundant due to the vicinity of natural habitat.

Making growers aware of pesticide resistance and possible resistance avoidance tactics was a major goal of the project. Pesticide susceptibility is a necessary prerequisite for successful pest control. Keeping pests susceptible must be one of the goals of selective pest management. Judicious pesticide use, alternation of controls with different modes of action, preferred use of controls with low resistance risk, and other resistance avoidance tactics hopefully will reduce the incidence of resistance and assure the long-term viability and stability of pest management programs on pears.

The appearance of pests previously controlled by broad-spectrum pesticides is a potential problem when growers lower broad-spectrum pesticide use and switch to a selective pest management program. This also was apparent during the 4 years of the study. Careful monitoring can reduce the risk that secondary pests go undetected and cause unacceptable damage. Obliquebanded leafroller and pear rust mite were two pest problems for which it was sometimes difficult to assess the need for chemical control before damage became too high.

Production costs are of primary concern to growers. The costs for pest management were higher for the IFP program primarily because of the high cost of mating disruption. However, the net incomes to the growers from the IFP and conventional blocks were essentially the same. Therefore, the IFP program did not have a negative financial impact on growers' profits. We expect that the costs of pest management under the IFP program will decrease gradually as biological control of pear psylla and other pests becomes more effective and reduces the need for chemical control.

The on-farm IFP demonstration project concluded in 1997 after 4 years. A complete summary of the project is forthcoming. The IFP Committee of the Hood River Grower Shipper Association expressed the need for a permanent IFP site for grower training and demonstration purposes. In response, the Mid-Columbia Agricultural Research and Extension Center made a mixed pear block (Anjou, Bartlett) available as an IFP demonstration site. This site was used in 1998 to evaluate IFP practices including selective codling moth control with "Attract & Kill" technology and IGRs (tebufenozide), augmentation of biological control of pear psylla by providing habitat for predatory insects, irrigation scheduling based on soil moisture monitoring, and ground cover management practices. The IFP demonstration site also served as an outdoor laboratory to train orchard scouts in monitoring techniques, pest identification, and pest management decision making.

The fruit industry has shown a strong interest in the IFP program as evidenced by the support it has received from the local grower organization since 1994. With an intensive educational program in place, we hope that the acreage under IFP will expand in the years ahead from the original 25 acres in the demonstration project. With the rapidly expanding acreage under mating disruption, a key IFP pest management practice, this hope is not unfounded. As IFP acreage increases in the Hood River district, fruit grown under IFP practices will be available in larger volumes and can be identified and sold with an IFP label. The marketing effort for IFP fruit will have to be coordinated among the various packing houses that have been very supportive of the IFP program. It is hoped that the marketplace eventually will reward the fruit growers in the Hood River district for their extra effort to practice IFP and for being environmentally responsible stewards of the land they farm.

Acknowledgements

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The Economics of Mating Disruption in Pacific Northwest Apple and Pear

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Introduction

Mating disruption-based codling moth control strategies involve early season placement of mating disruption dispensers in the top third of apple or pear trees. The dispensers slowly release sex attractant pheromones to confuse male codling moths and prevent breeding. The first field scale applications of mating disruption in the U.S. occurred in 1993 and 1994 on a pear orchard site in the Sacramento Delta area known as Randall Island. This initial cooperative project between University of California researchers and orchard owners demonstrated mating disruption as a codling moth control approach with significant potential to minimize use of synthetic pesticides, maximize effects of natural control agents, and maintain acceptable fruit yield and quality. At that time, widespread voluntary adoption of mating disruption seemed unlikely. The additional cost of mating disruption and dispensers exceeded the cost of materials and application associated with the alternative codling moth control strategy, two to five or more applications of organophosphate (OP) insecticides, most commonly 2 or 2.5 lb of Guthion per application (Williamson et al.).

Best prospects for eventually realizing cost competitiveness appeared to be development of programs which created significant secondary pest control cost savings by combining mating disruption with limited supplemental application of OP and other soft materials which minimally disrupted populations of predatory beneficials. Alternatively, it was thought that decreases in dispenser cost or decreases in the required numbers of mating disruption dispensers to achieve adequate control might eventually make the practice cost effective (Beers et al., 1998).

To encourage development of cost effective mating disruption approaches in the Pacific Northwest, beginning in 1995, the USDA sponsored five codling moth areawide program (CAMP) sites in the region. At these CAMP sites, the USDA provided groups of growers on contiguous orchard blocks technical assistance with mating disruption, pest monitoring, and, until 1997, subsidies on purchases of mating disruption dispensers. The CAMP sites served as an opportunity to develop strategies for effective and economical use of mating disruption through cooperation between growers and research scientists.

At least partially as a result of CAMP site experience, the use of mating disruption on apple and pear acreage has grown by almost 40 percent per year over the last 5 years. In 1997, an estimated 60,000 acres of apple and pear were in mating disruption with most of the acreage in central Washington, 37,000 to 40,000 acres (Alway, 1998). While the acreage in mating disruption is large in absolute terms, it only represented about 22 percent of central Washington apple and pear acreage and less than 10 percent of all U.S. apple and pear acreage in 1997.

Objectives

The central objective of this research is to investigate the extent to which mating disruption-based pest control in Pacific Northwest apple and pear is cost competitive with multiple OP cover spray approaches. More specifically, the objectives are to assess (1) how the cost effectiveness of mating disruption varies across major Northwest fruit growing districts, and (2) how the cost effectiveness of mating disruption is influenced by pest pressure within growing districts. Understanding the cost or savings to adoption of mating disruption aids in understanding how cost effectiveness of policies to induce further adoption of mating disruption can be improved by targeting specific regions and types of growers. The research outcome also allows a better understanding of factors influencing voluntary adoption on additional acreage and likely consequent reductions in organophosphate use in the region.

Scope

The objective of this partial budgeting application was to estimate expected *average* difference in profit experienced by orchards using mating disruption-based pest control and orchards using OP based pest control. The partial budgeting methodology has been applied widely to pesticide economics issues (see Norton and Mullen, 1994, for a review of many studies using the method). This application of partial budgeting involves developing pest control cost budgets for mating disruption blocks and multiple OP blocks. Each partial budget is a tally of costs which vary across pest control treatment. Initial statistical analysis and background research showed that transitioning to mating disruption induces shifts in pest population dynamics which do not settle to a new equilibrium for several years. As a result, cost of the strategy appears to vary over the first several years in a systematic way. To capture the impact of these dynamic effects on cost, multiple-year partial budgets are used rather than a single representative year budget. To include regional and practice related differences in the cost effectiveness of mating disruption, four separate sets of partial budgets were developed, two for apple and two for pear.

Partial budget estimates of pest control cost represent the costs a grower would experience using the set of representative typical practices. While care is taken to ensure that the partial budget estimates derived for this study are not systematically biased, the estimates are not likely to represent the actual cost that any one grower experiences. Instead, the costs of pest control experienced by regional growers follows a distribution. Some experience higher costs than average and others lower costs. Initial interviews, surveys (Alway, 1997), and statistical analysis suggested that variation in codling moth pressure and leafroller pressure are key determinants of the relative cost effectiveness of mating disruption. Fruit blocks with higher codling moth pressure require more OP cover sprays to achieve adequate control, and consequently greater savings are realized on such blocks through reduced OP use if such blocks are placed in mating disruption. To give a sense of how pest population pressure affects the net cost or savings that would be realized if growers not currently in mating disruption adopted the practice, partial budget estimates are recomputed using alternative assumptions about pest pressure and pest control strategies.

Methods

The first step in the partial budgeting process is specification or deciding which factors influence costs and (or) revenues differently across pest control strategies, and which components of cost and (or) revenue can be treated as constant. Published reports, survey findings, and interviews with growers, Extension agents, Experiment Station researchers, and crop pest consultants in Washington, Oregon, and California were used to determine which costs of apple and pear pest control vary across pest control strategies in the region. The result of this process summarized in Figure 1 was specification of general cost categories assumed to vary across pest control treatment in this study, as well as cost categories treated as constant.

As summarized in Figure 1, five factors are assumed constant in the partial budgets used in this research. The assumption that factors 1 through 4 do not vary with variation in pest control cost are relatively uncontroversial maintained hypotheses that are not tested statistically. It simply is assumed that on well-managed farms, choosing to use mating disruption does not influence cost in these categories. Previous research suggests that some of these factors may influence pesticide use. For example, irrigation management practices have been shown to influence pest control practices in some settings. Typically, however, such "second order" interaction effects are small. Furthermore, more detailed surveys of management practices and outcomes than could be collected for this research effort would be required to estimate any such effects.

The assumption that revenue losses due to pest damage do not vary across pest control strategies is not standard in partial budget analyses of pest control strategy economics. Generally, it is assumed that damage varies between strategies. In this study, statistical comparisons showed that assuming no damage difference is justified in this particular case. Results of the statistical comparison are summarized in Appendix 1: Basis for Partial Budgeting Assumptions.

The second step in the partial budgeting process involves developing meaningful quantitative estimates of how factors assumed to vary across treatments of interest. The results of this process is the set of assumptions about inputs used in pest control summarized in Table 1. These assumptions are based on: (1) statistical analysis of spray records from samples of orchard blocks using both mating disruption and multiple OP cover spray approaches to pest control, (2) secondary survey data summaries, and (3) expert opinion. Procedures used in developing assumption are described in Appendix 1: Basis for Partial Budgeting Assumptions. In short, partial budgeting assumptions were chosen to generate estimates which cover the range of cost effectiveness growers in a given region are likely to experience given the observed variation in OP cover sprays for codling moth and numbers of leafroller treatment.

Figure 1. Costs treated as variable and those assumed constant.

Factors which are treated as constant across pest control strategies

1. Production inputs not directly related to insect pest control (e.g., fertilizer, irrigation water, fungicides, herbicides)
2. Costs of operating and maintaining machinery not directly related to insect pest control (e.g., tillage related machinery costs, irrigation system cost)
3. Costs of labor not directly related to insect pest control (e.g., labor costs of pruning, fertilizing, weed control, irrigation, fungicide and herbicide control)
4. Other fixed costs not directly related to insect pest control (e.g., land and building rents or mortgages, taxes, general management overhead)
5. Revenue losses due to pest damage

Factors treated as variable across pest control strategies

6. The costs of insect control materials used to control codling moth
7. The costs of insect control materials used to control secondary pests which may be effected by changes in codling moth control strategy
8. Costs of labor and management used in insect pest control and monitoring
9. Costs of operating capital assets used in insect control (e.g., sprayers and tractors used in spray operations)
10. Costs of borrowing operating capital used in pest control

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Table 1A. Overview of partial budgeting analysis assumptions.

Analysis / Per acre treatment	1. Northern California Pear	2. Northern California Pear -	3. Southern Oregon Pear Reduced MD Rates
# of OP cover sprays	1 - MD blocks 4 - OP blocks	1 - MD blocks 4 - OP blocks	1- MD blocks 3.5 - OP blocks
Mating Disruption dispensers/a	400 on MD blocks	300 on MD blocks	400 on MD blocks
Leafroller control	2 qt Lorsban	2 qt Lorsban	2 qt Lorsban
Psylla & mite Insecticides	7 oz Agrimek on MD blocks 10 oz Argrimek on OP blocks	7 oz Agrimek on MD blocks 10 oz Argrimek on OP blocks	20 oz Agrimek, 3 oz Apollo, 3 lb Mitac, 8 oz Savey on OP blocks
Horticultural Oil	20 gal on MD, 14 gal on OP	20 gal on MD, 14 gal on OP	14 gal on MD, 6 gal on OP
CM monitoring traps per 10 acre	4 on MD blocks 2 on OP blocks	4 on MD blocks 2 on OP blocks	4 on MD blocks 2 on OP blocks
LR monitoring traps per 10 acre	2 on MD blocks 1 on OP blocks	2 on MD blocks 1 on OP blocks	2 on MD blocks 1 on OP blocks

Table 1B. Overview of partial budgeting analysis assumptions.

Analysis / Per acre treatmet	4. Central Washington Apple, High CM Pressure	5. Central Washington Apple, Low CM Pressure	6. Central Washington Apple, Moderate CM Pressure	7. Central Washington Apple, High CM Pressure & Increased LR Pressure
# of OP cover sprays	2 year 1, 1.5 year 2, 1 years 3 & 4-MD blocks 5 - OP blocks	1.5 year 1, 1 year 2 0.5 years 3 & 4, MD blocks 2.5 on OP blocks	2 year 1, 1.5 year 2, 1 years 3 & 4-MD blocks 3.5 - OP blocks	1.5 year 1, 1 year 2, 0.5 years 3 & 4, MD blocks 5 on OP blocks
Mating disruption dispensers/a	300 year 1, 200 years 2-4 on MD blocks	200 on MD blocks	300 year 1, 200 years 2-4 on MD blocks	300 year 1, 200 years 2-4 on MD blocks
Leafroller control	2 qt Lorsban	2 qt Lorsban	2 qt Lorsban	2 qt Lorsban on OP blocks 2 qt Lorsban & 1.5 lb Dipel (Bt) on MD blocks
Horticultural Oil	5 gallons	5 gallons	5 gallons	5 gallons
CM monitoring traps per 10 acre	4 on MD blocks 2 on OP blocks	4 on MD blocks 2 on OP blocks	4 on MD blocks 2 on OP blocks	4 on MD blocks 2 on OP blocks
LR monitoring traps per 10 acre	2 on MD blocks 1 on OP blocks	2 on MD blocks 1 on OP blocks	2 on MD blocks 1 on OP blocks	2 on MD blocks 1 on OP blocks

Results 1: Partial Budgets and Average Cost Comparison

Figures 2 and 3, as well as Tables 2 and 3, summarize comparisons of average cost of mating disruption and multiple OP cover spray strategies. Tables 4 through 9 contain partial budgets representing estimates of the cost of insect pest control for Pacific Northwest apple and pear. While these pest control cost estimates and comparisons do not represent the actual cost that any single grower experiences, they do give an overall sense of how costs of the two strategies compare.

Key findings that emerged are:

1. In Northern California, pear mating disruption is relatively costly compared to the multiple OP cover spray strategy. High mating disruption dispenser densities are required in the region, and the costs of dispensers, application, and additional monitoring is not fully offset by savings in OP materials and application costs savings or savings in secondary pest control cost, which are relatively modest in the region. In the Sacramento Delta of Northern California, prospects for further voluntary adoption of mating disruption may be relatively limited. However, if reduced dispenser rate (300/acre) strategies prove to be effective, there is potentially a relatively large sub-population of pear growers using four to five cover sprays who may find the relatively small additional costs in the $20/acre range to be acceptable.

2. In southern Oregon pear, the mating disruption and foliar period horticultural oil program is very cost effective, despite requiring high mating disruption dispenser densities, and modest savings in OP materials for codling moth control. The most significant savings to mating disruption and foliar oil program in Southern Oregon are costs savings on secondary pest control cost. Average expenditures by multiple OP cover spray growers in the region for pear psylla and mite control are very large. Horticultural oil and the additional natural predatory control that the less disruptive mating disruption approach provide are an effective and very low cost alternative to synthetic pesticides for control of psylla and mites.

3. In central Washington, the cost competitiveness of mating disruption is significantly influenced by the level of codling moth pressure at a given site. In many areas of central Washington, codling moth pressure is quite low, so savings from OP cover sprays do not fully offset the cost of mating disruption. In contrast, in high codling moth pressure areas of central Washington, where many OP cover sprays typically are applied, savings from reduced OP use do appear to offset the additional costs of mating disruption, even if additional leafroller control inputs are required.

Results suggest that in settings where growers can use 200 dispensers per acre in the first year and reduce supplemental OP applications to approximately one-half per acre, and do not experience increased leafroller cost, they can expect to break even by the 3rd year if they began at an average of 3.25 OP covers per season. Still, initial year costs for growers using less than 3.5 cover sprays are likely to be in the $30/acre range. As Table 10 results indicate, growers using 5 or more OP cover sprays are likely to realize savings if they adopt mating disruption, even if an additional leafroller treatment is required. These growers represent a significant percentage (greater than 60 percent) of the small sample of growers in the area south of Yakima used in this study to compute multiple OP cover sprays in high codling moth pressure settings.

4. In some parts of central Washington, a mating disruption strategy involving significant reductions in organophosphates for codling moth control can lead to increased leafroller pressure and consequently increased costs of leafroller control.

5. In central Washington apple, the decision to adopt mating disruption is frequently equivalent to an investment decision, in the sense that additional costs can be expected in the first years of mating disruption, but offsetting savings can be expected in future periods. This pattern of initial cost and later savings is a result of the biology of mating disruption. Establishing effective mating disruption control requires relatively high rates of dispensers and supplemental OP sprays the first year. In later years, codling moth pressure tends to decline systematically, so reduced dispenser densities and supplemental sprays are required and cost drops.

Research Limitations

Data available for this study allows only limited inferences to be drawn regarding distribution in the "population" of pest control cost of alternative strategies for three reasons: (1) Available data contain no individual observations characterizing variation in several factors determining pest control costs, including variation in monitoring effort, labor cost, and how adopting mating disruption influences costs of owning and operating capital assets; (2) While sample data describing variation in one of the most significant determinants of pest control cost in the sample population (insecticide use) is available, the sizes of samples of conventional growers are too small to allow meaningful inferences regarding population distribution of insecticide use levels. Samples used in evaluating each scenario in this study are based on information from between 5 and 9 blocks.

This research provides only estimates of the producer cost of apple and pear pest control using mating disruption and multiple OP pest control strategies. Producer cost is just one component of total economic impact of producers' pest control strategy choices. No attempt is made to provide estimates of public and private external benefits (i.e., health and environmental benefits to the producer directly or the public) in dollar terms. Methods for estimating certain categories of such benefits exist (Beach and Carlson, 1993; Lohr and Wetzstein, 1997). However, confidence that can be placed in dollar value external benefit estimates is limited by uncertainty associated with estimated impact of pesticides on health and environmental quality, and difficulty quantifying how the public values environmental and health improvements.

This research also does not estimate costs or benefits of widespread mating disruption adoption to consumers in the form of changes in food prices and resultant expenditures. In other words, the methodology is based on two simplifying assumptions. One simplifying assumption is that significant acreage switching to mating disruption will not influence apple or pear prices significantly as the result of market supply effects. This assumption is likely to introduce little bias in estimation because, as documented in the methodology section below, the effect of mating disruption on crop yield is minimal. The other simplifying assumption is that consumers do not perceive differences in the quality of fruit produced using mating disruption and, consequently, are not willing to pay a premium for such fruit.

Table 2. Results summary: annual savings or cost to mating disruption in Northern California pear, mating disruption and foliar oil in southern Oregon pear.

Northern California, 400 dispensers/acre	-$65.28
Northern California, 300 dispensers/acre +miticide savings	-$30.30
Southern Oregon	$161.16

Figure 3. Projected net savings from adoption of mating disruption in northern California and mating disruption and foliar oil in southern Oregon pear.

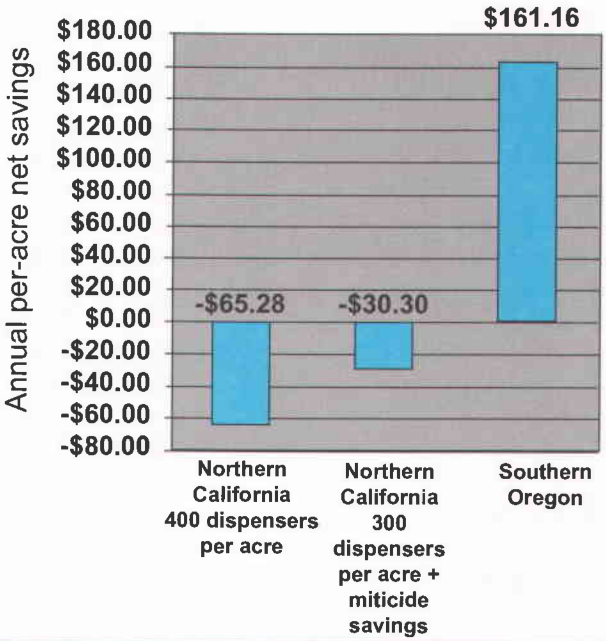

Figure 4. Four-year projected net savings from adoption of mating disruption in central Washington apple.

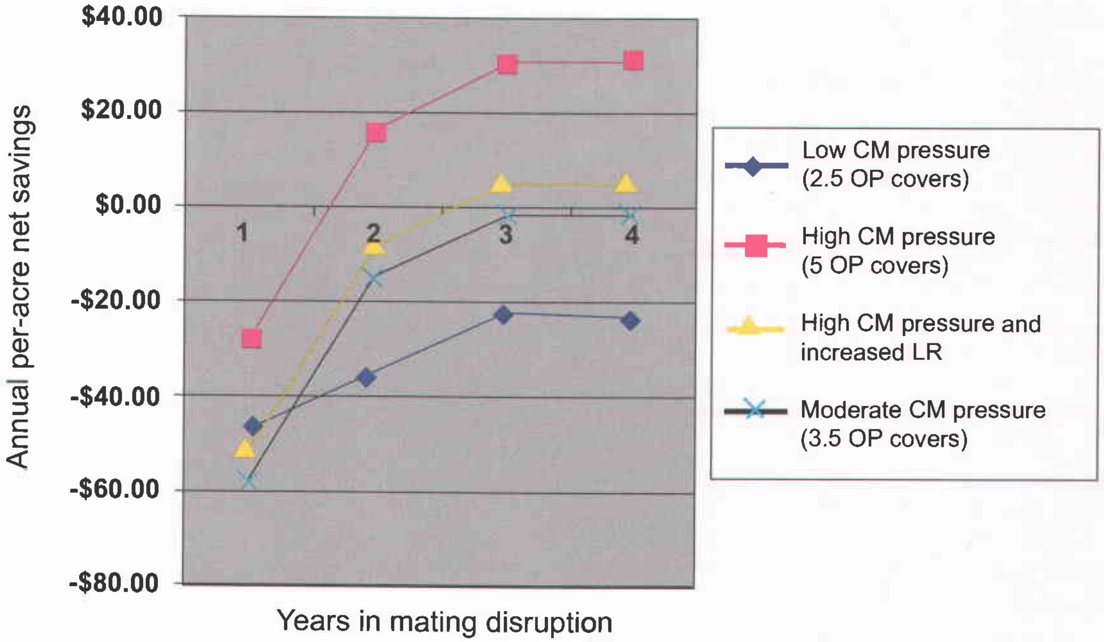

Figure 4. (continued)

Year:	1	2	3	4
Low CM pressure (2.5 OP covers)	-$47.70	-$35.10	-$22.51	-$23.30
High CM pressure (5 OP covers)	-$28.82	$15.90	$30.26	$31.31
High CM pressure & increased LR	-$52.67	-$8.37	$5.14	$5.32
Moderate CM pressure (3.5 OP covers)	-$58.41	-$14.72	-$1.44	-$1.49

Table 4. Four-year projections of costs assumed to vary across pest control strategy, low codling moth pressure, central Washington (cost $/a).

		Mating Disruption		
Item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$ 15.00	$ 15.53	$ 16.07	$ 16.63
Mating disruption dispensers (200/a)	$ 51.50	$ 53.30	$ 55.17	$ 57.10
OP cover spray (Guthion) 3.75 lb-yr 1, 2.5 lb-yr 2, 1.25 lb-yr 3 & 4)	$ 31.61	$ 21.81	$ 11.29	$ 11.68
Learoller control (Lorsban 2 qt)	$ 26.85	$ 27.79	$ 28.76	$ 29.77
Mating disruption dispenser installation	$ 8.28	$ 8.57	$ 8.87	$ 9.18
Variable cost of spray-rig use	$ 19.50	$ 18.50	$ 17.41	$ 18.02
Codling moth & leafroller trap monitoring	$ 25.97	$ 26.88	$ 27.82	$ 28.79
Cost of operating capital	$ 10.72	$ 9.41	$ 8.96	$ 9.27
Total	$189.44	$181.79	$174.34	$180.45
		Multiple OP Cover Spray		
Item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$ 15.00	$15.53	$ 16.07	$ 16.63
Mating disruption dispensers				
OP cover spray (Guthion) 6.25 lb (2.5 applications of 2.5 lb)	$ 52.69	$ 54.54	$ 56.44	$ 58.42
Leafroller control (Lorsban 2 qt)	$ 26.85	$ 27.79	$ 28.76	$ 29.77
Mating disruption dispenser installation				
Variable cost of spray-rig use	$ 22.75	$ 23.55	$ 24.37	$ 25.22
Codling moth & leafroller trap monitoring	$ 16.42	$ 16.99	$ 17.59	$ 18.21
Cost of operating capital	$ 8.02	$ 8.30	$ 8.59	$ 8.89
Total	$141.73	$146.69	$151.83	$157.14

Table 5. Four-year projections of costs assumed to vary across pest control strategy, moderate codling moth pressure, Central Washington (costs $/a).

		Mating Disruption		
item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$ 15.00	$ 15.53	$ 16.07	$ 16.63
Mating disruption dispensers				
year 1: 1/2 @ 400/a,1/2 @ 200/a, years 2-4: 200/a	$ 77.25	$ 53.30	$ 55.17	$ 57.10
OP cover spray (Guthion)				
5 lb-yr 1, 3.75 lb-yr 2, 2.5 lb-yr 3 & 4)	$ 42.15	$ 32.72	$ 22.58	$ 23.37
Leafroller control (Lorsban 2 qt)	$ 26.85	$ 27.79	$ 28.76	$ 29.77
Mating disruption dispenser installation	$ 12.42	$ 8.57	$ 8.87	$ 9.18
Variable cost of spray-rig use	$ 22.75	$ 21.86	$ 20.89	$ 21.62
Codling moth & leafroller trap monitoring	$ 25.97	$ 26.88	$ 27.82	$ 28.79
Cost of operating capital	$ 13.34	$ 11.20	$ 10.81	$ 11.19
Total	**$235.74**	**$197.85**	**$190.96**	**$197.65**
		Multiple OP Cover Spray		
item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$ 15.00	$ 15.53	$ 16.07	$ 16.63
Mating disruption dispensers				
OP cover spray (Guthion)				
3.5 applications of 2.5 lb Guthion	$ 73.77	$ 76.35	$ 79.02	$ 81.79
Leafroller control (Lorsban 2 qt)	$ 26.85	$ 27.79	$ 28.76	$ 29.77
Mating disruption dispenser installation				
Variable cost of spray-rig use	$ 32.50	$ 33.64	$ 34.81	$ 36.03
Codling moth & leafroller trap monitoring	$ 16.42	$ 16.99	$ 17.59	$ 18.21
Cost of operating capital	$ 9.87	$ 10.22	$ 10.58	$ 10.95
Total	**$174.41**	**$180.51**	**$186.83**	**$193.37**

Table 6. Four-year projections of costs assumed to vary across pest control strategy, high codling moth pressure, and increased leafroller pressure, central Washington.

		Mating Disruption		
Item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$15.00	$15.53	$16.07	$16.63
Mating disruption dispensers				
year 1: 1/2 @ 400/a,1/2 @ 200/a, years 2-4: 200/a	$77.25	$53.30	$55.17	$57.10
OP cover spray (Guthion)				
5 lb-yr 1, 3.75 lb-yr 2, 2.5 lb-yr 3 & 4)	$42.15	$32.72	$22.58	$23.37
Leafroller control (Lorsban 2 qt + 1.5 lb Dipel)	$50.30	$52.06	$53.88	$55.76
Mating disruption dispenser installation	$12.42	$8.57	$8.87	$9.18
Variable cost of spray-rig use	$22.75	$21.86	$20.89	$21.62
Codling moth & leafroller trap monitoring	$25.97	$26.88	$27.82	$28.79
Cost of operating capital	$14.75	$12.66	$12.32	$12.75
Total	**$260.59**	**$223.57**	**$217.59**	**225.20**
		Multiple OP Cover Spray		
Item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$15.00	$15.53	$16.07	$16.63
Mating disruption dispensers				
OP cover spray (Guthion)				
5 applications of 2.5 lb Guthion	$105.38	$109.07	$112.89	116.84
Leafroller control (Lorsban 2 qt)	$26.85	$27.79	$28.76	$29.77
Mating disruption dispenser installation				
Variable cost of spray-rig use	$32.50	$33.64	$34.81	$36.03
Codling moth & leafroller trap monitoring	$16.42	$16.99	$17.59	$18.21
Cost of operating capital	$11.77	$12.18	$12.61	$13.05
Total	**$207.92**	**$215.20**	**$222.73**	**230.53**

Table 7. Four-year projections of costs assumed to vary across pest control strategy, Scenario 4: High codling moth pressure, central Washington.

		Mating Disruption		
Item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$ 15.00	$ 15.53	$16.07	$16.63
Mating disruption dispensers				
year 1: 1/2 @ 400/a,1/2 @ 200/a, years 2-4 (200/a)	$ 77.25	$ 53.30	$55.17	$57.10
OP cover spray (Guthion)				
5 lb-yr 1, 3.75 lb-yr 2, 2.5 lb-yr 3 & 4)	$ 42.15	$ 32.72	$ 22.58	$ 23.37
Leafroller control (Lorsban 2 qt)	$ 26.85	$ 27.79	$ 28.76	$ 29.77
Mating disruption dispenser installation	$ 12.42	$ 8.57	$ 8.87	$ 9.18
Variable cost of spray-rig use	$ 22.75	$ 21.86	$ 20.89	$ 21.62
Codling moth & leafroller trap monitoring	$ 25.97	$ 26.88	$ 27.82	$ 28.79
Cost of operating capital	$ 13.34	$ 11.20	$ 10.81	$ 11.19
Total	**$235.74**	**$197.85**	**$190.96**	**$197.65**
		Multiple OP Cover Spray		
Item:	**Year: 1**	**2**	**3**	**4**
Dormant horticultural oil (5 gallons/acre)	$ 15.00	$ 15.53	$ 16.07	$ 16.63
Mating disruption dispensers				
OP cover spray (Guthion)				
5 applications of 2.5 lb Guthion	$105.38	$109.07	$112.89	$116.84
Leafroller control (Lorsban 2 qt)	$ 26.85	$ 27.79	$ 28.76	$ 29.77
Mating disruption dispenser installation				
Variable cost of spray-rig use	$ 32.50	$ 33.64	$ 34.81	$ 36.03
Codling moth & leafroller trap monitoring	$ 16.42	$ 16.99	$ 17.59	$ 18.21
Cost of operating capital	$ 11.77	$ 12.18	$ 12.61	$ 13.05
Total	**$207.92**	**$215.20**	**$222.73**	**$230.53**

Table 8. Four-year projections of costs assumed to vary across pest control strategy, pear production, northern California.

	Mating Disruption Dispensers/Acre	
Item:	**400**	**300**
Dormant horticultural oil (20 gallons/acre)	$60.00	$ 60.00
Mating disruption dispensers		
400/a	$103.00	$ 77.25
OP cover spray (Guthion)		
1 application of 2.5 lb Guthion	$ 21.08	$ 21.08
Leafroller control (Lorsban 2 qt)	$ 26.85	$ 26.85
Mite control (Agrimek 7 oz)	$ 35.56	$ 35.56
Mating disruption dispenser installation	$ 16.00	$ 12.00
Variable cost of spray-rig use	$ 42.25	$ 39.00
Codling moth & leafroller trap monitoring	$ 25.97	$ 25.97
Cost of operating capital	$ 19.84	$ 17.86
Total	**$350.55**	**$315.57**
	Multiple OP Cover Spray	
Item:	**2**	
Dormant horticultural oil (14 gallons/acre)	$ 42.00	$ 42.00
Mating disruption dispensers		
OP cover spray (Guthion)		
4 applications of 2.5 lb Guthion	$ 84.31	$ 84.31
Leafroller control (Lorsban 2 qt)	$ 26.85	$ 26.85
Mite control (Agrimek 10 oz)	$ 50.80	$ 50.80
Mating disruption dispenser installation		
Variable cost of spray-rig use	$ 48.75	$ 48.75
Codling moth & leafroller trap monitoring	$ 16.42	$ 16.42
Cost of operating capital	$ 16.15	$ 16.15
Total	**$285.27**	**$285.27**

Table 9. Projections of costs assumed to vary across pest control strategy, pear production with mating disruption and foliar oil, southern Oregon.

Mating Disruption	
item:	
Horticultural + foliar oil (14 gallons/acre)	$42.00
Mating disruption dispensers	
400/a	$103.00
OP cover spray (Guthion)	
1 application of 2.5 lb Guthion	$21.08
Leafroller control (Lorsban 2 qt)	$26.85
Mite control	
Pear psylla control	
Mating disruption dispenser installation	$16.00
Codling moth & leafroller trap monitoring	$25.97
Cost of operating capital	$14.09
Total	**$248.99**
Multiple OP Cover Spray	
Item:	
Dormant horticultural oil (6 gallons/acre)	$18.00
Mating disruption dispensers	
OP cover spray (Guthion)	
3 1/2 application of 2.5 lb Guthion	$73.77
Leafroller control (Lorsban 2 qt)	$26.85
Mite control (Agrimek 20 oz + Apollo 3 oz)	$139.10
Pear psylla control (Mitac 3 lb + Savey 8 oz)	$103.12
Leaf miner control (Pounce 8 oz)	$9.68
Mating disruption dispenser installation	
Codling moth & leafroller trap monitoring	$16.42
Cost of operating capital	$23.22
Total	**$410.15**

Appendix 1.
Basis for Partial Budgeting Assumptions.

Assumption 5: Revenue losses due to pest damage constant across treatments.
As summarized in Figure 1, five factors are assumed constant in the partial budgets used in this research. The assumption that factors 1 through 4 do not vary with variation in pest control cost are relatively uncontroversial maintained hypotheses that are not tested statistically. It simply is assumed that on well-managed farms, choosing to use mating disruption does not influence cost in these categories. Previous research suggests that some of these factors may influence pesticide use. For example, irrigation management practices have been shown to influence pest control practices in some settings. Typically, however, such "second order" interaction effects are small and, in any case, more detailed surveys of management practices and outcomes than could be collected for this research effort would be required to estimate any such effects.

The assumption that revenue losses due to pest damage do not vary across pest control strategies is not standard in partial budget analyses of pest control strategy economics. Generally, it is assumed that damage varies between strategies. In this study, statistical comparisons showed that assuming no damage difference is justified in this particular case. Results of the statistical comparison are summarized in Table 10. The table reports differences in average percentage of fruit damaged by codling moth, average percentage of fruit damaged by leafroller, and average percentage of fruit damaged by other pests on samples of mating disruption blocks and multiple OP blocks, as well as p-values for t-test comparisons of sample means.

Table 10 also reports estimated average revenue losses from pest damage for samples of mating disruption blocks and multiple OP blocks, and p-value results of t-tests comparisons. For this analysis, average revenue loss was computed in two ways. Where data permitted, revenue loss from all pest damage was estimated assuming all codling moth and leafroller damaged fruit was culled and received zero revenue, and fruit damaged by all other insects received 22 percent less income (average price difference between between fancy and grade A Washington apples from 1995-1997). Where only codling moth and leafroller damage data were available, it was assumed that all damaged fruit was culled and received zero revenue.

Loss was computed for each observation revenue as:

Revenue loss all insect damage =
{ (% CM damage + % LR damage) + 0.22 x % other pest damage } x regional average yield (tons per acre) x state average price ton

Revenue loss all CM and LR damage =
(% CM damage + % LR damage) x regional average yield (tons per acre) x state average price ton

The results summarized in Table 10 indicate that available data strongly support the hypothesis that on average over the sampled years, average revenue loss attributable to pest damage differences were very small, and the assumption that differences in pest damage across treatments does not effect revenue is justified.

Table 10. Results of hypotheses tests comparing damage difference on mating disruption and multiple OP blocks.

Data Sample Description	Sample Size	Statistical Measure	% Codling Moth Damage	% Leaf Roller Damage	% Other Pest Damage	Estimated Revenue Loss, All Pest	Estimated Revenue Loss, CM and LR only
1. Central Washington apples, 1996-1998	n=90	Conv avg	0.26%	0.21%	0.53%	$29.24	$19.36
	n=175	Md avg	0.08%	0.10%	1.18%	$29.77	$7.93
		p-value	0.01	0.02	0.03	0.90	0.001
2. Central Washington pears, 1995-1998	n=12	Conv avg	0.13%	0.07%	*	*	$5.90
	n=20	Md avg	0.17%	0.05%	*	*	$6.70
		p-value	0.57	0.64	*	*	0.82
3. Northern California pears, 1996-1998	n=18	Conv avg	0.08%	0.03%	*	*	$4.43
	n=19	Md avg	0.10%	0.16%	*	*	$10.5
		p-value	0.65	0.05	*	*	0.16
4. Southern Oregon pears, 1995-1998	*	Conv avg	0.05%	0.00%	1.15%	$2.42	$0.40
	*	Md avg	0.49%	0.15%	0.42%	$5.87	$5.07
		p-value	*	*	*	*	*

* Based on summary information; could not be tested statistically.

Assumed mating disruption dispensers and supplemental OP use on MD blocks

Estimating assumed use of mating disruption dispensers and supplemental OP application on MD blocks was a non-statistical process using expert opinion and the database of mating disruption areawide program performance summary measures compiled by Alway (1998). This database is summarized in Tables 11 and 12. The information in these tables and interviews suggested that densities of mating disruption dispensers as well as supplemental OP use have declined significantly since 1995. Personal discussion with Jack Jenkins, the general manager of Pacific Bio-Control, supplier of the market-leading Isomate 2 dispenser, revealed that these reductions were not due to changes in product efficacy. Formulation and efficacy of the product has remained the same since 1995.

Table 11. Mating disruption dispenser density, number of OP cover sprays, and CM pressure at 5 "original" CAMP sites.

Site	Location	Fruit	Year	Codling moth pressure (avg. seasonal trap catch)	MD dispensers /acre	OP cover sprays for codling moth
Randall Island	Northern California	Pear	1996		600	1
			1997	18.9	400	1
			1998	9.1	400 or 300	1
Medford	Southern Oregon	Pear	1996		400	1
			1997	3.2	400	1
			1998	7.9	400	1.75
West Parker Heights	Central Washington	Apple	1996		400	Just less than 1
			1997		400	Just less than 1
			1998		200 original blocks, 400 expansion blocks	1 on 50%, borders and hotspots on others
Howard Flats	Central Washington	Apple	1996	3.6	400	1 + border, hot spots
			1997	0.31	just less than 300	30% - 0
			1998		200 to 250	75%-0, 25%-1
Oroville	Central Washington	Apple	1996	4.3	400	1.75 (avg)
			1997	0.8	400	0.2 (avg)
			1998	0.22	400	0 - original blocks, 1 or 2 on expansion

Table 12. Mating disruption dispenser density, number of OP cover sprays, and CM pressure at 6 CAMP sites new in 1998.

Site	Location	Fruit	Year	Codling moth pressure (avg. seasonal trap catch)	MD dispensers /acre	OP cover sprays for codling moth
South Shore	Central Washington	Apple	1998	3.3	200, 400 on top edge of slope	1 + border and hot spots
East Wenatchee	Central Washington	Apple	1998		50% 200 50% 400 including some organic	50% 0, 50% 1 or 1 + borders
Babcock Ridge	Central Washington	Apple	1998	1.3	200	Just <50% 0, Just >50% 1
Bench Road	Central Washington	Apple	1998	4.2, 50% <2	250, 400 hot spots	1 on most blocks, more on a few
Elephant Mountain	Central Washington	Apple	1998	17.1	200, 400 hot spots	1 on most blocks, more on a few
Lower Roza	Central Washington	Apple	1998	25, some >200	200 on 75%, 300 or 400 on 25%	Average of 2

As Table 11 suggests, smaller reductions in dispenser hanging density have been observed in Southern Oregon and Northern California pear than in Central Washington apple. Interviews suggested that growers and project managers do not feel compelled to further reduce dispenser densities in the pear regions studied, because codling moth pressure continues to be significant. This is reflected in the codling moth trap count numbers for the Randall Island and Medford CAMP project sites in 1997 and 1998.

Per acre dispensers rate at Randall Island decreased in 1997 as the result of threshold discovery with increased experience rather than systematic decreases in codling moth pressure resulting from mating disruption. Until 1996, growers had used two dispenser hangings per year, one 400 dispenser/acre hanging in the spring and a second 200 dispenser/acre hanging late in the season. The two hangings were used because both codling moth pressure and rates of pheromone release are dependent on temperature. It seemed that under warm California growing conditions, the potential for significant codling moth exposure could result if a single hanging were used. Experience through 1996 convinced growers and site managers that one hanging would provide very nearly full season coverage and cost savings benefits would outweigh risks. Results of less than 0.5 percent CM damage in the 1997 and 1998 seasons confirm that 400 dispensers and one supplemental OP spray provide adequate control in the region.

For both of the pear scenarios evaluated in the research, we assume that 400 MD dispensers/acre and one supplemental OP spray will remain standard practice. This reflects experience in the region to date and consensus of growers and the CAMP project manager we interviewed.

In central Washington apple production, mating disruption dispenser density declined significantly from 1995 through 1998. The declines appear to be the result of systematic declines in codling moth pressure at sites where mating disruption has been implemented for multiple years, as well as threshold discovery with increased experience.

Experience at the Howard Flats CAMP project (summarized in Table 11) is indicative of general trends in low codling moth pressure orchard settings in central Washington. At that site, where growers averaged 2 to 3 OP cover sprays before mating disruption, codling moth pressure declined over the years. In 1998, no codling moths were found in 75 percent of monitoring traps, MD dispenser rates declined to 200 or 250 in most blocks, and no OP cover sprays were applied on 75 percent of the project blocks. In 1997 and1998, fruit damage from codling moth observed at harvest was minimal (<0.1 percent), indicating that the reduced dispenser density is highly effective. Experience at the West Parker Heights CAMP site is illustrative of the similar but somewhat less dramatic declines in MD disruption dispenser use in central Washington regions with high codling moth pressure. In 1998, only about half of the growers, who had typically been applying 4 to 6 or more OP covers before using mating disruption, applied a cover spray despite reducing dispenser rates to 200/acre. In 1998, fruit damage from codling moth observed at harvest at both sites was minimal (<0.1 percent), indicating that the reduced dispenser density is highly effective.

Table 12 summarizes the experience of six areawide projects that began operation in 1998 and is indicative of a trend toward going into mating disruption with lower dispenser densities than typically had been the case 2 years earlier. At nearly all of these sites, growers decided to use 200 (or at most 250) dispensers per acre, except on blocks with a known history of particularly strong codling moth pressure, where 400 dispensers were typical. As Table 4 indicates, the most typical practice was application of one OP cover spray at first-year sites with a second applied to high pressure areas where codling moth trap counts indicated one was needed.

The experience in the region to date, and the consensus of growers and the CAMP project manager we interviewed, suggested the following assumptions for the apple scenarios 3 and 4. For scenario 3, the low to moderate CM pressure apple scenario, it is assumed that 200 MD dispensers/acre and 1½ supplemental OP sprays will remain standard practice in the first year of mating disruption implementation. It is assumed further that dispenser densities and rates of supplemental sprays in following years will decline as indicated in Table 1. For scenario 4, high CM pressure, it is assumed that 400 MD dispensers/acre and two supplemental OP sprays will remain standard practice in the first year of mating disruption implementation. It is assumed further that dispenser densities and rates of supplemental sprays in following years will decline.

Assumed cost of secondary insect pest control and the cost of OP covers on non MD blocks

Data exploration of the samples of spray records for CAMP and comparison blocks revealed that the major pest focus of insecticide treatment other than codling moth included leafroller, aphids, mites, campyloma, western tentiform leafminer, leaf hopper, and pear psylla. Next, several prior hypotheses about how mating disruption affects secondary pest control cost were developed for statistical testing based on site interviews and extensive secondary pest sampling data from CAMP and comparison blocks (Beers et al., 1998).

One prior hypothesis relating to central Washington apple orchards was that use of mating disruption slightly increases secondary pest control cost because additional insecticide expenditures are required to substitute for the forgone leafroller suppression that multiple OP cover sprays provide. The second prior hypothesis was that cost of insect control for other secondary pests in central Washington apple probably is not different for blocks in mating disruption. The key hypothesis expressed by pear experts we interviewed was that secondary pest effects likely decrease secondary pest control cost, primarily as the result of increased natural control of pear psylla, which allows reductions in expenditures for pear psylla control insecticides. Furthermore, reduced use of psylla control materials disruptive to predaceous mites capable of controlling twospotted spider mites may lead to reduced demand for mite control insecticides. It also was believed that savings on secondary insect control materials would be more pronounced in scenario 2 because horticultural oils applied in the foliar period have significant larval and ovum suppression capacity.

In order to test for differences in secondary pest control cost on MD and multiple OP blocks, the samples of spray records for each block type and CAMP site summarized in Table 13 were used.

Expenditures on insecticides targeted at the most important insect pests were summed and compared using two tailed t-tests for populations with unequal variance. The data also were used to estimate average expenditures on organophosphates on blocks not in mating disruption. Results summarized in Appendix: Statistical Analysis of Spray Records Tables A.1 – A.5 suggest that prior hypotheses regarding secondary pest materials expenditures largely were confirmed.

Table 13. Mating disruption and comparison block spray record data samples.

Site	1995	1996	1997	total
Howard Flats				
Conventional apples		n=8	n=7	n=15
MD apples	n=127	n=127		n=358
West Parker				
Conventional apples	n=4	n=8	n=8	n=20
MD apples	n=37	n=38	n=38	n=113
Medford				
Conventional pears	n=9	n=9	n=4	n=18
MD pears	n=8	n=7	n=4	n=15
Randall Island				
Conventional apples		n=6	n=6	n=12
MD apples		n=5	n=5	n=10

In northern California, savings on pear psylla and mite control material were observed but were small and not statistically significant at traditional confidence levels of 90 percent or more. In southern Oregon, savings on pear psylla and mite control material were large and statistically significant. Additionally, southern Oregon pear growers using a mating disruption and dormant oil strategy realized savings on materials targeted at aphids and leaf miner. At both Northern California and Southern Oregon sites, larger and statistically significantly different expenditures on horticultural oil were observed on mating disruption blocks.

In the high codling moth pressure areas of central Washington studied (Oroville and West Parker Heights), apple growers on mating disruption blocks spent more to control leafroller. At West Parker Heights, the expenditure difference was highly statistically significant, while at Oroville the difference was statistically significant at the 80 percent confidence level. In the low pressure area of central Washington (Howard Flats), expenditures on materials for leafroller control were nearly identical on mating disruption and multiple OP cover spray blocks. As Tables A.3 and A.4 indicate, small and nearly statistically significant savings in other categories of secondary pest control cost also were realized by central Washington apple growers using mating disruption. There is no obvious entomological reason for these differences. One possibility consistent with findings from past studies is that the differences are a result of the intensity of monitoring and use of threshold for these pest on CAMP blocks (Norton and Mullen, 1994).

In the partial budgets developed for this study, any secondary cost insect control costs are included for any category where differences were found to be statistically significant at the 90 percent level. The impact of including less statistically significant secondary pest cost is discussed in results and conclusion sections.

Assumed costs of insect materials application

Applying both chemical pesticides and pheromones entails costs: tractor and sprayer use costs, labor, and overhead. Because the use of inputs varies across the two strategies compared here, application costs also were expected to vary. Using mating disruption involves additional costs of installing mating disruption dispensers. Block specific information on the cost of dispenser application was unavailable. Interviews suggest that it requires about 2 hours per acre of labor effort on average. Assuming that the full cost to growers of labor (wages, Social Security, disability etc.) is $8/hour, this translates into a cost of $16/acre. This estimate is similar to Knight (1995), who surveyed Washington apple growers using mating disruption and found an average cost of $12.30/acre for application by hand and $17.30/acre for application with a telescoping pole.

Furthermore, tractor and spray rig use (labor, fuel, maintenance, and depreciation) are not likely to be the same on MD and OP blocks. Our prior hypothesis was that spray rigs and tractors used to pull them would see less use on blocks in mating disruption because fewer OP cover sprays are used on such blocks. However, interviews with growers and project personnel suggested that one less OP cover spray would not necessarily result in one less trip with spray equipment. Multiple materials included in a tank mix often are applied, so that some trips which would include an OP for codling moth are likely still to take place on mating disruption blocks.

In order to assess the extent of spray rig use reduction on mating disruption blocks, a t-test was used to compare average numbers of trips with tank mixes including insecticides for the samples of mating disruption and comparison blocks. The results presented in Table 14 show that statistically significant reductions in spray rig use were observed on mating disruption blocks, with the exception of the Medford blocks, which is not surprising, as mating disruption growers at this site use fewer OP sprays, but apply three foliar period horticultural oil sprays. The observed use reductions at the two apple sites roughly correspond to one less trip for two less OP cover sprays, which we assume in scenario 3 and 4 partial budget. At Randall Island, approximately one less spray rig trip was observed for three less OP cover sprays, which we assume in the scenario 1 partial budget.

Without detailed farm financial records, which were not available for this study, it is difficult to know what savings growers realize as the result of reduced spray rig use. The 1993 Washington State University enterprise budgets for apple production use a per acre and sprayer cost of $15.39, a value for orchard total tractor and spray rig depreciation, repairs, maintenance, fuel, and labor divided by acres and spray rig uses. Because slight reductions in spray rig use will not allow many growers to reduce significantly tractor and spray rig capacity or slow replacement, this average number probably overstates marginal savings. We use a more conservative savings estimate of $6.50 per acre and spray trip which represents only the cost of labor fuel and maintenance.

Table 14. Comparison of spray rig use on mating disruption and OP blocks.

	Scenario 1 based on Randall Island	Scenario 2 based on Medford	Scenario 3 based on Howard Flats	Scenario 4 based on West Parker Heights
Avg # of sprayer uses on MD blocks	6.64	6.10	7.52	7.57
Avg # of sprayer uses on OP blocks	5.64	6.03	6.26	5.53
p-value of t-test comparison of means	0.1	0.74	0.07	<0.01
Assumed sprayer use reduction	1 for every three fewer OP covers	None	1 for every two fewer OP covers	1 for every two fewer OP covers

Assumed Cost of Pest Monitoring

Typical codling moth and leafroller monitoring practices in apple and pear orchards involve setting traps at the beginning of the season, visiting the traps weekly to count moths, and periodically changing the pheromone lures in the traps. Interviews with growers, CAMP project managers, and crop pest management consultants suggested that a higher density of traps typically are used in orchards in mating disruption, and, consequently, the cost of monitoring on mating disruption likely is higher. A survey of 25 central Washington pest management consultants found densities of codling moth traps in mating disruption were typically one per 2.5 acres though one per 5 acres was not uncommon. In multiple OP cover spray blocks, densities varied from one trap for each 5 to 40 acres, with typical densities of one trap per 5 to 7 acres (Alway, 1998).

In this study, one codling moth trap per 2.5 acres and one leafroller trap per 5 acres on mating disruption blocks are assumed, and one half that density on multiple OP cover spray blocks. To estimate costs of monitoring, six consultants or managers responsible for monitoring on significant acreage were interviewed to ascertain labor, materials, and overhead requirements associated with monitoring. Table 15 presents resulting estimates of monitoring cost on MD and OP blocks.

Table 15. Cost of codling moth and leafroller monitoring.

	Mating Disruption Blocks			OP Cover Spray Blocks	
Item	**$/unit**	**Units**	**$/acre**	**Units**	**$/acre**
CM trap materials	$22.50	one trap / 2.5 acres	9.00	one trap / 2.5 acres	4.50
LR trap materials	$19	one trap / 5 acres	3.80	one trap / 5 acres	1.90
CM, LR trap monitoring	$8	0.66 hours/acre	5.35	0.44 hours/acre	3.52
check and change lures	$8	0.34 hours/acre	2.79	0.22 hours/acre	1.76
Remove traps	$8	0.11 hours/acre	0.93	0.08 hours/acre	0.64
Overhead item 1, ATV	$0.35	6 miles/acre	2.10	6 miles/acre	2.10
Overhead item 2, Pickup	$0.50	4 miles/acre	2.00	4 miles/acre	2.00
Total			25.97		16.42

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Table A.1. Results of testing for differences in expenditures on insecticides for secondary pest control, Scenario 1.

Scenario 1: Northern California pear—data: Randall Island CAMP Project mating disruption and comparison blocks, 1996–7.

Target insect	Leafroller	Pear psylla	Mites	Campyloma, Lygus, Stink bug	General ovum, Larva suppression
MD blocks					
Avg. expenditure	$0	$2.88	$52.17	$5.48	$80.32
Typical application		Asana 8 oz.	Agrimek 8 oz, Apollo 3 oz (1/4 of acre)	Diazinon 4 lb (1/3 of acre)	Dormant horticultural oil (20 gal)
OP blocks					
Avg. expenditure	$17.50	$3.25	$69.34	$3.73	$61.10
Typical application	Lorsban 2 qt (1/2 of acre)	Asana 8 oz	Agrimek 10 oz, Apollo (1/2 of acre)	Diazinon 4 lb (1/4 of acre)	Dormant horticultural oil (15 gal)
Test of equal expenditure					
p-value	<0.01	0.72	0.19	0.58	0.06

Table A.2. Results of testing for differences in expenditures on insecticides for secondary pest control, Scenario 2.

Scenario 2: Southern Oregon pear—Medford CAMP Project mating disruption and comparison blocks, 1995–7.

Target insect	Pear psylla	Mites	Leaf miner	Campyloma, Lygus, Stink bug	Aphids suppression	General ovum, larva
MD blocks						
Avg. expenditure	$20.00	$0	$0	$0	$4.47	$41.21
Typical application	Comply 8 oz	Agrimek 8 oz, Apollo 3 oz (1/4 of acre)			Provado 10 oz (1/5 of acre)	Dormant horticultural oil (14 gal)
OP blocks						
Avg. expenditure	$130.33	$111.94	$13.30	$1.11	$14.89	$18.17
Typical application	Asana 10 oz or Savey 8 oz + Mitac 3 lb + Comply 8 oz (1/3 of acre)	Agrimek Apollo 20 oz 3 oz (1/2 of acre)	Pounce 12 oz		Provado (1/4 of acre)	Dormant horticultural oil (6 gal)
Test of equal expenditure						
p-value	<0.01	<0.01	<0.10	0.13	0.21	<0.01

Table A.3. Results of testing for differences in expenditures on insecticides for secondary pest control, Scenario 3.

Scenario 3: Central Washington apple, low CM pressure—Data: Howard Flats CAMP Project mating disruption and comparison blocks, 1995–6.

Target insect	Leafroller	Campyloma, Lygus, Stink bug	Aphids
MD blocks			
Avg. expenditure	$0	$2.88	$5.48
Typical application	Lorsban 2 qt or Bt 1.5 lb (1/8 of acre)		
OP blocks			
Avg. expenditure	$25.99	$10.18	$1.3
Typical application	Lorsban 2 qt	Carzol 2 lb (1/4 of acre)	Provado on very limited acreage
Test of equal expenditure			
p-value	0.91	0.13	0.33

Table A.4. Results of testing for differences in expenditures on insecticides for secondary pest control, Scenario 4.

Scenario 4: Central Washington apple, high CM pressure—Data: West Parker Heights CAMP Project mating disruption and comparison blocks, 1995–7.

Target insect	Leafroller	Mites	Campyloma, Lygus, Stink bug	Aphids	General ovum, Larva suppression
MD blocks					
Avg. expenditure	$60.46	$0	$0	$15.33	$16.89
Typical application	Lorsban 2 qt + Bt 3 lb			Provado 4 oz	Dormant Horticultural Oil (5 gal)
OP blocks					
Avg. expenditure	$32.77	$11.63	$3.94	$25.18	$13.03
Typical application	Lorsban 2 qt	Agrimek 10 oz or Vendex 3 lb	Carvol 1 lb (1/5 of acre)	Provado 7 oz	Dormant Horticultural Oil (4 gal)
Test of equal expenditure					
p-value	<0.01	0.17	0.16	0.17	0.61

Table A5. Organophosphate use on non-mating disruption blocks.

	Scenario 1 based on Randall Island	Scenario 2 based on Medford	Scenario 3 based on Howard Flats	Scenario 4 based on West Parker Heights
Avg. per acre expenditure on organophosphates	$80.83	$66.77	$48.73	$108.54
Typical organophosphate use	Four 2.5 lb Guthion or four 2 qt Penncap	Three and one-half 2.5 lb Guthion	Two and one-half 2.5 lb Guthion	Five and one-half 2.5 lb Guthion

Integrated Management of Postharvest Diseases of Pear

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Integrated management of postharvest diseases of pear presents a unique challenge, in that postharvest problems usually appear while the product is under the management of different individuals than those who must effect the control measures. The grower's task is considered complete when bulk fruit is delivered to the packinghouse; and, traditionally, growers regard postharvest problems—such as decay—the responsibility of the packing house and cold storage operators. We have identified a diverse array of practices, each of which contributes to reduction of decay in stored pears, that focus primarily on grower cultural practices. Thus, a critical aspect of implementation of this program has been encouraging growers to understand the importance of their cultural practices on the postharvest quality of the fruit that they deliver to packing houses.

Our research began with independently assessing the effects of fruit maturity at harvest, management of fertilizer timing for low-nitrogen fruit, and calcium enrichment through orchard calcium chloride sprays, on postharvest decay susceptibility in pears. Pears harvested earlier, within the range of harvestable maturity, had less decay than those harvested later. Fruit from trees fertilized 3 to 6 weeks before harvest had less fertilizer nitrogen in the fruit than fruit from trees fertilized in spring, and correspondingly less decay. Calcium-enriched fruit from trees sprayed with calcium chloride had less decay than fruit from unsprayed trees. Each of these practices resulted in reduced decay, although the level of control provided by each was relatively small. When the techniques were combined, however, the control was additive, and the combined benefit more substantial (Sugar et al., 1994). The nitrogen available to fruit also may be reduced by lowering overall rates of nitrogen fertilization. Furthermore, fruit from trees with lower vigor and higher fruit density have been shown to contain less nitrogen than fruit from higher vigor trees or those cropped less densely (Sanchez et al., 1995; Sugar, 1998).

After harvest, most pears intended for long-term storage are treated with a fungicide, thiabendazole (TBZ), for prevention of decay. It is known that control is only partially effective, and that some species of decay fungi are not sensitive to TBZ. Furthermore, resistant strains of otherwise sensitive species exist. Several yeasts and bacteria have been identified that have potential for biological control of pear decay fungi, either alone or in combination with TBZ. The next step in the development of an integrated program for pear decay was to combine the cultural practices described above with postharvest treatment with a biocontrol agent. Although several yeast species have been found to be effective on pear (Sugar and Spotts, 1999), our studies focused on *Cryptococcus laurentii*. In addition to postharvest yeast treatment, the atmosphere of the storage room was included as an experimental variable. Controlled atmosphere (CA) storage uses reduced oxygen levels to suppress fruit respiration and prolong quality maintenance in stored fruit. We integrated the cultural practices described above with postharvest yeast, or yeast plus reduced rate of TBZ, and storage in air or CA (2 percent oxygen, < 0.5 percent carbon dioxide). Again, the effects of all treatment components were additive, and resulted in substantial decay reduction (Sugar et al., 1998). The most effective postharvest treatment was the yeast *C. laurentii* applied as a line spray in combination with one-tenth the label rate of TBZ. CA storage had only a slight benefit for decay reduction.

Subsequent work has focused on improvement of the storage component of the integrated program, evaluation of yeast treatments in the orchard prior to harvest, and integration of field yeast with calcium and fungicide sprays. Substantial reduction in decay has resulted from short-term storage of pears in high carbon dioxide atmospheres. Storage of pears for 2, 4, or 6 weeks in 12 or 20 percent carbon dioxide with 5 percent oxygen resulted in significant suppression of postharvest decay, especially that caused by the gray mold pathogen, *Botrytis cinerea*. Control improved with increasing content of CO_2 and with increasing duration of exposure. Pears may be sensitive to internal injury from high CO_2 storage, resulting in core browning and cavity formation in the flesh. We found that CO_2 injury was avoided in early-harvested pears. In later-harvested pears, injury increased with duration of exposure to high CO_2 and with delay in initiation of the high CO_2 atmosphere after harvest. CO_2 sensitivity was not visibly affected by calcium treatments in the orchard or by the storage atmosphere following high CO_2 treatment (CA vs. normal air). Several species of yeast and one bacterial biocontrol agent were combined with short-term high CO_2 storage. Biocontrol agents appeared to be compatible with the high CO_2 atmosphere, and their effect on decay was additive to that of the atmosphere (Benbow and Sugar, 1997).

Application of yeast biocontrol agents in the orchard 3 weeks prior to harvest showed that the yeasts *Cryptococcus laurentii*, *C. infirmo-miniatus*, and *Rhodotorula glutinis* survived well on the surfaces of pears despite late-summer heat and drought. The yeast *Candida oleophila* did not survive well. The objective of pre-harvest treatment is to position the biocontrol agents on the fruit surface where they are available to colonize small wounds which commonly occur during harvest and transport and are important sites of infection for postharvest decay (Spotts et al., 1998). We found that orchard yeast treatment did contribute to reduction in postharvest decay at wounds, especially with the yeast *C. infirmo-miniatus*. *C. laurentii*, *C. infirmo-miniatus*, and *R. glutinis* are not yet registered for use on pear.

Pear growers commonly apply the fungicide ziram during the growing season to pears intended for long-term storage. We found that populations of *C. infirmo-miniatus* appeared to be slightly reduced when applied 1 week after ziram treatment, as compared to application to pears without ziram, although population means were not statistically different. Populations of this yeast were enhanced by application to pears which had received calcium chloride treatments.

In addition to these practices which may affect postharvest decay, there are two important fundamental concepts for decay reduction: avoiding injury to fruit during harvest and transport, and sanitation in the orchard, packing house, and storage facility to reduce pathogen availability. With some exceptions, wounds are required for infections which lead to postharvest decay, and most wounds occur during fruit harvest and transport. Because of their shape and the nature of their stems, pears are especially susceptible to puncture wounding by stems of adjacent pears. Sanitation includes avoiding bringing soil into the packing house on the skids of harvest bins, forbidding picking up fallen fruit from the orchard floor, weed and ground cover maintenance to reduce orchard floor humidity, and regular cleaning of packing house floors and fruit-handling surfaces.

Development of an integrated program for pear decay control is a work in progress. However, a list of components known to be of value in reducing postharvest decay follows.

Orchard Practices

- Managing fertilizer timing and dosage for low-nitrogen fruit; avoiding excess tree vigor
- Enriching fruit calcium through summer calcium chloride sprays
- Harvesting early in the range of harvestable maturity
- Applying ziram during the growing season
- Applying appropriate biocontrol agents (when registered) prior to harvest
- Careful harvest and handling to avoid wounding
- Sanitation

Packing house / Cold Storage Practices

- Line spray treatment with a biocontrol agent + TBZ
- Short-term storage of early harvested fruit in high CO_2 atmospheres
- Sanitation

Such diversity of methods directed at postharvest decay should provide breadth of control (individual components may differentially affect different pathogen species) and stability (failure of one component should not affect the performance of other components). With participation of both growers and packing house operators, a program such as we are developing can offer substantial benefit to the pear industry.

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Apple Ermine Moth and Its Biological Control in Oregon

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Abstract

The apple ermine moth, *Yponomeuta malinellus* (Lepidoptera: Yponomeutidae), first was detected in 1985 in British Columbia. It quickly spread southward and reached Oregon in 1991. An apple orchard in northern Oregon was monitored during 1997 and 1998 to determine ermine moth flight phenology and parasitism in the field. The ermine moth population and damage were moderate in the orchard. The peak flight period in the field was between late June to July. The most dominant parasitoid in the field was *Ageniaspis fuscicollis* (Hymenoptera: Encyrtidae), a polyembryonic egg-larval parasitoid. Field parasitism increased tenfold from 1997 to 1998. The parasitoid brood size and sex ratio in the field were evaluated during both years. Ermine moth cocoon cluster size also was assessed in an attempt to determine density dependent parasitism. *Ageniaspis* was released in the apple orchard during 1992, 1994, and 1995 in a classical biological control program. My study shows that the parasitoid is well established and is increasingly making an impact on the ermine moth population.

Key words Biological control, polyembryonic parasitoid, parasitism, apple ermine moth, *Yponomeuta malinellus, Ageniaspis fuscicollis.*

Introduction

The apple ermine moth (AEM), *Yponomeuta malinellus* Zeller (Lepidoptera: Yponomeutidae), is an univoltine defoliator of apples in the temperate regions of the Palaearctic. AEM (Figure 1) caused widespread damage to apples in Europe before modern pesticides were available (Affolter and Carl, 1986).

AEM infestations in North America first were detected in 1985 in British Columbia and the northern border of Washington State. The insect quickly spread southward throughout Washington and reached Oregon in 1991 (Unruh et al., 1993). Now 15 counties in Oregon are infested (Figure 2). AEM females lay eggs in clusters (Figure 3) in late summer, and larvae, after hatching, stay in clusters to feed during spring (Figure 4). Heavy infestations can cause complete defoliation of apple trees (Figure 5). A parasitiod biological control agent was introduced in Oregon between 1992-95 to battle the destructive ermine moth.

This paper presents results of a study on AEM biology and the effectiveness of the biological control agent in Oregon. My specific objectives are (1) to determine the distribution of AEM cluster size in the field and seasonal phenology of AEM, especially adult flight periods; (2) to determine the effectiveness of the parasitoid by measuring percent parasitism, sex allocation, and parasitoid brood size in the field.

Materials and Methods

The study was conducted in an apple orchard on Sauvie Island in Multnomah County, OR during 1997 and 1998. The orchard was within historical Bybee Howell Park and has been managed organically for many years. A polyembryonic parasitoid, *Ageniaspis fuscicollis* (AF) (Hymenoptera: Encyrtidae), was introduced and released in the orchard during 1992-95.

Pheromone traps were used to monitor the AEM adult flight period in the orchard (Figure 6). Four to five traps were deployed and checked weekly from June to August. The number of adult moths caught in each trap was recorded during each check.

To assess the cluster size of AEM, the orchard was visited three to four times in spring. AEM cocoon clusters were collected randomly and taken to the laboratory to count the number of individuals in each cocoon cluster.

To evaluate parasitism by AF (Figure 7), field-collected AEM cocoons were examined carefully.

Parasitized AEM can be recognized easily by mummified larvae inside cocoons (Figure 8). The number of these parasitized AEM was counted. Percent parasitism was calculated by dividing the parasitized individuals by the total number of individuals contained in a cluster.

Individual mummies were put in glass shell vials before the parasitoid adults emerged. These vials were held under normal laboratory conditions (20 ± 3°C; 50± 10% RH). After emergence, the parasitoids in each vial were counted and sexed. From these, the parasitoid brood size and sex ratio were calculated. Brood size was defined as number of parasitoid offspring produced from one parasitized AEM larva, i.e., one brood. Sex ratio was the proportion of males in one brood.

Results

AEM adults can be seen in the field from June to August. The peak adult flight period varies from year to year, likely due to the weather. In 1997, the peak was between late June and early July; however, this peak was delayed for 2 to 3 weeks in 1998 (Figure 9).

AEM eggs were laid in a cluster. The larvae from the same egg cluster feed and pupate together as a group. The number of AEM contained in a cocoon cluster varied from 1 to 86. The majority of cocoon clusters contained 10 to 40 AEM individuals (mean = 25) (Figure 10).

Field parasitism varied between 2 years. A mean of 2.5 percent AEM were parasitized in 1997, whereas about 10 times more (23.2 percent) were parasitized in 1998 (Figure 11). Percent parasitism tends to decrease with the increase of AEM cluster size.

The polyembryonic parasitoid can produce 20 to 160 individuals in a single brood (Figure 8). Majority of the brood contained 60 to 120 offspring, with a mean of 81 progeny per brood (Figure 12).

The parasitoid allocated either male or female offspring within a host. In some cases, the parasitoid allocated mixed sexes in a single AEM host. When this happens, a bigger brood size tends to have a lower proportion of males (Figure 13).

Discussion

AEM is an exotic pest newly introduced in the Pacific Northwest. The pest poses a threat to fruit tree and nursery industries because of its direct damage and its significance in quarantine.

Oregon is the frontier of AEM's southward spread and distribution. Only part of the state is infested now. The peak adult flight period of AEM in Oregon is in June or July.

AEM lay eggs in clusters. Larvae also feed and pupate in clusters. Although a cocoon cluster can contain up to 86 individuals, an average cocoon cluster has only 25 AEM.

The polyembryonic parasitoid, *Ageniaspis fuscicollis,* has exerted some effect on AEM since the biocontrol agent was introduced and released in Oregon. Field parasitism can be as high as 100 percent on some AEM clusters, and average parasitism can reach 23 percent. However, variations between years are considerable. Percent parasitism generally decreases with cluster size of the AEM. These findings are consistent with the effect of *Ageniaspis fuscicollis* on AEM in Europe (Kuhlmann, 1994).

The parasitoid can produce a large brood (mean of 81 individuals per brood) in the field. The brood will be either all males or all females. However, sometimes a brood with both sexes occurs. In such cases, fewer males tend to be produced with bigger brood sizes. From a biological control standpoint, a bigger brood size means more parasitoid offspring available to parasitize target pests.

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Figure 1. AEM adult on an apple leaf.

Figure 2. History of AEMs southward and eastward, spread and its current distribution in Oregon.

Figure 3. Egg clusters laid by female AEM in late summer. Newly laid eggs are bright yellow, while week-old egg clusters become reddish in color. The egg clusters eventually will turn gray, mimicking bark colors.

Figure 4. A group of larvae feeding on apple foliage (top) and feeding damage on fruits (bottom).

Figure 5. A tree completely defoliated by the AEM (top) and close-up of defoliation damage (bottom).

Figure 8. Many individual parasitoids emerged from a mummified AEM larva. Cocoon cut open to reveal the mummy (photo courtesy of Ulli Kuhlmann).

Figure 6. A pherocon II type of trap baited with AEM pheromone placed in an apple tree.

Figure 7. A female *Ageniaspis fuscicollis* ovipositing into a cluster of AEM eggs (photo courtesy of Ulli Kuhlmann).

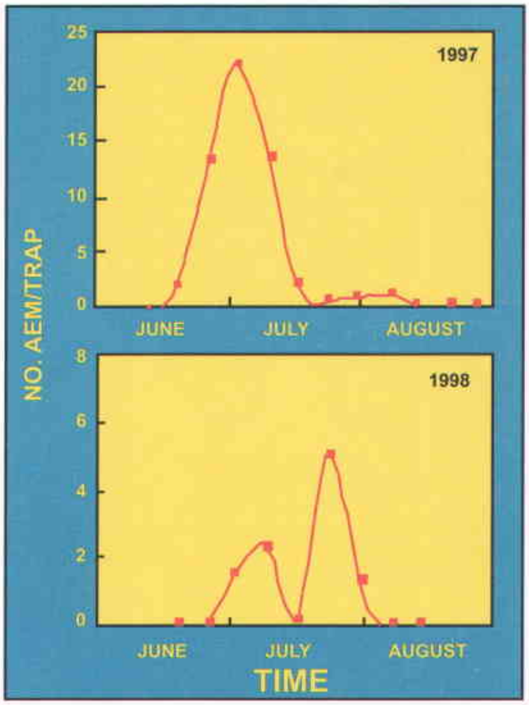

Figure 9. AEM adult flight period in the field as indicated by pheromone trap catches in 1997 and 1998.

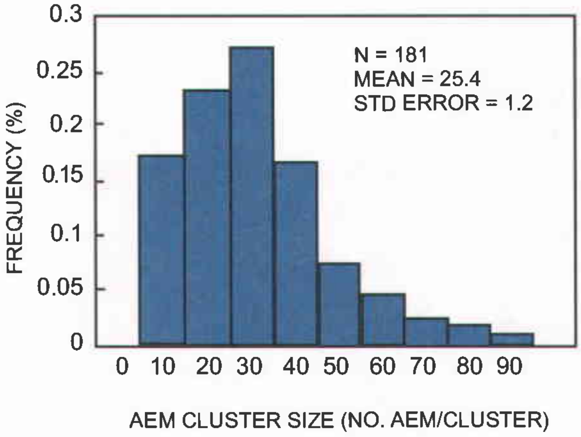

Figure 10. Frequency distribution of AEM cocoon cluster size in the field.

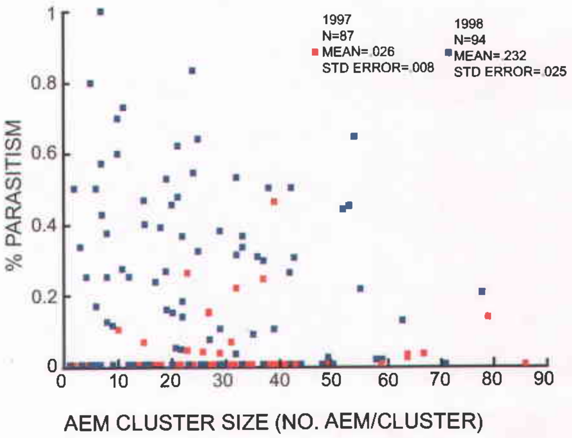

Figure 11. Parasitism of AEM as influenced by the cocoon cluster size.

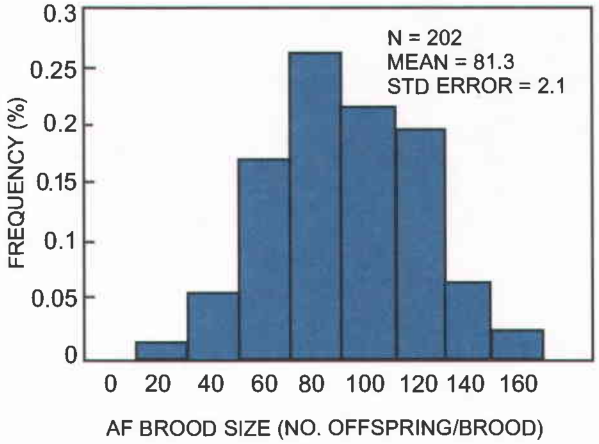

Figure 12. Frequency distribution of *Ageniaspis fuscicollis* brood size.

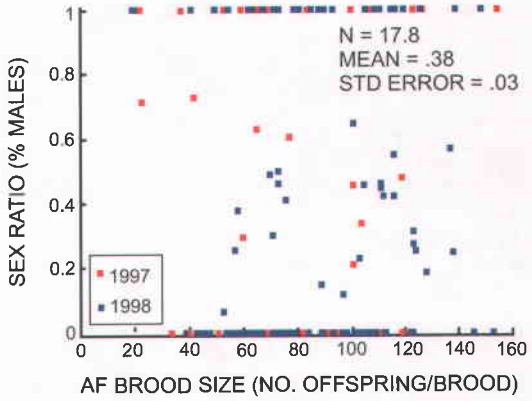

Figure 13. Sex ratio of *Ageniaspis fusciollis* as influenced by its brood size.

Summary of Results—
Codling Moth Areawide Management Program (CAMP)
Milton-Freewater, OR 1999

L. Lampson
Milton-Freewater CAMP Coordinator

Site Description

The 1999 CAMP project in Milton-Freewater, Oregon, involved 20 apple growers and included 1,044 acres. The main site encompassed 541 acres of apples just north and west of the city of Milton-Freewater. The main site was flat, included numerous stone fruit blocks within the CAMP boundaries, and was surrounded by more apples, stone fruit, and grapes. Residential suburban homes also were scattered throughout the main site. A second site, the grower-monitored site, was just southwest of the main site and encompssed 503 acres of fairly contiguous apple orchards owned by four growers. In the second site, the topography was hilly, with apple orchards mostly surrounded by wheat, grapes, and alfalfa, and no residences within the CAMP area. Apple orchards were adjacent to the grower-monitored site on portions of the north and west boundaries of the CAMP area.

Mating Disruption Implementation

Growers were responsible for the purchase and application of pheromone dispensers. Monitoring traps and lures, monitoring of these traps, and coordination of the entire program was provided through a 1-year, $40,000 USDA CAMP grant. The majority of the growers used Isomate C+ at 200 dispensers/a, but approximately 15 percent of the growers applied 400 dispensers/a because of heavy codling moth pressure. On 15 percent of the acreage in the main site, NoMate® and CheckMate® were used. Most growers preferred the "hoop" method for applying the Isomate C+ pheromones.

With the exception of one grower, all growers applied an initial cover spray for first generation timed at 250 codling moth degree-days. Additional covers were applied if justified by trap counts or if growers became overly concerned. In the main site, the average number of cover sprays applied for codling moth in 1998 was 4.2 and ranged from 1 to 6 cover sprays; in 1999, the average number of covers was 2.5 and ranged from 1 to 5 covers, a 40 percent reduction in cover sprays. In the grower-monitored site, the average number of cover sprays applied in 1998 was 3.5, ranging from 1 to 4 covers; and in 1999, it was 1.8, ranging from 1 to 3 covers, a 50 percent reduction.

Damage Assessments

In the main site, approximately 250 fruit were examined per acre (135,000 total fruit) for the bin sample damage assessments conducted by the CAMP coordinator. In samples taken at harvest time, 4 of the 20 growers suffered codling moth damage in excess of 1 percent on some borders. In two of the border damage cases, bin piles were the likely outside-infestation source. In the other two cases, the blocks had histories of high codling moth pressure and were small isolated blocks (1 to 2 acres). There were two backyard trees that were treated regularly by one of the growers but still sustained unacceptably high levels of damage.

Growers with acreage both in the CAMP program and outside generally reported codling moth damage to be higher outside the CAMP area. Within the CAMP program, only one grower sustained unacceptable damage levels overall. This grower sustained 1.4 percent damage overall, but had failed to apply codling moth covers when needed in the last 5 weeks prior to harvest. The grower across the road, who also was exposed to the same bin pile problems but regularly applied border sprays as indicated by trap counts, suffered very low damage.

In the grower-monitored sites, no regular fruit damage assessments were made, but thinners and pickers looked for damage, and one of the packing houses provided cull analyses. No codling moth sting damage was reported in any of the grower-monitored sites.

Obliquebanded leafroller damage varied between 0.5 to 12.5 percent in fruit damage assessments.

This damage was similar to that found outside the CAMP borders. Lacanobia cutworm damage was largely absent this year. Stink bug damage exceeded 30 percent on some borders.

Main Problems Encountered During Season

1. At the main site, the major problem encountered was recurring infestation from homeowners' "backyard trees" or neglected, unsprayed commercial orchards near the CAMP apple orchards. A total of 27 such locations were identified during the course of the season, and about 25 percent of the sites were cleaned up by removing offending trees; another 25 percent are expected to be removed after harvest. Various ways of dealing with the remaining problem sites are being addressed by the local horticulture society.
2. A second problem encountered was that the pheromone dispensers ran out of pheromone by mid-September, a couple of weeks earlier than preferred. Only one grower was required to apply an additional cover spray as a result of the pheromone depletion. However, as the 1999 season had a very cool summer, growers can expect that pheromones could be depleted by mid-August in a very hot year. In heavy pressure areas, this could present a problem requiring a final cover spray close to harvest for Red and Golden Delicious apples. Improvements in pheromone technology should solve this problem eventually, but for the next couple of years, insufficient pheromone could plague growers in Milton-Freewater, which has the longest growing season of fruit-growing regions in the Pacific Northwest.
3. Some growers had trouble adjusting to spraying based on trap counts and found it difficult to trust the trap counts. Two of the big growers chose to apply a full second cover, and one of these growers also applied a full third cover. In both cases, no fruit damage had been found, trap counts were elevated only in some traps, and border sprays probably would have been sufficient. For the first year of the program, these growers chose to take a very conservative approach, figuring the extra treatments would improve chances for success with mating disruption next year.
4. Wherever bin piles were stacked, codling moth counts were elevated and required additional border sprays. In two cases, significant damage was experienced along the borders closest to the bin piles.
5. Close to harvest, a couple of growers decided not to apply a cover spray, even though their trap counts were high. In both cases, trap counts were quite high, and significant codling moth damage resulted.
6. In the grower-monitored site, there were problems with growers failing to monitor for the full season. Growers failed to turn in regular trap counts, or did not turn them in at all in one case. Communication between the CAMP coordinator and growers in these sites was not adequate.

Projected Future for CAMP in Milton-Freewater

All of the larger growers plan to put all their acreage into codling moth mating disruption next year, which would double the current CAMP acreage. Some of the small CAMP growers may opt out of using mating disruption next year, but it is projected that a greatly expanded CAMP program will continue in 2000, funded entirely by the growers. Fears of losing organophosphates through resistance and/or Food Quality Protection Act regulations help fuel the change.

Implementing an IPM Program for Obliquebanded Leafroller on Sweet Cherry

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Prior to 1989, few Mid-Columbia growers were familiar with obliquebanded leafroller (OBLR) on cherries or any other crop for that matter. Although native to the Northwest, OBLR was not previously recognized as a pest of cherries. However, during harvest of that year, a single grower in The Dalles began to find small worms infesting his harvested cherries. When the Japanese inspector found these same worms on cherries bound for Japan, the packing house took the fruit to the landfill and refused to accept the remaining unharvested fruit.

In order to control the insect population prior to the next harvest, multiple post-harvest applications of parathion were applied in late summer 1989 without regard to the beneficial insect complex. It was this one incident, more than any other, that highlighted the need, in the mind of many growers, to implement an Integrated Fruit Production (IFP) program on cherries in The Dalles. The clear motivation was the fact that a massive insect population had developed in an orchard without grower or fieldman recognition of the situation.

For this reason, growers and university personnel began working on an IFP program. One of the primary rationales for interest in this IFP program was the realization that all orchard professionals, growers, fieldmen, and university personnel needed to become more aware of conditions within area orchards. In addition, an IFP program would help growers make better, more informed decisions.

However, before an IFP program could be implemented successfully, a solid Integrated Pest Management (IPM) program needed to be developed for all major cherry pests. Unfortunately, in 1989 we had a new cherry pest without knowledge of its identity.

Therefore, the first step in the process of developing an IPM program for this pest was to properly identify the insect. This procedure, which included rearing the larvae to the adult stage, took OSU entomologists 2 to 3 weeks. Once it was determined that the insect in question was obliquebanded leafroller, the next step was to determine the population density of the insect throughout the district. We knew we had a high insect population in at least one block, but we assumed that there was a population of leafroller in other blocks that was non-detectable at the packing shed. That summer we immediately set out traps and found the largest population in, and immediately adjacent to, the orchard in question. In subsequent years, as we continued to monitor the population distribution, we found the population moving away from this center, eventually impacting the entire district. In fact, by 1995 OBLR populations had increased to the point where one packing house refused delivery of fruit from 19 of 40 growers.

It took several years to determine the best IPM control measures for OBLR. In this period, trials were conducted and observations made that eventually provided us with the information we needed to develop an effective IPM program.

Since we knew little about OBLR, we tried to relate its apple biology to cherries. This helped, but it was far from adequate. We needed to learn such things as timing of over-wintering emergence, scouting techniques, and threshold levels for both adults and larvae. It was critical that we had an understanding of these factors, so growers would know whether or not they had a problem developing within their orchards. Eventually, we were able to develop a relatively reliable process based on scouting to determine population densities of larvae within an orchard.

Since the conventional control program prior to our work included such chemicals as Penncap M and pyrethroids, it was obvious that we needed to develop a soft, alternative method for controlling OBLR. Initially, we pursued two separate paths of control, *Bacillus thuringiensis* (B.t.) and mating disruption. Initially, OSU scientists did not believe that Bt would be an effective control measure. However, we soon found that OBLR was controlled very effectively with applications of Bt, especially when larvae were small. Bt's are now the backbone of our spring and summer OBLR control program. Results of mating disruption work, however, did not prove as promising. Dispenser formulations, while effective, proved both expensive and labor intensive, while sprayable pheromone formulations had unacceptably poor results.

After several years of research, we finally had an effective IPM control program for OBLR. This program consisted of an early delayed-dormant spray followed by orchard monitoring to determine population densities and the need for B.t. applications.

Introducing this program to growers was an ongoing effort that continues to this day. Scouting techniques and threshold management were new concepts that took time for growers to learn and adopt. These concepts were taught over a period of several years in workshops and tours, newsletters, and a published brochure.

The success of this research and educational effort is evidenced by successive years of problem free harvest. In the year prior to program implementation, the harvest of 48 percent of the growers from one packing house was terminated due to high OBLR populations. Since implementation, there have been no further harvest disruptions.

Two Steps Forward: One Step Back

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Grower
Hood River, OR

I am a fruit grower in Hood River, and also the owner of rented farms in Washington and Yamhill counties. I also manage grower based organizations which commit funds for supplementing research. Those include most tree fruits in the Northwest. The amount of grower commitment to supplement research is about $4 million annually.

From 1962 through 1990, I managed a large pear, apple, and cherry orchard north of White Salmon, Washington, near Hood River, OR. We tried many experiments, including attempting to spray less or not at all on given plots in that isolated, higher elevation location. In each instance, after 1 to 4 years, the plots "crashed" either from codling moth, mites, pear psylla, or other pests.

In 1989, we established a high density pear orchard on the east side of the lower Hood River Valley at about 700 feet elevation. The orchard was not sprayed during its first two growing seasons. After that, only very minimal sprays were used, principally in the pre-bloom period. In 1992-94, one general pesticide, Morestan, was used at the pink stage. In 1995-1997, Comply was applied in the delayed-dormant stage for pear psylla. No other pesticides were applied, except experimental use of Confirm and Bt's for leafroller in 1997 and 1998.

Compared with neighboring orchards and the other two orchards we operate in the Hood Valley, costs of material and application were reduced greatly. Furthermore, we had no residues and no problems scheduling worker re-entry around irrigation issues. And, we had minimal fruit injury through 1994. A small experimental planting of apples experienced codling moth damage starting in 1994. In 1996, we began using pheromone mating confusion ties for codling moth in the pears, which has been successful.

USDA-ARS scientists from Yakima (Wapato) have been doing survey work in the orchard since 1996. They make periodic evaluations of pests and predators. We also initiated a rotational mowing system in 1996. In 1997 and 1998, that was more specific, with three principal regimes: mowing every 10 days, mowing once a month, and no mowing. ARS scientists are learning the role of ground cover, pests, and predators. Compared to conventional orchards, this orchard has a much better complex of predators and beneficials. Ground traps catch several times more carabid beetles compared with conventional orchards. Those sections of the orchard with less mowing generally have more natural control agents. Leaving the orchard floor unmowed has not caused the build-up of any damaging pests. There may be some benefits of a ground cover of broadleaf material as opposed to grasses.

Pear psylla, the most significant pest of pears, is not an issue. There is an early season population, but psylla is virtually impossible to find post-bloom. Codling moth is controlled with pheromones. Aphids are controlled. Twospotted and red spider mites are controlled, but each of the past 5 years have had populations near the damage stage.

We have some problems. Leafroller has caused some damage each of the past 3 years. Stink bugs have caused commercial damage. The 1998 crop was severely damaged by pear rust mite, which caused some of the fruit to be unmarketable. Scab was a serious problem on one variety in 1998 and caused heavy economic loss.

Table 1 illustrates our chemical inputs versus a commercial orchard with a full program.Table 2 lists dollar loss from fruit damage where chemicals could have prevented such loss.

While we are committed to a low spray operation, we find that we are now, after 10 years, about even in benefit gained from not purchasing chemicals versus having high quality fruit.

The situation is not altogether comfortable, and well illustrates why growers in general spray to ensure control of pests and high quality fruit. In our situation, as long as the fruit damage is negligible, can be sorted easily at the packing house, and does not damage market quality, we can take some risks and save costs of chemicals. However, when a more serious fruit damage situation occurs, we incur high losses, and the packing operation is very unhappy as is the sales entity.

We have been told that the packing operation does not want further deliveries of fruit with considerable down grading from pest damage.

Table 1. Pesticide inputs and fruit values.

Pesticide Costs Per Acre:

		1994	1995	1996	1997	1998
COMMERCIAL orchard	$	474	414	438	448	459
ING experimental orchard	$	101	127	142	154	128
Savings: per acre	$	373	287	296	294	331
Add'l savings-application	$	47	50	53	57	60
Total savings per acre	$	420	337	349	351	391

Table 2. Fruit values compared with commercial orchards.

	1994	1995	1996	1997	1998
BOSC—2 acres	same	same	same	same	same
Accumulated savings	$3,696				
Accumulated savings	$1,848 per acre				
STARKCRIMSON—2 acres:					
Fruit value loss	$0	-644	-1386	-816	-10,697
Accumulated loss	$0	224	1049	465	10,304
Total Accum. loss	$12,046				
Accumulated loss	$6,023 per acre				
RED ANJOU—2 acres:					
Fruit value loss	$ 0	-104	-216	-140	-410
Accumulated loss	$870				
Accumulated savings	$1413 per acre				

Overall 6 acres:
Accumulated savings——$11,088
Accumulated loss of fruit values $12,914
Accumulated combined loss——$1,826

NOTES:

1. Prior to the 1998 season, when rust mite decimated the Starkcrimson crop and damaged Red Anjous, the project was very much on the plus side.

2. Our packing house has indicated it does not want to handle fruit with substantial commercial damage from pests.

3. There has been no evident enhancement of fruit quality caused by chemical non-usage.

Nematode Management With and Without Nematicides: Opportunities and Challenges

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Significance of Nematode Management for Potato Production in the Pacific Northwest

The Pacific Northwest (PNW) is the largest potato production area in the U.S. In 1997, Idaho, Oregon, and Washington produced 54 percent by weight and 47 percent by value ($1 billion) of all potatoes in the U.S., making potatoes one of the most important cash crops in the region. While a large number of pests impact production, the most important soil borne diseases of potato in the Pacific Northwest are Columbia (*Meloidogyne chitwoodi*) and northern (*M. hapla*) root-knot nematodes; corky ringspot disease (CRS) caused by tobacco rattle virus, which is vectored by stubby-root nematodes (*Paratrichodorus allius*); and early dying, a wilting disease caused by the fungus *Verticillium dahliae*. Root-lesion nematodes are also common, but the predominant species in the PNW potato fields (*Pratylenchus neglectus*) does not appear to reduce yield significantly or interact strongly with *V. dahliae* as reported for *P. penetrans*. In many fields, the pathogen of greatest concern is Columbia root-knot nematode (CRN). While field infestation with *V. dahliae* can reduce yield significantly and thus, crop value, quality reduction due to tuber infection by CRN can cause complete crop loss due to rejection. Crop rejection from tuber infection by northern root-knot nematodes or CRS also may occur, but the acreage affected is not as large as for CRN.

A large portion of the potato crop produced in the PNW must be protected from root-knot nematodes (primarily CRN) each year. Much of the acreage (25-50 percent, personal communication, Hafez, Ingham, and Santo) already is infested with nematodes, and uninfested ground may become infested at any time through the transfer of nematodes in soil on machinery, in canal water, or in infected seed, etc. Root-knot nematodes infect the tubers to produce quality defects such as galls on the tuber surface and brown spots inside the tuber. The brown spots are caused when female nematodes lay eggs in the tuber and surround them with a protective gelatinous matrix that initiates a host response by the tuber. Once an infected tuber is peeled, the spots may be visible over the entire tuber surface, and found as deep as the vascular ring, a quarter inch into the tuber. In addition, because Food and Drug Administration has zero tolerance for animal matter in processed potato products, such as french fries, tubers with even a low level of infection must be rejected. If 5 to 15 percent of the tubers in a field are infected, the entire crop from that field may be substantially devalued or rejected. At an estimated value of $3,100/a (based on average yield and market price for the Columbia Basin in 1997), the rejection of a potato crop grown on an average 130-acre irrigated circle means the loss of $406,000 to the grower. The total economic loss is considerably greater because of the value-added dollars associated with potatoes between grower and consumer.

One biological property of CRN that makes this nematode so hard to control is its ability for rapid population increase. In a long growing season, CRN populations may complete four to six generations. Estimating a conservative 10-fold increase per generation would mean that a population at the detection limit of 1/250 g soil at planting would increase to several thousand/250 g soil by the end of the growing season (Figure 1). Tuber infection and crop rejection are a certainty under these conditions. Furthermore, since CRN can continue to develop at storage temperatures, infected tubers put into storage without symptoms may express enough symptoms after storage to warrant rejection.

Management with Nematicides on Food Quality Protection Act Priority List of Pesticides

Because crop rejection may occur even with low population levels at planting, growers must try to keep populations of CRN as low as possible. At present, soil fumigation is the primary management option for nematodes, CRS, and early dying in potato. Soil fumigants containing metham sodium (Vapam, Sectagon, etc.) are the only materials that control early dying and allow growers to maintain high yields in fields infested with *V. dahliae*. Thus, these products have been the fumigants of choice for the areas where early dying is a chronic problem. Usual application methods include injection through an irrigation system (water-run), generally a center pivot, in ∫ to 1 acre-inch of water. Water-run metham sodium alone cannot control *M. chitwoodi*, however (Table 1, 1994 and 1996). Chemigation rarely applies material deeper than 12-18 in into the soil, and surveys have documented that CRN can be found as deep as 6 feet. Migration studies also have confirmed that CRN can migrate vertically as far as 4 feet during the growing season to cause significant tuber infection (Mojtahedi et al., 1991). Thus, the nematodes which survive below the depth of metham sodium penetration can migrate upward into the fumigation zone once the material has dissipated.

Supplemental nematode control can be achieved with nonfumigant organophosphate (ethoprop-Mocap) and/or carbamate (aldicarb-Temik, oxamyl-Vydate) nematicides applied before, at, or after planting. These nematicides remain active in the soil longer than metham sodium, which is phytotoxic and must dissipate before planting. Thus, nonfumigants can intercept nematodes migrating upward and reduce populations capable of infecting tubers. Ethoprop may be effective for control of *M. hapla* (Ingham et al., 1991) or CRN in short season potato, fields with low population pressure, or when augmenting a green manure cover crop, but it cannot control CRN in long season potato crops (Table 1, 1996). Aldicarb suppressed infection under low population pressure in 1996, but did not control higher CRN pressure in 1997. Multiple post emergent applications of oxamyl through chemigation successfully suppressed CRN infection in 1996 and 1997 (Table 1).

The fumigant 1,3-dicloropropene (1,3-D, Telone II) has very good nematicidal activity injected to an 18-inch depth. The material diffuses upward and downward, thus penetrating a larger and deeper soil volume than water-run metham sodium. Nematode control with 1,3-D is generally far superior to that achieved by metham sodium (Table 1). However, 1,3-D does not control *V. dahliae* or potato early dying, so metham sodium, as well as1,3-D, needs to be used in fields with both pathogens. This is an expensive proposition for the grower, since the use of full labeled rates (55 gpa metham sodium and 20 gpa 1,3-D) at a cost of $374/acre plus ground preparation costs was necessary for the grower to have the option of requesting compensation from fumigant manufacturers if fumigation did not control the targeted problem. Several years of research by Oregon State University and Washington State University researchers documented that adequate control of early dying and CRN could be obtained when reduced rates of metham sodium (40 gpa) and 1,3-D (15 gpa) were used in combination (see Table 1, 1994 and 1997). This led to the development of special joint labels by the manufacturers of the two materials that permitted reduced rates of each fumigant when used together. This reduced rate label now saves growers nearly $100/a. Current research also is attempting to increase the effectiveness of metham sodium as a nematicide by injecting it into soil in a manner similar to 1,3-D. However, since metham sodium does not diffuse through soil as well as 1,3-D, special shanks were developed to inject the material at several points within the soil profile during application. Initial studies found that control of CRN by shanking-in metham sodium was nearly equal to that by 1,3-D in 1994 but did not control CRN in 1997 (Table 1).

During the early part of the growing season, CRN juveniles leave the soil to penetrate roots from the germinating seed piece so that, by several weeks after planting, no juveniles can be recovered from the soil (Figure 1). Once the nematodes complete their development and begin to lay eggs, the number of second generation juveniles in the soil increases very rapidly. These nematodes may infect potato roots, producing subsequent generations, or infect developing tubers. Developmental models have determined that the beginning of the second generation occurs at approximately 900-1,100 degree days (base 5C), with additional generations at 500-600 degree day intervals (Pinkerton et al., 1991). Research on timing chemigation applications of the systemic nematicide oxamyl with degree-day accumulation has documented additional suppression in plots fumigated with water-run (1996) or shanked-in (1997) metham sodium (Table 1).

Nematodes can be controlled successfully with these chemical nematicides, but a substantial amount of these products is required for successful potato production in areas with long growing seasons and high disease pressure. For example, the amount of active ingredient used on the 30,000 acres of potato grown in the Columbia Basin of Oregon during 1997 included 2.2 million lb of metham sodium; 927,000 lb of 1,3 D; 60,000 lb of aldicarb; and 6,050 lb of ethoprop (McMorran and Reed, personal communication). Only a small amount of oxamyl was used. However, all nematicides currently used in the potato industry are high on the FQPA priority list of pesticides for tolerance review by Environmental Protection Agency. Without these chemicals, potato production in many fields throughout the PNW would not be possible and the loss, or more restricted use, of these materials could result in abandoned potato production fields.

Promising Alternatives to Management with Nematicides

Plant Resistance

Breeding potato for resistance to nematodes may be the optimal alternative for management of these pests, but the availability of germplasm with those properties is still many years in the future. A more unique approach to using plant resistance is being studied at Oregon State University. In most cropping systems, resistance is sought in the cash crop which is damaged by the nematode. The approach in Oregon's program has been to screen for nematode resistance in rotation crops, even though these crops may not be damaged directly by nematodes. Resistance found in these crops can reduce nematode populations to nondamaging levels before potato is planted, reducing the need for nematode resistance in potato itself. The influence of different crops on nematode reproduction determines whether they are categorized as good, poor, or nonhosts. Host status is quantified by a reproductive index, R, where R = final population/initial population. R values greater than 1 indicate a good host, those between 0.1 and 1.0 describe poor hosts, and those below 0.1 define non-hosts. Table 2 provides an example of how different crops may effect the reproductive capacity of CRN. Field corn is used extensively in rotation with potato and is an excellent host for CRN. Less popular rotation crops reduce CRN populations substantially. Greenhouse studies determined that wheat cv Stephens is often a better host (R = 24.9) than field corn cv Pioneer 3578 (R = 3.93) (Cardwell and Ingham, 1997). However, since wheat is harvested much earlier in the season, populations of CRN generally do not reach the same magnitude as under field corn, where there is time for more generations to develop.

Green Manure Cover Crops

Several plants may suppress different nematodes if grown as a cover crop and incorporated into the soil while vegetation is still green (Mojtahedi et al., 1993). This strategy can be used independently or as a part of a crop rotation scheme and is increasing in popularity as a nematode management strategy. Incorporation of green plant material from most crops increases biological activity in soil that may reduce nematode populations, but some plant materials are more actively antagonistic. Use of sudangrass and rapeseed has been particularly encouraging in suppression of *M. chitwoodi* in Oregon and Washington. Sudangrass leaves contain dhurrin that breaks down under microbial decomposition to hydrogen cyanide, which is nematicidal. Rapeseed leaves, stems, and roots contain glucosinolates which are not nematicidal but are broken down by the enzyme myrosinase to nematicidal isothiocyanates, similar to the active ingredient in metham sodium. Green manure cover crops are most effective if they are also a nonhost for the target nematode species (see Table 2). Table 3 illustrates how incorporation of sudangrass and rapeseed green manure cover crops can effect populations of CRN. While a fall incorporated sudangrass green manure cover crop suppressed populations at planting to low levels, the suppression did not persist throughout the season. In contrast, a spring incorporated rapeseed green manure cover crop suppressed population growth until October (Ingham, 1993).

Cover Crops plus Nonfumigant Nematicides

While green manure cover crops can reduce nematode populations substantially, they may not be sufficient in fields with very high initial densities or in areas with long growing seasons where damage occurs at very low preplant densities. In these instances, augmenting the nematode suppression with a nonfumigant nematicide may provide such control, since there is a slim margin between what is acceptable and what is rejected. Table 3 demonstrates that the combination of the nematicide ethoprop and green manure cover crops was more effective than either strategy alone. While infection in the sudangrass-ethoprop treatment would not have been acceptable in this study, it appeared that nematode suppression did not break down until after August, and tubers harvested earlier than October may have had very low levels of infection. This may also have been true for the rapeseed only plots.

Since nonfumigants are much less expensive than typical rates of soil fumigants presently used in the region, combining such materials with cover crops potentially could reduce the cost of nematode control to the grower. This strategy has potential environmental advantages because nonfumigants are less disruptive to soil health and potential biocontrol organisms than fumigants, and require fewer pounds of active ingredient.

Crop Rotation

In many cropping systems, crop rotation using crops that do not support reproduction can be very effective for nematode management. In the PNW, however, most crops currently grown in rotation with potato (e.g., wheat, corn, and alfalfa, if race 2 [alfalfa race] is present) are good to excellent hosts and tend to increase populations of *M. chitwoodi* between potato crops. Research has demonstrated that populations of *M. chitwoodi* can be suppressed with selected cropping sequences that utilize poor or nonhost crops, determined by resistance screening described above, and green manure cover crops. Occasionally, nonfumigant nematicides were used to augment suppression by cover crops. A 3-year crop rotation study using these strategies was completed in 1993. Percent culls in a conventional potato-wheat-wheat-potato rotation averaged 91 percent, but in several of the experimental rotation sequences, percent culls averaged less than 5 percent. In some cases, including nematicides of any kind was unnecessary for adequate control (Table 4). Furthermore, nematode populations after a full growing season of potato remained very low in plots where nonhost crops had been grown (Ingham, 1994). In another study, populations of *M. chitwoodi* averaging nearly 1,000/250 g soil after a 1993 potato crop, were reduced to 9/250 g soil with a field corn-wheat-rapeseed green manure sequence; and to 2/250 g soil with a field corn-supersweet corn-rapeseed green manure sequence (Ingham 1997b).

The Future Opportunities and Challenges of Nematode Management in Potato

Management with Nematicides

The history of nematode management has gone through a cycle of developing an arsenal of effective chemical nematicides followed by a decline in available products, as uses are cancelled due to health and environmental concerns. Few registered nematicides remain, so it is essential to maintain all existing nematicide registrations. However, the current challenge to nematicides within the FQPA may be the most critical yet. All current nematicides are B2 carcinogens (1,3-D), organophosphates (ethoprop, fenamiphos), or carbamates (aldicarb, oxamyl) which are the chemistries at the top of the FQPA list of products to review. Metham sodium is the only product discussed that is not based on these chemistries, but it is inadequate for nematode control alone and is also high on the FQPA review list for other reasons. In addition to providing support for these products during FQPA review, growers need to emphasize exemplary product stewardship to prevent threats to the existing labels. Recent history with aldicarb in 1989 and 1,3-D in California in 1990 demonstrated that a single incident can result in the immediate loss of necessary labeled uses. Growers and consumers need to be educated better on the threat nematodes pose to world food production and the extreme difficulty in maintaining yield and quality in many crops without these products. While research ultimately may develop replacement chemistries for those used to make current nematicides, existing products are needed to maintain economic stability in farming systems until new products become available.

Strategies that need to be developed during this transition include procedures that could reduce the frequency and rate of nematicide use while maintaining effective control. This would reduce both the threat to health and environment as well as each product's contribution to the "risk cup" concept of the FQPA. Linking improved application technology and nematode life cycle biology may improve performance, permit reduced rates, lower costs to the grower, and improve profit margins. New nematicides that are more effective and/or less toxic need to be developed under a realistic risk-benefit umbrella. Perhaps the best new nematicide being tested is more effective and less toxic than comparable materials, but since its production is based on organophosphate chemistry, it may be considered "guilty by association" and its approval by EPA may be problematic. Other new developmental materials are less toxic than currently registered nematicides, but they are not nearly as effective and may require new application techniques for adequate control. Because of the high cost of development and lack of new discoveries, very few synthetic materials are on the immediate horizon, and even products with promise will be dropped if the profit projections for the manufacturer are insufficient.

Management without Nematicides

Ultimate control of nematodes may come from nematode resistant cultivars developed with conventional breeding or bioengineering, but the timeframe is long and uncertain, and resistance may not persist. In the interim, continued screening of potential rotation crops for poor-nonhost status will increase growers' options for nematode resistant plants that can suppress nematode population growth during rotations. Effectiveness of green manure cover crops also may be improved as research develops more nematode suppressive plants, determines the mechanisms for that suppression, and begins breeding cultivars with greater suppressive properties. Strategic planning of crop rotation sequences which are poor or non-hosts, and green manure cover crops, can reduce nematode populations dramatically. Reducing nematode pressure at time of planting can permit control with reduced rates or less toxic nematicides and perhaps eliminate the need for nematicides, if the program is maintained through several rotations. Reducing "biocidal" chemical inputs and increasing the inputs of biologically active organic matter to soil stimulates growth of the soil biological community. This may encourage the development of endemic biological control which could reduce further the need for nematicides.

Significant challenges remain to the development of a new paradigm in nematode management. In order to develop new cropping sequences that will control nematodes, the alternative poor-nonhost crops also must be economically attractive to growers and processors. Increasing grower options may require developing new markets and/or new uses for these crops in order to create demand and maintain grower profitability. Even if markets are developed, an additional challenge will be faced in convincing growers to grow new and unfamiliar crops. The situation for potato production in the Columbia Basin is complicated further because much of the land planted to potatoes is leased by the grower for that one season. Coordination of nematode management in land that is leased to different growers may be a substantial challenge, so growers need to be educated on the importance of field history to the lessee. Finally, in developing management systems to control CRN, caution must be observed not to create management systems for root-knot nematodes that might exacerbate other problems such as CRS or early dying.

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Table 1. Effects of various fumigant and nonfumigant nematicide treatments on the percentage of tubers culled by Columbia root-knot nematode (*Meloidogyne chitwoodi*) infection. Umatilla Co., OR.

Treatment	Percentage of culled tubers[1]
1994[3]	
Untreated check	90 a[2]
Water-run metham sodium at 55 gpa	30 b
1,3-D at 20 gpa	2 a
Water-run metham sodium at 55 gpa plus 1,3-D at 20 gpa	1 a
Water-run metham sodium at 40 gpa plus 1,3-D at 15 gpa	0 a
1996[4]	
Untreated check	38 a
Water-run metham sodium at 50 gpa	22 ab
Shanked-in metham sodium at 50 gpa	1 bc
Water-run metham sodium at 50 gpa plus 1,3-D at 20 gpa	0 c
Water-run metham sodium plus ethoprop at 12 lb a.i./a	34 a
Water-run metham sodium plus aldicarb at 3 lb a.i./a	2 bc
Water-run metham sodium plus oxamyl at 2 lb a.i./a (3x)	3 bc
1997[5]	
Untreated check	64 a
Shanked in metham sodium at 40 gpa	49 ab
Shanked in metham sodium at 40 gpa plus aldicarb at 3 lb a.i./a	55 a
Shanked in metham sodium at 40 gpa plus Vydate at 2 lb a.i./a (5x)	2 b
Shanked in metham sodium at 40 gpa plus 1,3-D at 15 gpa	4 b

[1] Tubers with six or more infection sites

[2] Means within the same year that are followed by the same letter are not significantly different (P £ 0.05).

[3] Data from Ingham 1995

[4] Data from Ingham 1997a

[5] Data from Ingham 1998

Table 2. Effects of different summer crops on reproduction by Columbia root-knot nematode (*Meloidogyne chitwoodi*) grown in field microplots for five months. Hermiston, OR. (Data from Ingham, 1991).

Crop	Reproductive Index (R)
Potato cv Russet Burbank	68.00
Cereal corn cv Pioneer 3283W	22.66
Field corn cv Pioneer 3732	12.38
Popcorn cv Robust 30-77	0.77
Sudangrass cv Trudan 8	0.04
Rapeseed cv Cascade	0.03
Pepper cv California Wonder	0.01
Squash cv Butternut	0.00
Muskmelon cv Superstar hybrid	0.00
Lima Bean cv Henderson Bush	0.00

Table 3. Effect of green manure cover crops on populations of Columbia root-knot nematodes (*Meloidogyne chitwoodi*) (No./250 g soil) and potato tuber infection. (Data from Ingham, 1993).

Treatment	April	August	October	Percent Culled Tubers[1]
Wheat-Stubble[3]	186 b[2]	3,246 b	4,289 c	82 b
Wheat-Stubble-Ethoprop[4]	75 b	2,158 b	2,781 c	81 b
Wheat-Sudangrass[5]	2 a	145 a	951 bc76 b	
Wheat-Sudangrass-Ethoprop	2 a	8 a	186 ab	28 a
Wheat-Rapeseed[6]	0 a	6 a	28 a	13 a
Wheat-Rapeseed-Ethoprop	0 a	6 a	15 a	2 a

[1] Tubers with six or more infection sites.

[2] Means within the same column that are followed by the same letter are not significantly different (P £ 0.05).

[3] Spring wheat cv Pennewawa as stubble cover over winter before potato crop.

[4] 10 G formulation at 12 lb a.i./a broadcast applied and incorporated before planting potato.

[5] cv Trudan 8 planted after wheat harvest and incorporated on October 30 after first killing frost.

[6] cv Jupiter planted after wheat harvest and incorporated on March 3, 48 days before planting.

Table 4. Effects of cropping sequences on Columbia root-knot nematode (*Meloidogyne chitwoodi*) infection of potato tubers. Hermiston, OR. (Data from Ingham, 1994).

Cropping Sequence				Percent
1990	1991	1992	1993	Culls[1]
Potato	Wheat[3]	Wheat[4]	Potato[5]	91 d[2]
Potato	Wheat	Wheat	Ethoprop[6]-Potato	45 c
Potato	Wheat	Wheat + Sudan[7]	Potato	48 c
Potato	Wheat	Wheat + Sudan	Ethoprop-Potato	47 c
Potato	Lima Bean[8] + ?	Supersweet Corn[9] + ?	Potato	19 b

Addition of rapeseed after lima bean and/or sudangrass after supersweet corn added no benefit

Potato	Lima Bean + Rape[10]	Supersweet Corn + Rapeseed	Potato	<1 a
Potato	Lima Bean + Rape	Supersweet Corn + Sudan	Ethoprop-Potato	<2 a
Potato	Popcorn[11]	Lima Bean + ?	Potato	2 a

Insufficient infection remained to determine if addition of rapeseed green manure and/or ethoprop before potato provided further benefit. Of the 30 plots, 21 had 0 percent culls, and only 3 plots had more than 4 percent that may have been due to grassy weeds during the lima bean crop in those plots.

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[1] Tubers with six or more infection sites.
[2] Means within the same column that are followed by the same letter are not significantly different (P £ 0.05).
[3] cv Pennewawa spring wheat in 1991
[4] cv Stephens winter wheat in 1992
[5] cv Russet Burbank
[6] 10G formulation preplant incorporated at 12 lb a.i./a
[7] cv Trudan 8 incorporated as green manure in the fall
[8] cv Maffi 15
[9] cv Crisp and sweet 710
[10] cv Humus incorporated as a green manure in the spring
[11] cv Robust 85-210

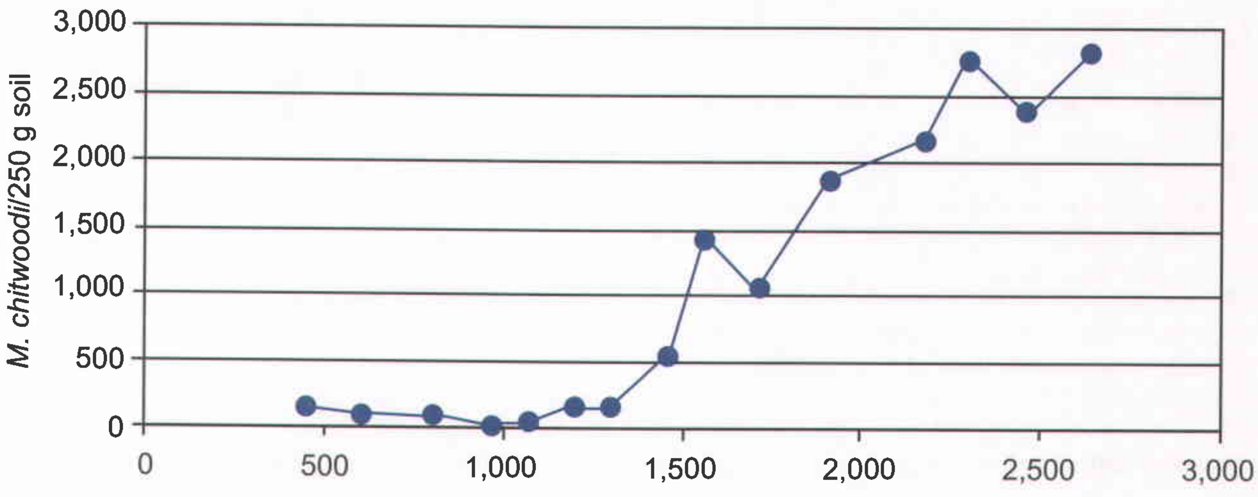

Figure 1. Degree Days (base 5°C) after Planting

Even Modest Labor Requirements Pose a Significant Constraint on the Adoption of IPM Monitoring and Scouting Procedures

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Abstract

Recent surveys of Willamette Valley sweet corn, snap bean, and cole crop growers indicate that the majority of the field scouting to determine insect pest populations trends is conducted by agricultural chemical field representatives. Narrow profit margins have resulted in the consolidation of agricultural chemical suppliers. Agricultural professionals are more time-limited than in the past. There is significant resistance to the introduction of field scouting procedures that require extra time in the field. In the absence of accurate field scouting, the concepts of pest population monitoring and the use of action thresholds in spray decisions have not been widely accepted in the Willamette Valley processed vegetable industry. Application decisions based on plant phenology are fast and easy to manage. Insecticide applications are relatively cheap. The risk of crop damage and the damage to a field representative's reputation when a needed pesticide application is not made are very high. The OSU snap bean mold scouting program requires three 15-minute field-scouting visits. The program that was developed in the early 1980s and refined in the mid-1990s has not been adopted. Regional monitoring of key lepidopteran pests, however, has been well received. The results are broadcast to the field representative community. Population trends inform field representatives as to when they need to intensify their site-specific field scouting procedures. A new technique using kairomone-laced yellow sticky traps to monitor the western spotted cucumber beetle (*Diabrotica undecimpunctata*) activity at critical periods during corn and bean crop development will be introduced in 1999. The technique may be adopted, because it will save time by replacing the traditional sweep methods currently used by the industry.

Introduction

With a farm gate value of 27 million dollars, snap beans for processing are one of the most important vegetable crops in Oregon (Miles, 1995). In a recent survey of Oregon vegetable growers, the majority of the respondents (91.2 percent) listed mold as the most difficult problem to control in snap beans (McGrath and Kogan, 1996, unpublished). Ninety-eight percent of the respondents indicated that they used a single fungicide, Ronilan by BASF, to control mold during the 1995 and 1996 growing seasons. The Ronilan label has been uncertain (McGrath, 1989); registration for its use on snap beans in 1997 followed 13 years of FIFRA Section 18 emergency registrations.

Diabrotica beetles, referred to as "12-spot beetles," damage developing snap beans, causing them to be deformed. Many snap bean plantings routinely are sprayed with insecticide at "pin bean" stage regardless of *Diabrotica* pressure. The majority of plantings are sprayed with the broad-spectrum insecticide carbaryl. This effectively strips the cropping system of natural enemies and routinely causes losses of important insect pollinators. With the recent decline in feral hives of *Apis melifera* due to infestation by tracheal mites, the loss of feral or native insect pollinators needs to be reduced. Recently developed synthetic analogs of cucurbitins (Diabrotica beetle feeding attractants and feeding stimulants) provide new opportunities for more biological 12-spot beetle control strategies. These included insecticide/feeding attractant mixtures and enhanced effectiveness of feeding attractant-laced yellow sticky traps for monitoring 12-spot beetle populations.

Agricultural field representatives use sweep nets to estimate Diabrotica populations before making spray recommendations. The efforts are relatively haphazard. The action threshold is very low. Ironically, the commitment to monitoring of 12-spot beetles with a sweep net interferes with the goal of introducing mold scouting procedures. Field representatives were unwilling to make separate scouting trips across bean plantings for *Diabrotica* and mold. If the two scouting procedures could be combined, total effort could be reduced and the value of the scouting procedures increased.

No one involved with the processed vegetable industry in Oregon is comfortable with the insecure situation related to uncertain pesticide registrations. The industry is not static. From 1987-96 the industry has evaluated alternative fungicides, fungicide combinations, and spray timing to improve efficiency (Johnson and Powelson, 1981; Powelson, 1980; Powelson and McGrath, 1988). During 1990 and 1991, the industry evaluated the effect of alternative planting arrangements on mold in snap beans (McGrath et al., 1991). During 1993 and 1994, the industry evaluated the impact of spray timing (Hunter and Lugwig, 1988; Lugwig, 1990) and irrigation cut-off timing on mold development (Abawi and Hunter, 1979; McGrath, 1996).

In the early 1980s, OSU published an IPM manual for snap beans. The risk assessment procedures for determining risk of gray mold, white mold, and 12-spot beetle damage were based on several years of research that studied the correlation between observable parameters in bean production and resulting bean quality. The mold scouting procedures have not been adopted. They required a significant scouting effort (six to seven visits per planting) and they led to a single high risk decision to spray or not to spray. Sweeping bean fields for 12-spot beetle using a 2 beetle per 20 sweep action threshold is now a common practice in the Willamette Valley.

During the 1995 and 1996 growing seasons, the processing industry began re-testing bean mold scouting procedures (McGrath, 1997) using elements drawn from three scouting modes (Petzoldt and Koplinka-Loehr, 1990; Stewart and Stevenson, 1990; and Winzierl et al., 1983). The elements were assembled into an integrated scouting program with two goals: (1) reduce scouting effort, and (2) increase the value of information produced by the scouting effort (see Appendix 1). Applied research on integrated control of white mold (*Sclerotinia sclerotiorum),* gray mold (*Botrytis cinerea*), and the western spotted cucumber beetle *(Diabrotica undecimpunctata)* has been conducted on complimentary scales, relatively small scale single component research trials, and field scale simple paired comparisons.

Starting in 1996, a second project was initiated to monitor disease and insect population trends in the Willamette Valley. The monitoring and reporting program called "Vegnet" includes a regional insect trapping program and a communication network. Moth and insect trap counts as well as disease and pest observations by Ag professionals are summarized and broadcast by FAX and email (see Appendix 2). The Vegnet reports are designed to stimulate site specific field scouting during higher risk periods.

Snap Bean Field Scouting Program

The OSU Snap Bean Scouting Program was modified. Limiting scouting to the three highest risk areas of the fields reduced scouting effort per field. Field visits leading to a spray decision were limited to three. At the first spray decision (early bloom) the following questions were addressed: Is this a high risk planting? Does it need to be sprayed *twice?* Is this a low risk planting? Can the grower use a *more economical one-spray program?* Should the grower apply one *spray at early bloom* or *wait* a couple of days so that the single spray covers the higher risk period at canopy closure? Will this planting be responsive to *irrigation cut-off timing*? Should the grower dry the field out prior to nightfall? Is this planting at *risk* of heat-stress induced *split set*? Should the grower ignore mold and cool the field down with irrigation? Is this planting at risk of Diabrotica *beetle* to the developing beans? At the second spray decision (pre-harvest spray interval) the following questions were addressed: Should the grower apply a second spray? Is mold infection spreading rapidly through the field? Should the grower plan, if possible, to harvest early?

According to the scouting program, the majority of the bean plantings (69 percent) in the Willamette Valley are at low risk of mold development. Approximately 18 percent of the low risk plantings are sprayed twice with Ronilan. The grower could skip the second spray, according to the scouting program. In many cases, single spray programs are initiated too early in low risk plantings. The residual effectiveness of the fungicide (Ronilan) is 7 to 10 days. Mold inducing conditions occurred after canopy closure when the Ronilan was no longer an effective protectant. Twelve percent of the plantings were identified as highly responsive to irrigation cut-off timing when not at high risk of heat-induced split set.

A kairomonal attractant was made by mixing equal parts by weight of the chemicals beta-ionone, benzyl alcohol, and indole (Metcalf et al., 1987).

The attractant was applied to cotton dental wicks on yellow tangle-foot coated cups. The kairomonal traps were monitored weekly beginning near first bloom and continuing through harvest. The number of 12-spot beetles caught with the traps was compared to the number caught with sweep net samples.

Regional Pest Monitoring

The intensity of insect pest infestations of vegetable crops in the Willamette Valley varies from year to year. In 1995 and 1998, there were high levels of cabbage loopers (*Trichoplusia ni*) in broccoli and cauliflower. From 1996-1998, cabbage looper and bertha armyworm egg laying flights had two distinct egg laying periods per growing season using a degree day model available on the OSU Integrated Plant Protection Center Web Page (http://www.ippc.orst.edu). The second egg laying period of the looper was successfully forecast. Early warnings were broadcast. Field scouting intensified. Preemptive actions were taken in some fields. The processors had advance notice that a higher level of worms would be coming into the processing plants on harvested broccoli.

In 1996, bertha armyworm (*Mamestra configurata*) infestations were sudden and dramatic. The bertha armyworm lays it eggs in tight clusters. After the worms hatch, they spread out in the field. The egg laying event is very difficult to detect with traditional field scouting techniques. Pheromone trapping provided an early warning system in 1997. In 1997, there was a remarkable level of black cutworm (*Agrotis ipsilon*) activity. It was detected and announced via Vegnet. Significant acerages of sweet corn were saved.

During the winters of 1997 and 1998, a series of regional workshops and focus sessions (McGrath et al., 1992) were held with participating growers and ag professionals. The results of applied research were shared and discussed. Participants were asked to evaluate the research and make suggestions on how to improve the scouting program. Ag professionals received training in the identification of the adult and juvenile stages of key vegetable pests, the use of pheromone traps, and the use of computer based degree-day calculators.

Discussion

The OSU snap bean scouting program as a whole has not been accepted by ag professionals in the Willamette Valley. Field representatives continue to use sweep nets to monitor Diabrotica beetle activity. One independent pest consultant is using the symphylan pre-plant soil sampling technique for corn and beans. To the author's knowledge, no one is using the mold scouting technique. The Vegnet disease and insect pest monitoring program is popular and growing. In 1996, the FAX newsletter was sent to 75 terminals. In 1998, it was sent to 150. The expansion was due to specific requests by ag professionals and growers that they receive the newsletter.

The use of kairomone-laced sticky traps as a replacement is still in the developmental stage. Ag professionals greet the new technology with enthusiasm because it may save them time. The "action threshold" of 2 beetles per 20 sweeps is very low and might be considered a "detection threshold." The sticky trap monitoring device may be just as accurate as the sweep net for detection.

Although beans are a very important crop to Oregon vegetable growers, snap beans are still a relatively low margin processing crop. Each fungicide spray costs about $25 per acre. It costs less than $10 per acre to add an insecticide to the tank. The market for processed snap beans is very competitive. Moldy beans and beans deformed by bug bites are difficult to separate from healthy beans in the processing plant. Poor quality beans from one grower reduce the value of the entire pack. So, growers cannot afford to under-spray plantings that are at high risk of mold or insect damage. Today in the Willamette Valley, scouting procedures for mold and 12-spot beetle are still haphazard, and they do not take full advantage of available research results, but they get the job done. The field scouting procedures introduced by OSU that have been adopted, save the ag professional time and labor. The labor-intensive procedures that increase accuracy have not been adopted.

Future efforts at increasing the accuracy of spray decisions for control of mold in beans probably will be based on regional weather-based forecasting models (Stewart and Stevenson, 1990). Labor intensive mold scouting procedures probably will be limited to validation of regional forecasts. In developing IPM procedures, the work and decision-making environment of the practitioner must be fully understood and appreciated. IPM research and educational activities should be conducted in concert. In a truly collaborative research project, researchers, Extension personnel, and ag professionals might work more closely together to improve the development and the rate of adoption of monitoring and scouting procedures.

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Appendix 1: Snap Bean Scouting Form

OSU Extension White Mold Scouting Project 1999

Oregon Processed Vegetable Commission, OSU Integrated Plant Protection Center Cooperating.

For more information contact: Dan McGrath (503) 931-8307; FAX (503) 585-4940 daniel.mcgrath@orst.edu

Grower ________________________________ **Planting Date** ______________

Field ________________________________

CROP HISTORY: Beans or other susceptible crops grown in the past 5 yrs: One time - score = 2 ; Two times - score = 4; Three or more times - score = 6; 1998__________1997__________1996_________1995_________1994__________		**Score**
HISTORY OF MOLD PROBLEMS: Yes_____ No_____	White mold has been a problem one or more times in past bean plantings - score = 10	
VARIETY	Romanos - score = 2, Others - score = 0	
BASE SCORE	Crop History Score plus Mold History Score plus Variety Score equals base score	Total:

Drawing of Field plus Surroundings - Indicate Three Scouting Areas Within Field

Surrounding area

Field

OSU Extension White Mold Scouting Project 1999

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MOISTURE CONDITIONS:

Cool, wet weather at early bloom - score = 3; Afternoon or evening irrigation during bloom - score = 1; More than 2 irrigations between 1st and 2nd spray decision - score = 3

Date:	**Date:**	**Date:**	**Date:**
Score:	Score:	Score:	Score:

CANOPY CLOSURE:

More than 18 inches "open" between rows - score = 0; 13 to 18 inches "open" between rows - score = 3
8 to 12 inches "open" between rows - score = 4 ; Less than 8 inches "open" between rows - score = 5

Inches:___________	Inches:___________	Inches:___________	Inches:___________
Score:___________	Score:___________	Score:___________	Score:___________

PRE-BLOOM GRAY MOLD POINT SOURCE COUNTS:

Prior to 1st bloom, the highest daily average count of visibly sporulating gray mold "point source" per 15 row feet: 1 to 2 - score = 2; 2 to 10 - score = 5; More than 10 - score = 8

Count:_____	Count:_____	Count:_____	Count:_____	Count:_____
Score:______	Score:______	Score:______	Score:______	Score:______

APOTHECIA COUNTS (Grand Total):

Score Apothecia counts using the total number or grand total found on all sample dates.
None - score = 0; 0 to 2 apothecia - score = 3; 3 to 5 apothecia - score = 6, More than 6 - score = 10

Count:___________	Count:___________	Count:___________	Count:___________
Score:___________	Score:___________	Score:___________	Score:___________

TOTAL SCORES

Add Base Score	Add Base Score	Add Base Score	Add Base Score
Total	**Total**	**Total**	**Total**

OSU Extension White Mold Scouting Project 1999

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Date	Recommendation
	High Risk - Stop scouting. A two-spray fungicide program may be justified. Apply first spray at early bloom. Apply second spray 7 to 10 days later.
	Moderate Risk - Continue scouting. A one- or two-spray fungicide program should be used depending on weather forcast and other risk factors. Apply first spray at early bloom. A second spray decision will be required prior to the fungicide preharvest application interval.
	Low Risk - Continue scouting. A one-spray fungicide program may be adequate. A single spray may be delayed until when scouting indicates increased risk (due to weather forecast, apothecia discovery, etc.) or just prior to canopy closure. A second spray decision will be required prior to the preharvest application interval.
	12-Spot Beetle. This field has exceeded the action threshold for 12- spot beetle. Apply first insecticide at early bloom. Continue to monitor populations. Sweep net count/date: #_____/date ______ ; #_____/date _____; #_____/date_____ Sticky trap counts: #_____/date ______ ; #_____/date _____; #_____/date_____ **Irrigation Cut-off Timing -** This field will be highly responsive to
	irrigation cut-off timing. During bloom period, begin irrigation early in the morning. Cut off irrigation in the early afternoon, in time for the foliage to dry out prior to nightfall. **Second Spray Recommendation:**

July 28, 1999

Appendix 2

VegNet

VegNet is a pest and disease monitoring and reporting network serving the Willamette Valley Processed Vegetable Industry. VegNet is sponsored by the OSU Integrated Plant Protection Center and the Processed Vegetable Commission.
Contact: Dan McGrath, OSU (503) 931-8307

Corn earworm:

We still are catching only a few moths in our traps around the valley. Pressure appears normal to low so far. The most conservative programs for controlling corn earworm involve an insecticide application at first silk, regardless of the moth trap counts. Followup sprays are applied at 5- to 7-day intervals if continuing moth trap counts reach 5-10 moths per trap day. Willamette Valley trap counts are below this threshold so far.

Cabbage aphid flights:

Winged cabbage aphid catches remain very high. Check carefully for aphid infestations increasing in the late broccoli and early cauliflower plantings. Aphids colonies are moving up into broccoli buds as the buds begin to elongate.

In one field, 7 days after an early spray, winged cabbage aphids re-infested the planting at levels comparable to the pre-spray counts. Be sure to check broccoli plantings about a week after applying aphicides to be certain that the spray program got the job done.

Diamondback moth:

Moth counts and egg laying by diamondback moth continue to be intense in the central and northern parts of the Willamette valley and in the Stayton area. At current temperatures, the diamondbacks progress from egg to pupa in about 2 weeks. Look for "window panes" on the broccoli or cauliflower leaves. If you find larger 3rd and 4th instar diamondback larvae (about 1/3 inch long) and the broccoli buds are elongating, you should be concerned. Once pupae are formed in the buds, it is very difficult to clean them up prior to harvest.

Cabbage loopers and Bertha armyworm:

Moth counts continue to be low compared to the 1998 growing season. If you scout fields, you will probably find limited numbers of looper eggs, looper worms, and a few armyworm strikes. Pressure is normal.

12-spot beetles and mold:

Numbers continue to be high in most parts of the Valley. Continue to sweep bean plantings prior to first bloom. Morning sweep counts generally will be higher than afternoon counts in the same field. Bright afternoon light drives the beetles lower in the bean canopy, where they are missed by the sweep net. Two to 3 beetles per 20 sweeps is the "gray zone" right at the action threshold. Mold pressure in beans has been low so far.

Weather during the planting period:

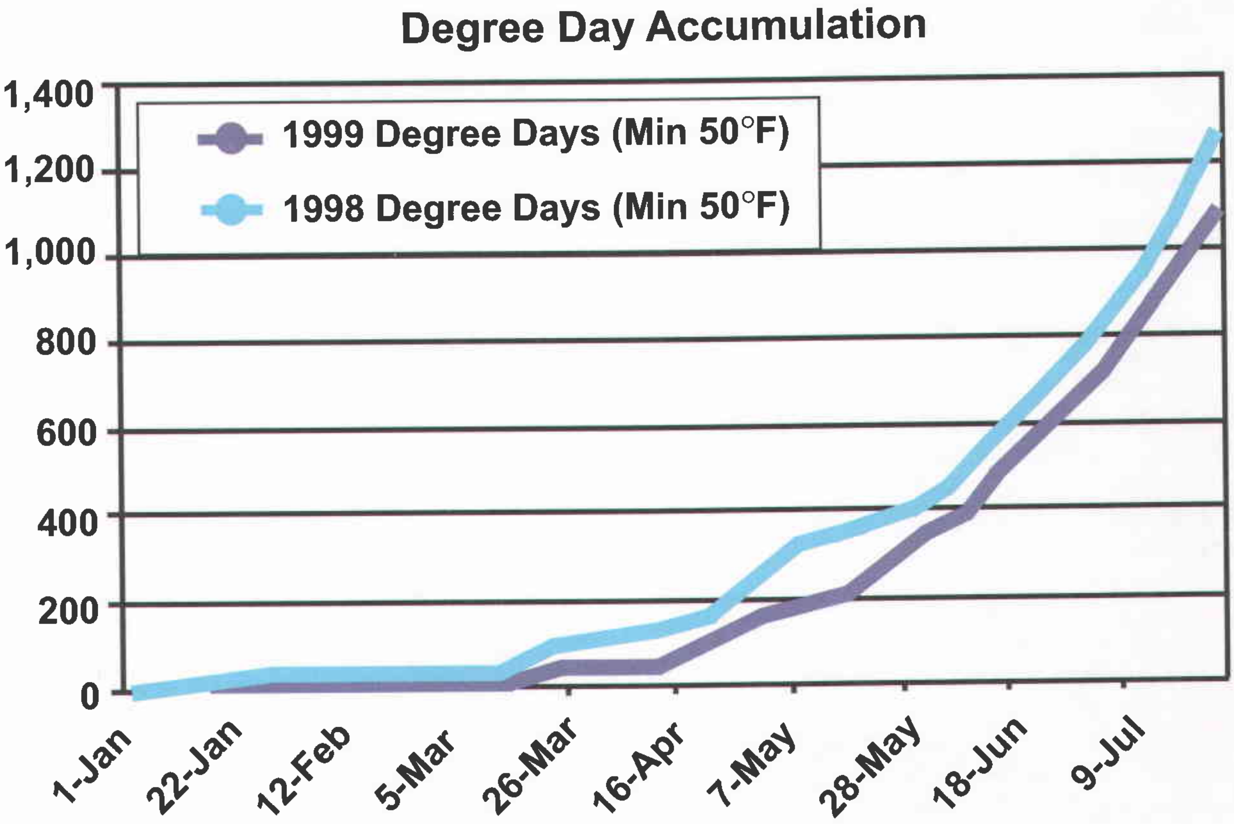
Some of the problems that we see in our corn and bean plantings at this time are associated with the weather conditions at planting (see attached).

Degree day accumulation based on 50°F minimums are behind about 8 days compared to the 1998 growing season (see attached).

Dan McGrath, Salem, Oregon

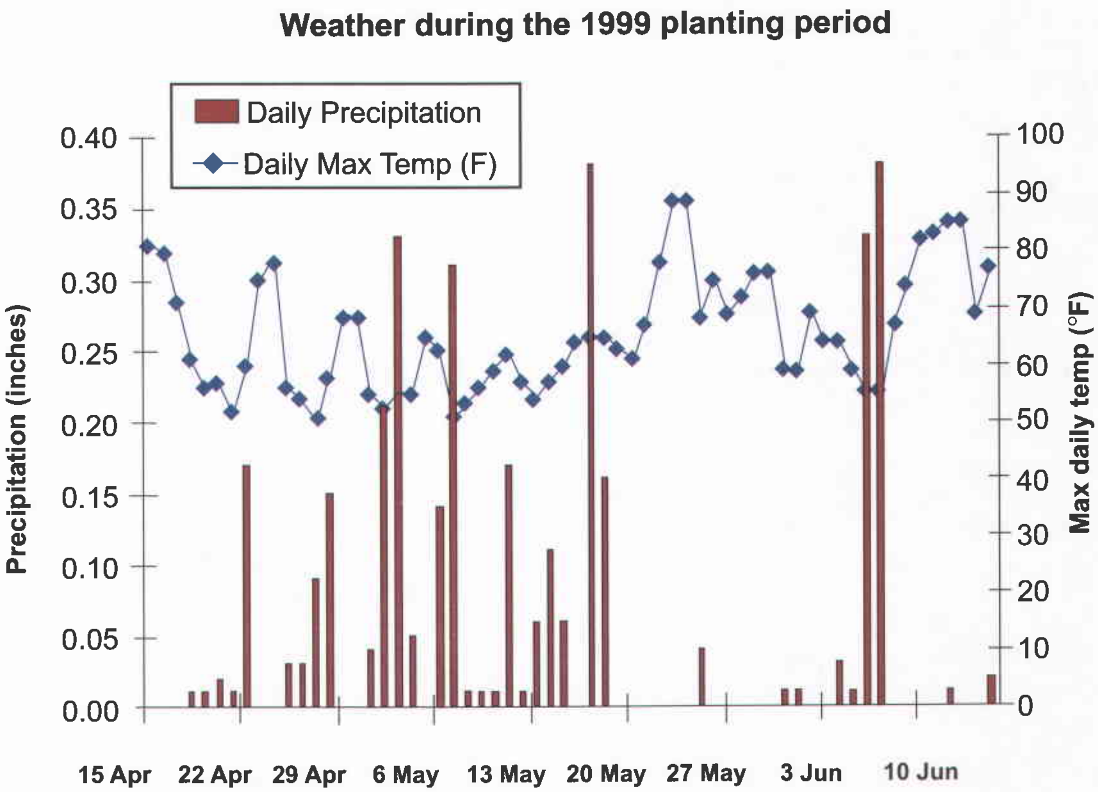
Vegnet August 1, 1999

OSU Extension Service
Dan McGrath, Salem Oregon



Vegnet August 1, 1999

OSU Extension Service
Dan McGrath, Salem Oregon



Evaluation of Technological Methods to Monitor the Spread of the Gorse Spider Mite in Oregon

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Abstract

Gorse (*Ulex europaeus* L.) is a spiny, prolific, and highly invasive exotic plant from Europe. Along Oregon's southern coast, gorse has displaced native flora in state parks and thousands of acres of otherwise productive pastureland, causing annual losses of $2 million per year. Biological control was implemented because gorse is resistant to most conventional weed control practices. In 1994, the gorse spider mite (*Tetranychus lintearius* Dufor) was released as an additional biological control agent against gorse to complement the effects of the gorse seed weevil. We evaluated techniques to monitor gorse infestations and mite colonization using spatial technologies: remote sensing, geographic information systems, and global positioning systems. Nine 1-hectare plots were set up at two study areas. Mites were released in three randomly selected plots, one from each of the following site classifications: (1) gorse-dominated and wind protected, (2) gorse-dominated and windy, and (3) mixed-dominated plant communities. Standard color film proved best for recording spider mite damage and gorse infestations, when in bloom. Spider mite colonies, surface area averaging 0.6 m^2, were detectable 14 weeks after release. Dispersion of mite colonies was greatest at the gorse-dominated and windy sites. After 16 months, the surface area of all associated windy colonies was 49.12 m^2 and the greatest distance traveled was 39.6 m.

Introduction

Gorse is a member of the family Leguminosae and is a well-adapted, early pioneer plant species (Hoshovsky, 1986). It was introduced into Oregon before 1894. Gorse invades and dominates disturbed sites and early successional plant communities (Hoshovsky, 1986). Its leaves are minimized into slender, extremely sharp spines and can form an impenetrable barrier 1 to 5 meters tall (Coombs, et al., 1996). In Oregon, gorse occupies over 20,000 hectares in at least nine counties, mostly on the coast, but with increasing frequency at inland sites (Isaacson and Miller, 1992). Gorse has major economic considerations such as the loss of grazing land, control costs in rights-of-way, limited access and use of recreation areas, and competition and interference in conifer plantations (Isaacson and Miller, 1992).

Biological control is a preferred management technique in areas with extensive infestations, rugged terrain, and high economic costs associated with herbicides (Isaacson and Miller, 1992). Gorse seed weevil (*Apion ulicis*) was the first biological control agent released in Oregon in 1956 (Ritcher, 1966). Although the weevil attacks the seed pods, plant density has not noticeably decreased (Isaacson and Miller, 1992).

The biological control agent that causes the most damage in Europe and which has shown the best results in New Zealand is the gorse spider mite, *Tetranychus lintearius* (Hill et al., 1991). The gorse spider mite was released in California and Oregon in 1994 (Coombs et al., 1996; Peters et al., 1997). The mites quickly established colonies and were widely distributed in the area.

The objectives of the study were to: (1) develop mapping (monitoring) techniques of gorse infestations, (2) monitor rate and distribution of expanding mite colonies, (3) determine biotic and/or abiotic factors governing mite colony spread, and (4) detect plant response to the biological control agent. To understand better the population dynamics and dispersal patterns of gorse and the gorse spider mite, we used near-earth remotely sensed data, geographic information systems, and global positioning systems. These techniques also were used to detect spatial patterns and determine relevant forces forming them.

Materials and Methods

Study Sites. Nine sites were established at two study areas in Coos and Curry Counties. Sites encompassed an area of 1 hectare and were selected as either gorse-dominated and windy, gorse-dominated and wind protected, or mixed-dominance plant communities. The mixed-dominance sites consisted mainly of gorse and shore pine and were also relatively wind protected. Sites were staked and located using a differentially-corrected global positioning system giving a global accuracy of under 3 m (Trimble, 1992).

Remote Sensing. A 5.5-m x 2-m tethered helium-filled blimp and paired 35 mm cameras with remote control film advance were used to obtain aerial photographs. Aerial imagery for mapping gorse infestation was obtained for all sites in March, 1996. The gorse plants were in heavy bloom and no other vegetation was flowering. Imagery for measuring colony distribution was obtained in late June and late September. In 1997, imagery was obtained in August and October. Before images were taken, a number on a piece of cardboard, 30 cm on a side, was fastened to the top of the geo-positioned stake to identify the site and allow the stake to be located visually in the image. A 1-square-meter quadrat made of 1-inch PVC pipe was placed on the ground near the stake for calibration of image scale for measurement purposes. Photos were processed into either slides or negatives then transferred to compact disk format.

Spider Mites. In May 1996, spider mite colonies were collected from random gorse plants at a previous release site and transferred to our study sites. Initial colonies consisted of a 15-cm-long segment of gorse shoot-tip heavily coated with webbing and spider mites. The colonies were tied loosely with baling twine to the inner branches of gorse plants at the geo-positioned stakes.

Ground Verification. Ground verification is an essential component in remote sensing technique (Avery and Berlin, 1985). Vegetation classification images produced from aerial photography were ground verified using 100 random sampling points per image. Twenty-five random square meter grids were used to estimate cover. Diameters calculated from the imagery were compared to those measurements obtained from ground-accessible colonies. A t-test for separation of means was used in our analysis.

Results and Discussion

If in bloom, gorse was mapped easily using aerial photography. Gorse begins to bloom in late February and March, before most coastal plant communities. The three visible wavebands (red, green, and blue) obtained from color film were most valuable for the gorse mapping. The infrared band was not as useful for this purpose. This agrees with the results obtained by Everitt and Escobar (1996), who found color film more effective for mapping many weed species. Computer classification routines were used to produce gorse distribution maps. Ground verification was used to produce Kappa Index of Agreement (KIA) values according to Eastman (1997). Site 6 had a Kappa score of 0.69 and site 7 had a score of 0.89. KIA values were lowered by errors of omission exclusively. This result was expected because the technique mapped only flowering gorse and not gorse that was not in bloom. At site 6, gorse bloom was estimated at 72 percent, and at site 7, bloom was 95 percent. For purposes of mapping and estimating cover of gorse infestation, aerial photography was an excellent tool.

We examined the usefulness of color and infrared photography to locate spider mite colonies and for assessment of damage to gorse plants. Analysis of spectral values obtained from vertical aerial photography and from ground-based oblique photography of healthy versus spider mite affected gorse plants showed good separation of means for the three visible bands. A spectral signature analysis that compares low, high, and mean values across the four wavebands as well as a comparison of means, showed no statistically significant differences between infrared values of healthy gorse and spider mite colonies. Four images were used in this analysis with four pairs of treatments. While there was some difference between means for the infrared band, the range of values was almost identical, making this band of little value for detecting and classifying mite colonies. Infrared film is more difficult to work with than color film, because it must be kept cool and loaded in total darkness (Avery and Berlin, 1985). For this reason, and because it did not produce any useful data for our monitoring, we do not recommend infrared film

for monitoring gorse or spider mite colonies.
It was of some surprise that damage to the gorse plants was not evident on infrared film, since reflection of this waveband is influenced by internal cell structure (Grant, 1987; Knipling, 1970). It appeared that feeding damage caused by the spider mites did not cause the cell collapse noticed in other plant species. This may be the result of the minimization of leaf structure of gorse, which is modified into a spine. The removal of chlorophyll by the sucking mites was evident in color photos, which showed blanched gorse shoots around mite colonies and heavy webbing produced by the spider mites.

Mite colonies were detected 14 weeks after release and showed distinct colonies averaging 25 cm in diameter. Windy site colonies occupied 0.62 m^2 and protected site had a colony 0.58 m^2. Adverse wind conditions did not allow scheduled flights for aerial photography at some times during the year; therefore, no measurements were taken in June, 1997. The gorse also can create imposing barriers to ground-based measuring techniques and would have involved destructive cutting of gorse plants to reach colonies physically.

Good coverage of gorse sites was photographed in October, 1997. Through analysis, it was shown that mites at the windy site traveled farther (36.23 m) and spread wider (49.12 m^2) than at the protected site, where they traveled 7.38 m and spread 19.04 m^2. The predominant wind direction is from the north. Mite spread followed the prevailing wind direction except for the protected site, which exhibited greater dispersal to the west than the windy site.

The coastal area was a difficult location to use our blimp/camera setup, and limitations to aerial photo monitoring of gorse existed. Overhead obstructions such as power lines and closed canopy forests precluded use. In addition, wind speeds greater than 25 km/hr resulted in blurred images, and transportation of the blimp between sites generally required deflation.

After two seasons of taking measurements, spider mite colonies became available to the general public through distribution and educational programs. Attempts were made to isolate our study areas from public releases. However, we discovered that our research sites had been planted with additional mite releases from the public, and the study was terminated.

In May, 1998, a predatory mite was discovered in areas where the gorse spider mites were released on the southern Oregon coast, near the town of Bandon. Other areas of Oregon and California where spider mites were released do not have this problem. The predatory mite and its impact on the gorse spider mite is being evaluated now.

Summary

Spatial technologies proved to be powerful tools for analysis of distribution dynamics of gorse and the gorse spider mite. Remote sensing allowed for accurate mapping and measurement of gorse and gorse spider mite colonies that would not have been possible using only ground-based techniques. Using low altitude aerial photographs, gorse can be mapped during flowering, and gorse spider mite colonies can be detected in late summer or fall before rains destroy the webbing. Spider mite webbing can be seen in photographs taken at 1:450. Color film was more useful in identifying mite colonies than was black/white infrared film. Weather conditions on the coast included frequent high winds and rain, which limited when blimp photographs could be taken. Researchers and land managers have expanded analytical and monitoring capabilities using these new technologies.

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Integrated Production Program for Oregon Vineyards
1999

A. McDonald
LIVE (Low Input Viticulture and Enology)

What is Integrated Production?

Integrated production is a system that produces high quality food and other products by using natural resources and regulating mechanisms to replace polluting inputs and to achieve sustainable farming (IOBC/WPRS, 1993).

Emphasis is placed on: (1) a holistic systems approach involving the entire farm as the basic unit, (2) the central role of agro-ecosystems, (3) balanced nutrient cycles, and (4) the welfare of all species in animal husbandry. The preservation and improvement of soil fertility and of a diversified environment are essential components.

Biological, technical, and chemical methods are balanced carefully, taking into account the protection of the environment, profitability, and social requirements (IOBC, 1993).

Program Goal Statement

As winegrowers in Oregon, we acknowledge that we are, in many ways, truly fortunate. Our vines are free of many of the pests and diseases that afflict vineyards in other regions of the world. Therefore, our chemical usage is rather limited at present. Our purpose, then, in crafting this program for Oregon vineyards, is to maintain and enhance these advantages which we currently enjoy.

The objectives and scorecard outlined below should not be seen as an endpoint, but rather as the beginning of an ongoing process. The Oregon vineyard is a dynamic entity, presenting us with fresh challenges requiring innovative solutions. New pests will require thoughtful responses, which preserve the integrity of our program objectives. Better solutions to old and chronic problems need to be encouraged. Clearly this program should be periodically reviewed and revised as necessary.

Finally, it must be emphasized that participation in this program should be entirely *voluntary*. We have no interest in compelling anyone to be a part of this plan who is not committed to the objectives outlined below. Although vineyards will be visited periodically to monitor compliance, the commitment of the participants will be assumed and relied on for this program to be successful.

Program Objectives

1. To see the vineyard as a *whole* system.
2. To create and maintain a viticulture that is economically viable over time.
3. To maintain the highest level of quality in fruit production. Integrated Production should not require any compromise of quality standards.
4. To implement cultural practices and to solve problems in such a way that minimizes the use of off-farm inputs, such as agricultural chemicals and fertilizers, with the goal of protecting the farmer, the environment, and society at large.
5. To encourage farming practices which promote and maintain high biological diversity in the whole vineyard.
6. To encourage responsible stewardship of the soil, its health, fertility, and stability.

Requirements

To meet these objectives, a grower practicing Integrated Production must fulfill a certain number of requirements that apply to the entire viticultural surface of the farm, specifically: (IOBC/WPRS, 1996)

1. Commitment of grape grower

   The grape grower or vineyard manager must:
   - Be qualified (trained) professionally for managing the vineyard according to LIVE principles and guidelines.
   - Commit to permanent education and actively participate in LIVE training courses.

- Maintain complete vineyard records on fertilization, pesticide application, pruning, soil management, etc.

2. Establishment of Vineyard

Choice of variety, clone, and rootstock
The choice must take into account integrated production principles (biodiversity, least susceptibility to diseases, healthy plant material, certified stock, etc.), take into consideration local soil and climate conditions, and respect the existing regional viticultural legal restrictions.

Training system
Preference must be given to training systems allowing application of cultural techniques favoring:

- production of high quality grapes
- vine longevity
- biological diversity (botanical and zoological)
- protection of soil against erosion
- reduction in circumstances leading to introduction or establishment of insect pests, diseases, and undesirable plants
- more efficient pesticide application
- reduction of the amount of pesticide applied
- recycling of spray drift (recovery panels, hooded booms, if available)

Analysis and preparation of soil prior to planting
Before planting, the following analysis and improvements must be carried out:

- soil analysis: texture, organic matter, macronutrients (at least P, K, and Mg)
- basic fertilization with organic and mineral components if necessary
- improvement of land if necessary (drainage, etc.)
- thorough elimination of sources of disease inoculum
- elimination of noxious perennial weeds
- devitalization (killing) before removing major virus infested vines (fan leaf)
- land left fallow with a green cover

Chemical soil sterilization is not permitted. The regional Integrated Production organization may allow exceptions in some serious cases of fan leaf or root rot, defining clearly which products can be used. In this case, nematologic analysis and virus testing by an official institution before removal of the old vines are mandatory.

3. Cultural Practices in established vineyards: The Scorecard

The purpose of the scorecard is to provide a concrete, situational measure of compliance with the program objectives. A score of zero in a particular case means compliance with the program. Negative scores suggest the need for improvement. Positive scores indicate a grower has done especially well in a particular area. Unacceptable scores would need to be corrected before compliance could be certified.

We have tried to be as inclusive as possible while not compromising the program objectives. Often, we chose to give negative scores for questionable practices rather than to absolutely forbid them. The goal of the system, after all, is not to exclude, but to encourage continual improvement over time.

Evaluation System

The certification is granted by the Oregon Integrated Production organization LIVE. The participants in the Integrated Production programs have to follow a set of rules, which may vary regionally, but satisfy an international standard. The performance of the grape grower is evaluated annually by means of a point system (scorecard). A score of zero in a particular case means that the grower has complied with the program. Negative scores suggest the need for improvement. Unacceptable scores would need to be corrected before compliance could be certified.

Bonus-points (10 to 20) are given to solutions and actions aimed at improving grape quality, diversification of the agro-ecosystem "vineyard," and reducing chemical inputs (pesticides, fertilizers, fuel, etc). One single unacceptable score will cause the disqualification of the respective grower. Additionally, the grower has to achieve at least 50 percent of the maximum number of positive-points. For instance, a minimum of 140 points out of 280 are necessary to participate in the Oregon Integrated Production association LIVE.

Control: The grower submits the complete records on fertilizers, pesticides, and cultural practices and is subject to unannounced inspection at least once a year for verification.

Label "LIVE"

The label "LIVE" is granted by the LIVE Organization to wines that fulfill the conditions for grapegrowing and winemaking.

Requirements

1. Wines with the LIVE label must be produced from grapes originating from certified LIVE vineyards.
2. The wines must respect regional appellation requirements. Blending with non-LIVE wines is not allowed.
3. Chaptalization cannot exceed 3 kg/hl or 1.7 Volume % alcohol unless an exemption is granted by the LIVE organization for that particular vintage.
4. Total SO_2 content cannot exceed 120mg/l. Exceptions: Barrel fermented wines and wines with residual sugar which must conform to regional legal restrictions.
5. For all other criteria, the Federal, state or regional legal restrictions apply.
6. Wines must be evaluated by an independent tasting panel and must be clean and have varietal character.
7. A wine analysis by an independent specialist must accompany the wine sample for tasting. It must include percent of alcohol, TA, total and free SO_2. For all other criteria, the regional legal restrictions must be respected.
8. The number of labels distributed is based on the quantity of wine produced.
9. Wines are subject to random testing.
10. Unauthorized use of labels is penalized with sanctions.

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Wine Grape Pest Management in Oregon

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Overview

Grape pest management in Oregon focuses on relatively few diseases and insect pests compared to other production regions. This probably is due in part to the wine grape industry being relatively new, small (9,000 acres), and somewhat dispersed. Pest management currently emphasizes just three major problems: the diseases powdery mildew and *Botrytis* bunch rot, and the insect phylloxera.

Disease control programs are aimed primarily at powdery mildew (*Uncinula necator*), a ubiquitous and potentially crop-destroying disease requiring annual control efforts. Bunch rot (*Botrytis cinerea*) is a frequent problem with the potential to cause serious crop loss in years with rainy harvest periods. Phylloxera (*Daktulosphaira vitifoliae*) is a recent pest in Oregon, having been found first in a commercial vineyard in 1990. It is a root-feeding aphid that ultimately kills *Vitis vinifera* (European wine grape) vines grown on their own roots.

Several other diseases cause occasional and usually isolated problems. Crown gall (*Agrobacterium vitis*) periodically has caused damage in years following cold injury from harsh winters. It also may be introduced into grafted plants at the nursery, or the disease can develop on field-grafted vines previously infected but symptomless prior to grafting. Eutypa dieback (*Eutypa lata*) has been diagnosed in a few older vineyards that had large pruning cuts to remove unproductive wood. Eutypa is expected to increase as existing vineyards age and older vines require large rejuvenating cuts. Phomopsis cane and leaf spot (*Phomopsis viticola*) can weaken vines and reduce yield; it has been an isolated problem in a few vineyards. Leafroll virus is present in many older vineyards that were not established with certified virus-free plants. In most cases, leafroll has not weakened vines enough to reduce fruit quality or productivity.

To date, phylloxera is the only significant insect pest problem, and it has changed Oregon viticulture dramatically. Because self-rooted vines ultimately succumb to phylloxera feeding damage (and perhaps subsequent root-rotting pathogens), the majority of Oregon acreage, which is self-rooted, eventually will need to be removed and/or replanted using vines grafted onto resistant rootstocks. The number of Oregon vineyards infested with phylloxera has increased steadily since the initial discovery (Hellmar and Fisher, 1998). Grafted vines cost about three times as much as self-rooted vines, and often require more care to establish successfully. Learning how to select appropriate rootstocks for a vineyard and how to manage grafted vines is an ongoing challenge for the industry and researchers (Candolfi-Vasconcelos, 1995; Candolfi-Vasconcelos et al., 1999a).

Several other insects have caused isolated, minor problems. Southern Oregon vineyards more commonly experience noticeable populations of spider mites, leafhoppers, and thrips compared to the Umpqua and Willamette valleys. Often these infestations do not increase to high populations until late in the season, and may not require control efforts. Sporadic, localized infestations of twig borer and black vine weevil sometimes have required insecticide applications. The grape Erineum mite is common in western Oregon vineyards, but it generally is kept at low levels by sulfur applications used for powdery mildew control.

Pest Management Practices

Oregon grape growers take the first step in pest management when they plan and develop their vineyard. Disease management is facilitated greatly by selection of an appropriate training system and vine spacing that enables maintenance of an open, well-exposed canopy. Canopy management during the growing season, using such techniques as shoot thinning, shoot positioning, hedging, and leaf pulling, is critical for good disease management with certain training systems. Leaf pulling in the fruit zone is the first defense against *Botrytis* bunch rot and, combined with shoot positioning, provides control as effective as fungicides alone in years of dry weather during harvest (Candolfi-Vaconcelos et al., 1999b). Developing fruit exposed to direct sunlight produces thicker skin and epicuticular wax, which reduces susceptibility to *Botrytis* infection (Percival et al., 1994). Improved air circulation facilitates drying, which reduces the duration of a favorable infection environment for both bunch rot and powdery mildew. Open canopies also enable better spray coverage, which improves the effectiveness of fungicide applications. Phylloxera control also begins with vineyard planning, since resistant rootstocks are the only effective solution to the problem.

Oregon's favorable climate for powdery mildew, combined with the high susceptibility of European wine grapes, requires that fungicides play a critical role in controlling the disease. The 1999 Pest Management Guide for Wine Grapes in Oregon (Candolfi-Vaconcelos et al., 1999b) lists 10 materials that can be used in a powdery mildew control program. Having the choice of so many tools is both unusual and a bit confusing. In the Pest Management Guide, OSU Extension has tried to provide some guidance to growers with an example strategy for powdery mildew control. The strategy illustrates the timing of canopy management practices and fungicide applications. It indicates the role that each fungicide is capable of playing in the strategy, primary or supplemental. It further illustrates the need to rotate among fungicides having different chemistry to avoid development of fungicide-resistant mildew. A fungicide efficacy table assists growers in selecting the most appropriate materials to use in their program.

A similar example strategy for *Botrytis* bunch rot control was prepared in 1999. The bunch rot strategy strongly emphasizes canopy management practices. As stated earlier, shoot positioning and leaf pulling are the first defense against bunch rot. These canopy management techniques provide a less favorable environment for infection, increase resistance to the pathogen, and enable better spray coverage if fungicide applications are necessary. Reliance on fungicides for bunch rot control is a little more tenuous than it is for mildew. Although seven fungicides are listed for bunch rot, only two provide moderate or good control. Pathogen resistance development is a concern, so growers are anxiously anticipating approval of new fungicides having different chemistry.

Insect pest management, other than a very occasional localized problem that may or may not require insecticide treatment, is not currently a regular production concern of Oregon growers. Phylloxera control is achieved through the planting of vines grafted onto resistant rootstocks.

Looking to the Future

The relatively simple spectrum of disease and insect problems presently in Oregon vineyards is expected to become more complicated in the future as the industry expands and becomes concentrated more locally. Other diseases that potentially could become established here include Young Vine Decline, a recently recognized problem involving several fairly common soil pathogens attacking young grafted vines that have been stressed (Pscheidt and Ocamb, 1999a). Downy mildew has not been reported here, but the western Oregon climate would be highly conducive to disease development if the pathogen is introduced (Pscheidt and Ocamb, 1999b). Fanleaf and other virus diseases could be introduced with contaminated planting stock. Tomato ringspot virus and its nematode vector (*Xiphinema americanum*) are both endemic to the Willamette Valley, but the virus has not yet been isolated from Oregon vines (Martin, 1998). Ring, root-knot, and dagger nematodes could become increasing problems, particularly in replanted vineyards.

Phylloxera will destroy increasing numbers of self-rooted vines, but eventually most vineyards will be planted with resistant rootstock. Leafhoppers, thrips, and spider mites could become more common problems as grape acreage increases. Future insect and mite problems perhaps could be minimized by widespread adoption of the new Low Input Viticulture and Enology (L.I.V.E.) integrated production program (Anon, 1998). The L.I.V.E. program promotes production practices that preserve or enhance native populations of beneficial insects that could keep pest populations from rising to damaging levels.

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Hazelnut IPM in Oregon

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Oregon State University worked to develop an Integrated Pest Management program in the early 1980s. The research and development phase of the program was funded through a USDA grant under the leadership of Dr. Glenn Fisher, OSU Extension Entomology Specialist, and Jim Calkin.

Prior to the development of the OSU IPM program, the hazelnut industry relied on a calendar approach to control insect pests. Survey results from 1981 and 1997 have shown that the OSU IPM program has reduced significantly the amount of insecticides applied to hazelnut orchards. The cost savings are estimated at $1/2 million each year.

The program was developed using growers' orchards that ranged throughout the Willamette Valley. All of the test site orchards were monitored on a weekly schedule. Sampling schemes and action thresholds were refined over a period of 4 years. At the end of the 4-year development period, the program was transferred to the hazelnut industry. Currently, the OSU Hazelnut IPM program is in widespread use by growers, consultants, and farm supply fieldmen. Table 1 lists insect pests, sampling schemes, and action thresholds.

Table 1. Hazelnut IPM sampling methods and action thresholds.

Insect	Sampling Period	Sampling Method	Action Threshold
European winter moth	Larvae: March 15 –May 31	3 terminals/tree and 3 leaf clusters/terminal. Each terminal is a sampling unit.	20% infestation
Big bud mite	March–April	By March 1, place Tanglefoot on twigs surrounding blasted buds. Check for extremely small, white, cigar-shaped mites with a 20x hand lens.	When consistent mite movement is observed.
Omnivorous leaftier	April 15–June	3 bud cluster per tree	5% infestation
Filbert aphid	April 1–September 30	3 terminals per tree—newest fully expanded leaf on each terminal	April – 20/leaf May – 30/leaf June – 40/leaf July – 40/leaf with increasing population.
Obliquebanded leafroller	Larvae: April–August Adult: Mid-May–Sept.	Larvae: 3 terminals per tree and 3 leaf clusters per terminal. Each terminal is a sampling unit. Adult: pheromone trap for each 5 acres. 6' height.	Larvae: 20-25% infestation. Adult: 40 moths per week and find larvae feeding on nuts.
Filbertworm	June–September	Adult: pheromone traps—4 for first 10 acres and one for each additional 4 acres. Place traps in the upper 1/3 of the canopy by mid-June.	2-3 moths per trap or 5 moths in any one trap

Filbertworm

The filbertworm is the most important insect pest in hazelnuts. Its life cycle is unusual, in that the emergence period for a single generation is extended from late June into October. This makes the use of pheromone traps even more vital in timing efficient controls.

The filbertworm overwinters as an inactive larva in a silken cocoon. These cocoons can be found under leaves and trash on the orchard floor or in any crack or crevice that they may find. There are also some larvae that hibernate 1 to 2 inches under the soil surface.

The larvae pupate in the cocoon in the spring, then emerge as adults about 2 to 5 weeks after pupation. This emergence usually begins around mid-June and continues through October. Once the adults emerge, they look for mates. Weather conditions that favor mating flights and egg laying are when temperatures at dusk (1/2 hour before and 2 hours after sunset) are above 60°F. The day after mating, egg laying occurs. Usually this is done during the sunniest part of the day. The eggs are laid one by one on leaves close to nuts. The eggs hatch in 8 to 10 days. The newly hatched larvae then move around and find a nut to feed in. They will feed in the nut for about 2 to 4 weeks. Then, they either enlarge their entry hole or bore a new exit hole. The larvae form a cocoon to overwinter.

Occasionally, there is a partial second generation of filbertworm. This usually includes about 10 percent of the population. This occurs when there is a strong, early emergence.

Our threshold recommendations are based on four traps for the first 10 acres and one for each additional 4 acres. Spraying is recommend when two to three moths accumulate in each trap, or when any one trap catches five moths cumulatively.

The traps should be placed in the top one-third of the tree canopy. This contrasts with the leafroller traps, which are placed at a height of 6 feet. The extra caps either should be refrigerated or stored in a freezer, and changed every 4 to 6 weeks. The trap bottoms should be changed when they have so much soil and other insects that the sticky surface is limited.

Experience reveals that growers should be aware of the conditions surrounding their orchards. If an abandoned block, or one that is managed yet heavily infested, is within 1/2 mile of an orchard, it should be observed closely. Traps should be placed in, or at least near, those sources of infestation.

Spot spraying can be employed successfully in specific situations. Growers should spray at least the four to six outside rows nearest infested blocks when their border traps show a strong flight of the moths. It would be best if growers could arrange to treat these sources of infestation. Sometimes, pregnant females from these infested blocks can fly into the orchards and lay eggs that produce worms in the nuts at harvest.

Filbert Aphid

The very first filbert aphids probably hitched a ride from their native Europe on filbert seedlings shipped here in the late 1800s. Filbert aphid first was found in the U.S. in 1903. To manage filbert aphid in hazelnut orchards, OSU researched the action thresholds for aphids and decided that a sliding scale for the number of aphids per leaf should change with the month. In April, there are 20 per leaf, rising to 30 in May, 40 in June, and 40 with increasing populations in July.

The hazelnut industry's approach to managing the filbert aphid has changed since the early 80s. The aphid parasitoid *Trioxys pallidus* was imported from Europe to Willamette Valley hazelnut orchards. It has spread on its own up to 10 miles from other known sites where it first thrived. There were only five original "seed" sites back in the mid-80s. Then, there were 60 more sites that had releases, once enough wasps were reared at OSU.

Today nearly every orchard checked shows signs of the wasp's presence. This usually is accompanied by a reduction in the number of filbert aphids. Many growers report that they haven't had to spray for aphids in many years. The OSU IPM program created a sampling scheme and action thresholds for growers to use in monitoring aphid populations. The parasitoid successfully established itself, and growers used the thresholds to confirm its success.

Here is a review of the aphid lifecycle. The filbert aphid overwinters as an egg on the tree trunk or branches. The eggs usually begin hatching around the beginning of March. Egg hatch continues for 3 to 4 weeks. The young aphids that emerge from the eggs molt four times and then produce winged adults. These adults give birth to young aphids without sexual reproduction.

During the season, there are as many as 10 generations of aphids produced. The populations seem to decline naturally in the heat of the summer. Then in the fall, the winged forms are produced. These winged forms produce the egg laying forms that create the overwintering population.

Another secondary problem comes with heavy aphid infestations: black, sooty mold. This is a secondary fungus that grows on the sweet honeydew left on the leaf surface by aphids feeding. This can reduce the photosynthetic capacity of the leaf.

Growers also report displeasure at working in orchards with sticky leaves caused by the honeydew.

Leafrollers

There are two leafrollers in hazelnut orchards: the filbert leafroller and the obliquebanded leafroller. The filbert leafroller is a native of Europe. It was accidentally introduced in 1915.

The filbert leafroller overwinters as an egg. Those eggs hatch in late March or early April. The newly hatched larvae feed on both sides of the new leaves. They soon pull the leaf into a roll. Nicely tucked in their hideaway, they feed for 4 to 8 weeks. Then they pupate right there in the webbed leaf. This normally occurs in late May or early June in the Willamette Valley.

The adults emerge from the pupae in late June or early July. Their emergence continues until mid-August. But, the adults only live for 2 to 4 weeks. Before they die, they lay their eggs in masses on the trunks and major branches, where they overwinter. There are an average of 50 eggs per mass. There is only one generation per year for the filbert leafroller.

The other leafroller in hazelnuts is the obliquebanded leafroller. The OBLR, as it is commonly called, overwinters as an inactive and partially grown larvae in the crevices and cracks of the tree bark and on the ground debris. As the temperatures warm in the spring, the overwintering larvae start to become active. In March and April, the larvae feed on buds and new leaves. Then, during late April or May, the larvae pupate in the leaves. The pupation lasts for 4 to 6 weeks.

The adults emerge from the pupae in early June through the middle of July. There is usually a sharp emergence peak in the middle of July. The adults mate and lay eggs within a few days of emergence. The eggs hatch within 2 weeks. The new larvae often can be found in the orchards by the first of July. They will feed for 6 to 8 weeks. In addition to their leaf feeding, they can cause nut damage at this stage. They feed on the shell underneath the husk, causing scarring and staining of the young nuts. After their feeding stage they pupate inside silk webs.

The adults of the second generation emerge 1 to 2 weeks after pupation. This emergence usually occurs from the first week in September through early October. The adults mate and lay eggs that hatch in 7 to 10 days. The larvae feed briefly, then overwinter until the following spring.

The thresholds for leafrollers are to spray when 20 to 25 percent of the terminals have larvae; while for adults, we spray in the first generation when there are 40 moths per week. For the OBLR, growers should check the nut cluster for the second generation larvae. If larvae are found feeding on the cluster, and the traps have high adult counts, then a spray is recommended.

The number of applications made to control leafrollers has reduced from one per year to one every 4 years. This is a result of natural predation buildup in the orchards early in the season. Since the aphid populations have declined below threshold levels due to *Trioxys*, the need for early season sprays has been reduced. Natural predators have, therefore, built up their populations, and leafroller suppression has been a side benefit.

The Oregon hazelnut industry now has a long history of using IPM. The OSU Hazelnut IPM program has served the industry well, helping growers both to avoid unnecessary sprays and to make timely applications when they were truly needed. The initial investment in the program has paid off handsomely, with the economic and environmental benefits continuing to accrue.

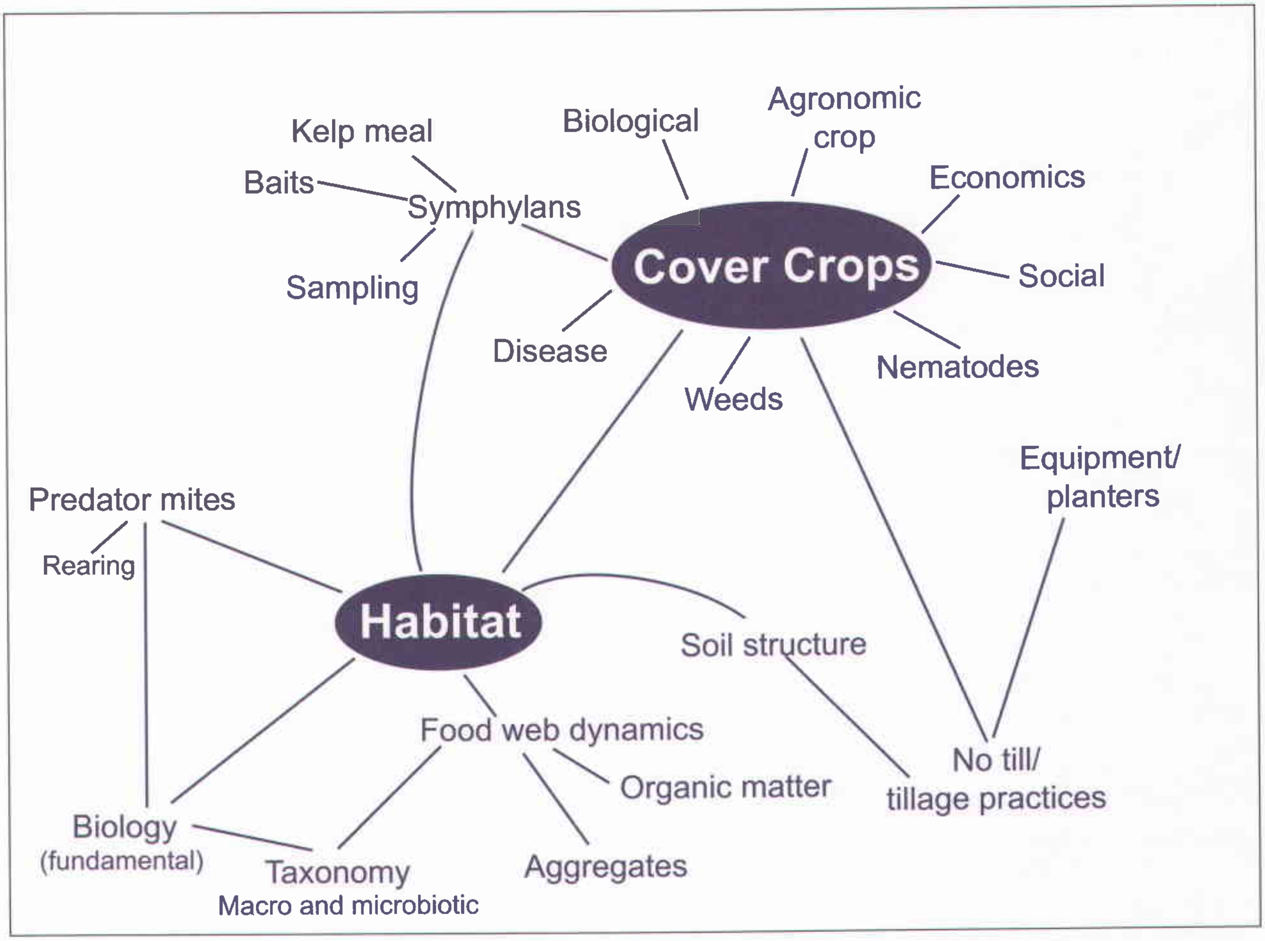

Figure 1. Diagrammatic representation of soil foodweb and cover crop system completed by three farmers, disciplinary entomologists, weed scientists, and soil foodweb ecologists.

Methods

All plots were fall-tilled and planted with a cover crop or left fallow. By late winter or very early spring, all plots were treated with glyphosate to kill cover crops or existing winter weeds. Half of each plot was tilled while the other half received no spring tillage; all were planted with a cross-slot planter to minimize soil disturbance except along the planting line, where both seed and fertilizer were placed in a narrow slot. Plot size ranged from 6 by 11 m to 8 by 14 m with four or five replications repeated on the same site for 3 years. Arthropod samples were collected using a golf-green cutter (5 cm dia) or from 1,000 cm^2 while weed counts were recorded from m^2 areas within each plot. Results represent a compilation of several experiments; specific methods for each trial are available upon request or are in preparation for publication.

Discoveries

Suppression of pigweed and nightshade was greater in untilled treatments compared to tilled systems (Figure 2). In fact, observations and initial data suggest that tillage may stimulate emergence and eventual maintenance of the weed seed bank compared to systems lacking disturbance in spring. 'Micah' barley emerged faster and suppressed more winter weeds than other cereals, even though biomass, plant height, and survival during winter were least. Although allelopathy can explain weed suppression, overwhelming evidence suggests lack of spring tillage reduces pigweed and nightshade by 0.70 percent. Adding a cereal residue mulch on the soil surface contributes another 15 to 20 percent to total weed control. Overwhelming evidence (85 to 90 percent of weed suppression) suggests that allelopathy explains a relatively minor amount of weed suppression in these system. In fact, it may be one of several other factors that explain the remaining 10 to 15 percent of weed suppression.

Impacts of Tillage and Cover Crop Residues on the Soil Foodweb and Multiple Pests in Vegetables

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Farmers describe their enterprises as whole systems with interactive relationships, feedback loops, and time considerations. In contrast, university faculty see the world as disciplines and assume that the grower is responsible for integration and implementation of technologies or research. Most disciplinary research, therefore, ignores interactions and relationships between organisms or impacts of one practice on multiple components of a functioning system.

Integrated pest management could provide this framework for inquiry. This paper briefly describes what "whole systems" pest management (IPM) might look like. It explores the approach we used to integrate the emerging sciences of ecology with the disciplinary methodologies used by pest management specialists. The purpose is to explore the effects of crop rotation, tillage, and cover crop residues on the soil foodweb and multiple pests within the context of vegetable cropping systems.

Background

Allelopathy is defined as "the injurious effects of one plant upon another" (Rizvi and Rizvi, 1992). The word suggests chemical regulation directly between plants, leachates from plants, or microbial release and/or transformations that impact plants. Scientists' interests either focus on explaining the phenomena or employing the tactic in weed management.

Barnes & Putnam (1986) described a Michigan farmer's observation that mustard failed to infest 'Wheeler' cereal rye. Numerous students and colleagues researched the hypothesis that allelopathic toxins, some derived from microorganisms, prevented mustard and other small-seeded weeds from germinating or emerging when planting large-seeded crops such as peas, beans, or corn into undisturbed residues of 'Wheeler' cereal rye.

Oregon research commenced to validate or adapt the Michigan results in vegetable systems beginning in the early 1990s. Emergence of small-seeded weeds such as pigweed and black nightshade decreased in plots containing residues of 'Wheeler' rye, 'Monida' oats, 'Micah' barley, and 'Steptoe' barley. While pondering the physiological response of several cereals causing similar weed suppression, growers expressed interest in a system that suppresses multiple pests including insects and diseases.

Symphylans are a root-feeding arthropod that dwell entirely in the soil. We hypothesized that cover crops also might affect symphylan populations. Results from several experiments conducted in the field and laboratory caused us to re-examine our methods, and eventually our hypotheses. Why did toxins from four cereal cultivars suppress two weeds but result in erratic suppression of symphylans? Should we expect similar results among three types of cereals? What research assumption should we reconsider? What might be learned by combining farmers' and researchers' perspectives?

A diverse group of three vegetable growers, disciplinary entomologists, weed scientists, and soil foodweb ecologists with microbial and arthropod specialties drew a diagram or representation of a cover crop and soil habitat system for vegetable production systems (Figure 1). Soil foodweb ecologists studied population dynamics of arthropods at time intervals throughout the season and between years, while disciplinary scientists asked about causal relationships associated with control of pigweed, black nightshade, and symphylan pests in snap beans and sweet corn rotations with wheat. Ecologists often focus part of their inquiry on *keystone* species. Although this seems like a reductionist approach, *keystone events* in our system might include crop rotation, tillage, and cover crop residue.

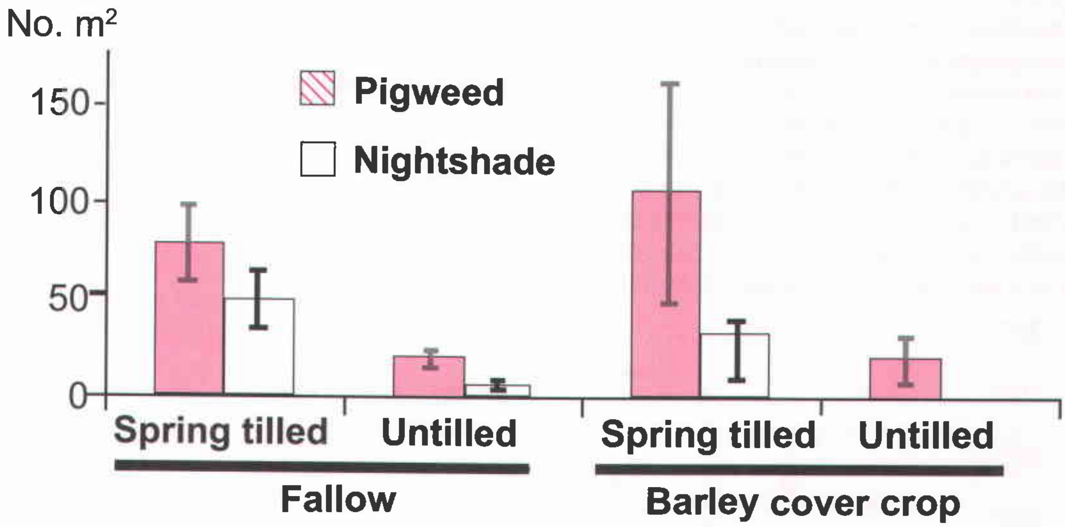

Figure 2. Control of pigweed and nightshade from lack of soil disturbance or cover crop.

Symphylan populations always were greater in 'Martiginia' white mustard (Figure 3), even though this cultivar contains glucosynilates known to be toxic to several soil-borne organisms. Spring tillage reduced symphylan infestations moderately, probably caused by crushing the soft-bodied arthropods (Figure 3). Cover crop residues enhanced predaceous arthropod populations (Figure 4). Sampling procedures using Berlese funnels or potato pieces as attractants were more effective on no-till soil, where channels may provide greater access or increased numbers of symphylans. Although we failed to correlate symphylan densities with shepardspurse or henbit found in winter fallow plots, both weeds are from plant families known to attract or expand symphylan populations. Thus, we conclude that symphylans respond to multiple factors such as presence and/or interaction of weed hosts, tillage, predaceous arthropods and cover crop residues, and possibly sampling procedures.

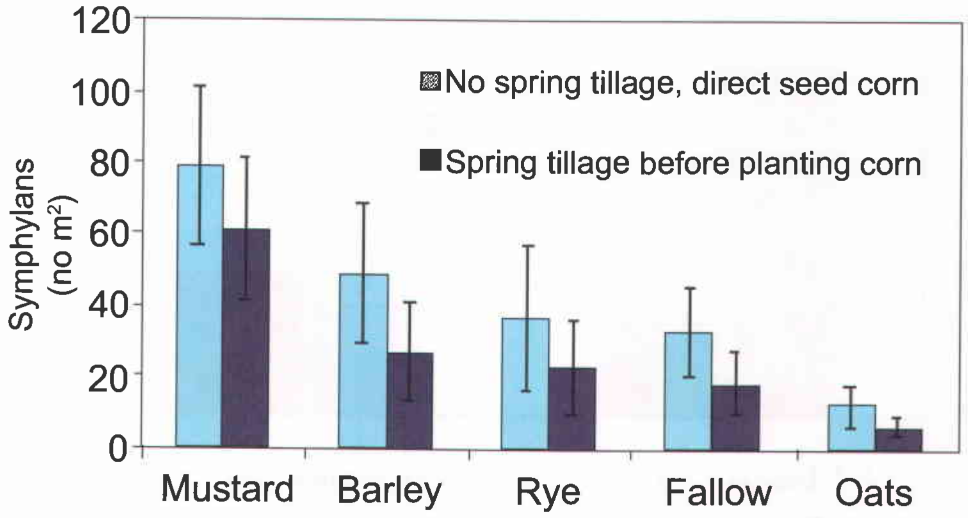

Figure 3. Effect of cover crop and spring tillage on symphylan abundance in sweet corn. Bars are average of samples taken in the fall of 1995 and 1997 (N=6, ± SE).

As an integral part of inquiry, we might ask about other components of the system. For example, will the spring no-till/residue system encourage new pests or pest complexes? We experienced more slugs with the spring no-till residue system. Also, herbicide rates (Figure 5) were halved with the cross-slot planting of beans or sweet corn into spring no-till systems. Although we have monitored *Diabrotica* and conducted trials to assess impacts of tillage and/or cover crops residues on *Sclerotinia* white mold in snap beans, no consistent hypotheses have emerged. Growers express concern about buying new planters, but when quizzed beyond the initial question or issue of cost, major concerns are revealed about the time required to *learn* a new system. In fact, they report that current economics or skepticism among individuals requires assessment of research results over several years followed by their personal learning over another 6 to 10 years to make a new or modified system work on their farm.

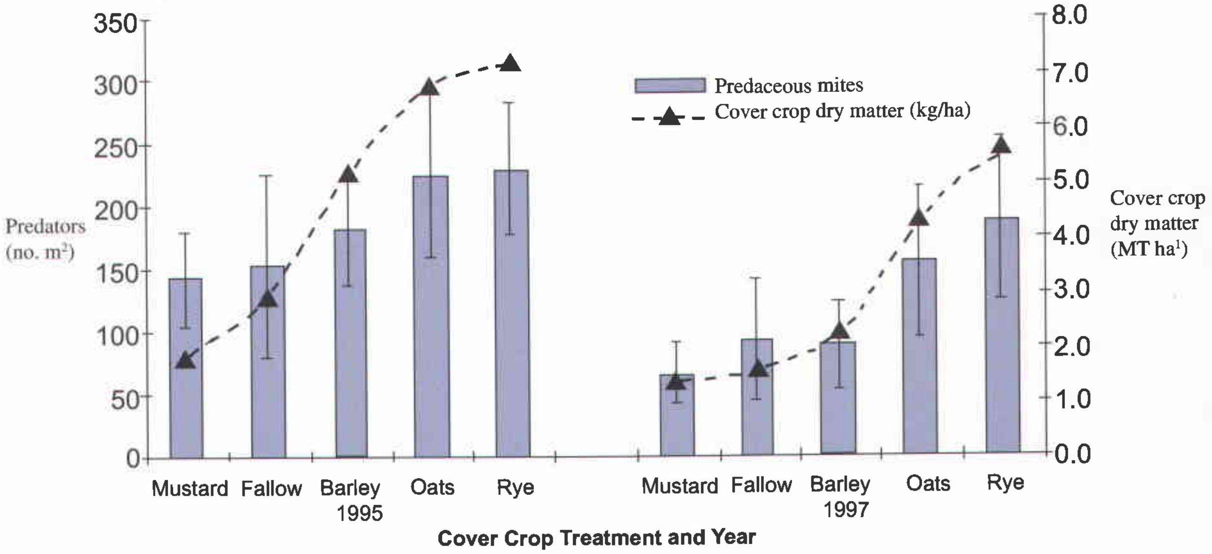

Figure 4. Year and cover crop effects of predaceous arthropods. The cover crop treatments are ordered from lowest drymatter to most in both years. Though there was a poor correlation between individual data points for predaceous mites and cover crop drymater (R-0.42; p-0.021), this figure indicates a close relationship between mean values.

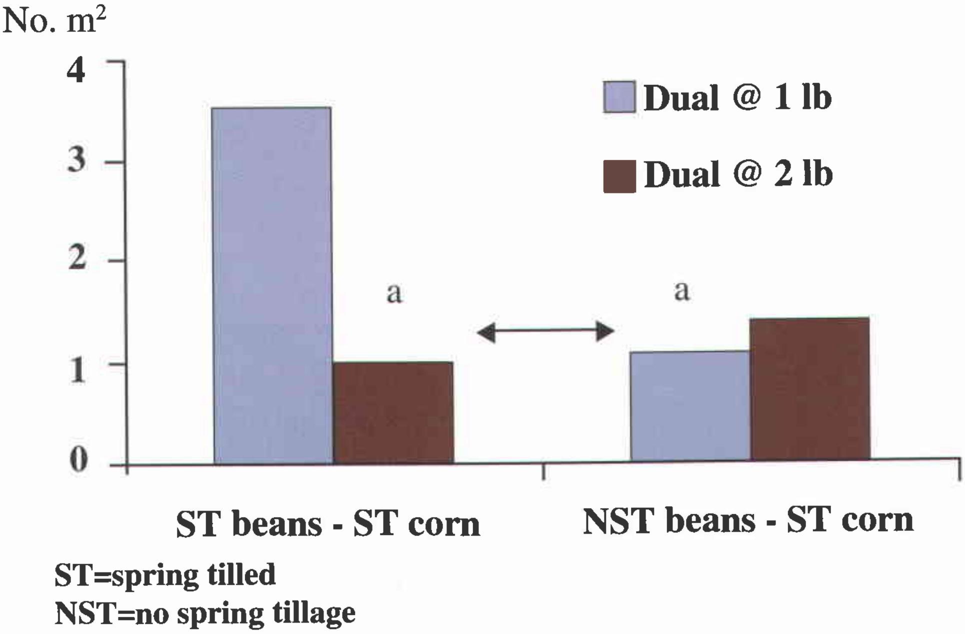

Figure 5. Pigweed presence from tillage regimes conducted in spring for snap beans followed by spring-tilled sweet corn in vegetable crop rotations.

Interpretations

Although allelopathy may explain weed results, soils are complex environments with physical, biological, and chemical variables that interact over time. Analysis and interpretation of foodweb data suggests that tillage and fallow season cover crops are key events in annual cropping systems. These practices impact multiple organisms and system dynamics over time. Allelopathy explains very little weed suppression in our trials. Reducing herbicide use required a change in the fundamental production system toward reduced spring tillage. Perhaps we need to ponder questions about research methodologies along with considering expected results of choosing any one or combination of approaches. Should we expect similar allelopathic results from several species or cultivars of cereal cover crops, or are there other hypotheses we should be considering? Shouldn't soil arthropods respond similarly as weeds to allelopathic toxins, or do all arthropods metabolize toxins or somehow avoid their impact? Can pesticides be reduced within current production systems, or is fundamental change required in the production system to achieve this goal?

In our foodweb studies, data representing flows or relationships over time complimented our causal or proof hypotheses for specific organisms. Our purpose was to suppress multiple pests within a soil ecosystem while minimizing unintended consequences, such as creating new pest complexes or increasing time management requirements by producers. Combining inquiry among farmers, ecologists, and pest disciplines has raised more questions than answers. As 21st century inquirers consider ways to integrate research approaches focusing on ecology, landscapes, causal proof, and human values, opportunities exist for exploring ways to research and implement IPM as an integrated science.

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Enhancing Biological Control with Beneficial Insectary Plants

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Introduction

Beneficial insectary planting refers to introducing flowering plants intentionally into agricultural ecosystems to increase pollen- and nectar-resources required by natural enemies of insect pests. Several species of natural enemies, including aphidophagous (aphid-feeding) hoverflies (Diptera: Syrphidae) and parasitic hymenoptera, depend on pollen and nectar for reproductive success and longevity (Schneider, 1948; Jervis et al., 1993). Surveys of weed and wild-plant compositions in agroecosystems have associated florally abundant, non-crop habitat with higher numbers of pollen and nectar-feeding natural enemies in and around farm fields (Cowgill, 1989; Cowgill et al., 1993) and orchards (Leius, 1967). However, because of agricultural practices such as frequent cultivation and herbicide applications, many farm fields have few flowering plants present, which may limit the potential benefit of these insects for biological control.

Several studies have demonstrated the potential for establishing flowering plants in or around farm fields to attract natural enemies and enhance biological control of crop insect pests in adjacent fields (Kloen and Altieri, 1990; White et al., 1995; Hickman and Wratten, 1996). However, natural enemies are selective in their feeding and show preferences for certain plant species (Cowgill et al., 1993; Lunau and Wacht, 1994).

The goals of the reported research were to assess the potential of selected flowering plants as beneficial insectary plants and to evaluate strategies for using insectary plants to enhance biological control. Three field experiments were conducted in 1997 to evaluate the relative attractiveness of potential beneficial insectary plants; one additional on-farm experiment evaluated the effectiveness of interplanting two species of insectary plants in a broccoli crop to enhance biocontrol of aphids.

Project Objectives

1. Evaluate relative attractiveness of selected flowering plant species to adult aphidophagous hoverflies and parasitic hymenoptera.
2. Identify species of hoverflies associated with selected insectary plants.
3. Evaluate the potential of interplanting alyssum or cilantro in a broccoli field to attract hoverflies and suppress cabbage aphid populations.

Procedures

Relative Attractiveness Studies. The relative attractiveness of 11 flowering plants to aphidophagous hoverflies (Diptera: Syrphidae) and parasitic wasps (Hymenoptera: Ichneumonidae and Brachonidae) was evaluated at the Oregon State University Vegetable Research Farm. Flowers included seven annuals: annual alyssum (*Lobularia maritima*), calendula (*Calendula officinalis*), cilantro

(*Coriandrum sativa*), mustard (*Brassica juncea*), Phacelia (*Phacelia tanacetifolia*), buckwheat (*Fagopyrum esceulentum*), and marigold (*Tagetes patula*), and four perennials: yarrow (*Achillea millefolium*), Korean licorice mint (*Agastache rugosa*), fennel (*Foeniculum vulgare*), and perennial alyssum (*Aurinia saxitalis.*). Flowering plants were grown in 1 m^2 plots in a complete randomized-block design with four replications.

Six of these plants also were evaluated for attractiveness to aphidophagous hoverflies at two organic farms (Denison Farm, Corvallis, OR and Persephone Farm, Lebanon, OR) including three annuals: annual alyssum, phacelia, and cilantro; and three perennials: yarrow, Korean licorice mint, and fennel. At the two on-farm sites, flowers were grown in 1 m^2 plots in a complete randomized-block design with three replications.

Relative attractiveness of flowering plants to hoverflies was assessed by conducting timed observations of feeding-visit frequencies. Numerical abundance of parasitic hymenoptera (Brachonidae and Ichneumonidae) wasps was estimated by timed vacuum sampling. Blooming times of plant species varied, and evaluations were made only during blooming periods.

A sweep net was used to collect hoverflies associated with each insectary flower species; representatives of these hoverflies were sent to Germany and identified by a hoverfly systematist. This reference collection then was used to identify all hoverfly species collected in the experiments.

On-Farm Insectary Interplanting in Broccoli. Alyssum and cilantro were interplanted in a 30-acre commercial broccoli field to asses the potential to attract adult hoverflies and suppress aphid populations on broccoli. Plots were 60 x 60 ft and treatments included: alyssum interplanted with broccoli, cilantro interplanted with broccoli, and a broccoli monoculture. The experimental design was a complete randomized block design with three replications of each set of treatments, with a 60-ft buffer zone of untreated broccoli plants between each treatment block. Alyssum and cilantro were transplanted at the same time the brocolli was transplanted into the field.

Adult hoverfly activity was monitored with yellow pan traps, and hover fly egg and aphid densities on the broccoli were assessed by counts from 60 randomly-pulled broccoli leaves within each treatment plot. All sampling was conducted on a weekly basis. Parasitism rates of the cabbage aphid by the aphid parasitoid, *Dieretiella rapae*, was determined by counting aphid "mummies" on the broccoli leaves.

Results

Relative Attractiveness Studies

In all, 15 species of aphidophagous hoverflies were collected and identified. Although species varied somewhat among the three experimental sites, the six most common aphidophagous species of hoverflies caught in sweep nets were: *Meliscaeva cinctella, Toxomerus marginatus, T. occidentalis, Sphaerophoria sulphuripes, S. pyrrhina,* and *Scaeva pyrastri* (Table 1). Attractiveness of flowering plants to hoverflies differed by dates and sites. Among early-season flowering species, cilantro was the most attractive to hoverflies, followed by alyssum and buckwheat. Mustard, buckwheat, and Korean licorice mint were most attractive to parasitic hymenoptera. Among late-season flowers, fennel and Phacelia were most attractive to hoverflies, but attractiveness to parasitic wasps did not differ among evaluated plants.

Table 1. Hoverfly species present at experimental sites and associated flower hosts in 1997.

Hover fly species	**Location**[a]	**Flower host**[b]
Allograpta micrura	P	cl
Eupoedes fumipennis	P	fn
E. lapponicus	P O	ag ph
Melanostoma mellinum	P	cl
Meliscaeva cinctella	P D O	bk fn yr
Paragus variables	D	yr
Parasyrphus insolitus	D	ag
Scaeva pyrastri	P D	ph
Sphaerophoria sulphuripes	P D O	al au ca cl mu yr
S. opinator	P D O	fn ph yr
Toxomerus marginatus	P D O	al cl ph
T. occidentalis	P D O	ag al cl fn yr

[a] P = Persephone Farm; D = Denison Farm; O = OSU Vegetable Research Farm.

[b] al = alyssum; ag = agastache; au = aurinia; bk = buckwheat; ca = calendula; cl = cilantro; fn = fennel; mu = mustard; ph = phacelia; yr = yarrow.

In this study, as in previous studies, foraging hoverflies exhibited a high degree of selectivity in their feeding (Table 2). Based on fixed time-of-day observations of hoverfly feeding, clearly certain plants evaluated in this study would be better suited as insectary plants. This approach, however, ignores differences in diurnal nectar flow among flowering plants, a factor that could have a major impact on relative attractiveness based on a single period of observation. Also, likely factors that could contribute to erroneous results are differences in hoverfly flight behavior under windy conditions. Although they are strong flyers, under windy conditions hoverflies have difficulty landing on flowers, and lower-growing plants (such as alyssum) would experience less wind than taller plants like yarrow or fennel. The research site at the OSU Vegetable Research Farm was usually quite windy during the late morning (when feeding behavior was observed) and the winds usually would subside in late afternoon.

Table 2. Mean number of adult aphidophagous hoverflies (± SEM) observed visiting flowering plants per 2 min at Oregon State University Vegetable Research Farm in 1997.

	Date							
Flower	**7 June**	**14 July**	**24 July**	**30 July**	**13 Aug**	**21 Aug**	**29 Aug**	**2 Sept**
Alyssum	3.8 ± 1.0a[a]	3.0 ± 1.1ab	1.3 ± 1.0b	1.0 ± 0.4ab	-	- -	-	
Buckwheat	3.3 ± 1.1a	3.0 ± 1.0ab	-	-	-	- -	-	
Calendula	0.8 ± 0.5b	2.3 ± 0.8ab	0.0± 0.0[c]	-	-	- -	-	
Cilantro	-[b] 4.0 ± 1.1a	5.3 ± 1.0a	2.0 ± 0.6a	-	-	- -		
Marigold	- -	0.5 ± 0.5b	0.3 ± 0.3b	0.0 ± 0.0	0.0 ± 0.0	- -		
Mustard	1.0 ± 0.7b	4.0 ± 0.7a	-	-	-	- -	-	
Phacelia	- -	-	-	1.5 ± 0.7	-	- -		
Agastache	- -	-	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	
Aurinia	2.0 ± 0.9ab	1.3 ± 0.5b	0.8 ± 0.5b	0.3 ± 0.3b	-	- -	-	
Fennel	- -	-	-	-	0.3 ± 0.1	0.00 ± 0.00	0.3 ± 0.3	
Yarrow	- -	-	0.3 ± 0.3b	0.3 ± 0.5	0.3 ± 0.3	0.5 ± 0.2	0.3 ± 0.3	

[a] Means followed by different letters within a column are significantly different at a = 0.05.

[b] Dashes indicate plant was not > 50% in bloom.

[c] Observations with 0.00 mean and 0.00 SEM are not included in analysis.

On-Farm Insectary Interplanting in Broccoli

In the interplanting study, *Toxomerus occidentalis* and *T. marginatus* were the two most abundant hoverflies caught in yellow pan traps. Throughout the season, more *T. occidentalis* were caught in pan traps in the alyssum plots than in controls ($p < 0.05$) (Figure 1). Analysis of pan-trap catches by date suggest that increased hoverfly activity associated with alyssum plots extended into the adjacent field (up to 15 m) on the date of peak hoverfly catches.

Aphid sampling revealed no significant differences among mean estimates of aphid densities on the broccoli; however, the overall density of aphids in the experimental blocks was considered a rather low level of aphid infestation. More hoverfly eggs were found in alyssum plots than in the control plots on the second to last sampling date ($p < 0.05$), when the aphid populations had began to increase (Figure 2). The species of hoverfly eggs found on the broccoli leaves was not identified.

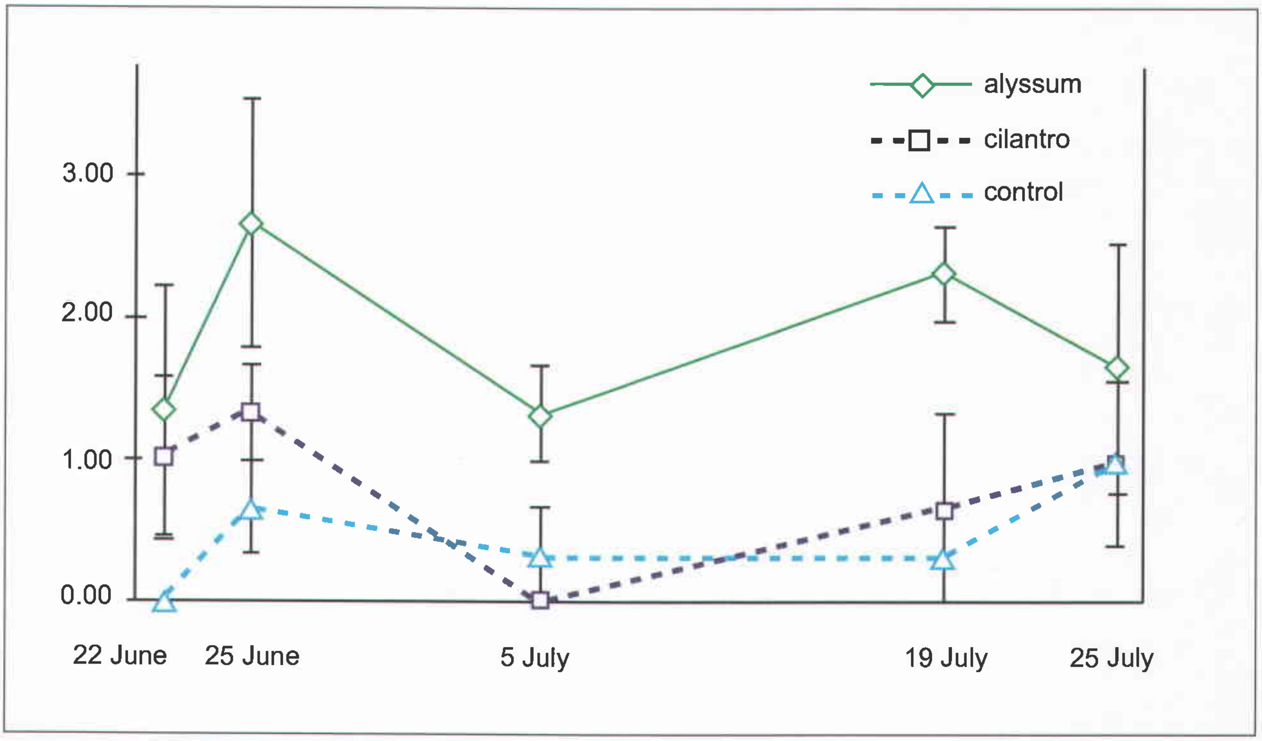

Figure 1. Mean number of female *T. occidentalis* caught in pan traps in treatment and control plots from 22 June to 25 July, 1997 (bars indicate standard errors).

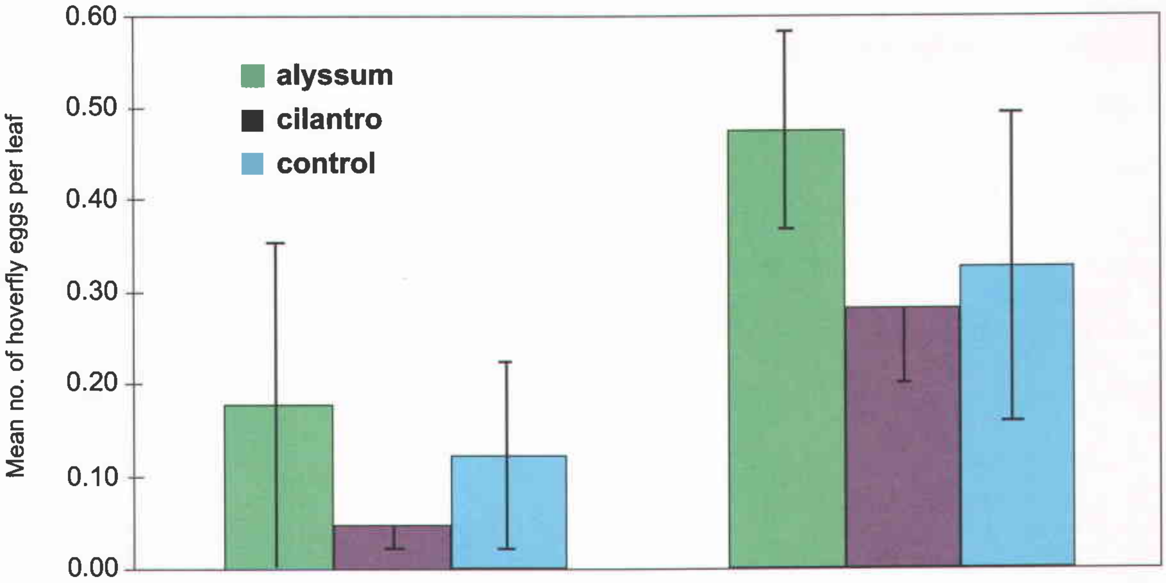

Figure 2. Mean number of hoverfly eggs found on broccoli leaves in treatment and control plots on 16 July and 23 July, 1997. (Bars indicate standard errors.)

Evidence of an association between hoverfly egg laying and aphid densities suggests that egg laying did not occur until late season, because aphid populations had not built up to a critical point earlier. Several published studies have documented a density-dependent oviposition response by some hoverfly species; however, other species lay eggs on the leaves independent of aphid densities. No oviposition behavior has been reported for the hoverfly species trapped in the reported experiment.

Significantly higher numbers of parasitized aphids were found in the alyssum plots than in either the cilantro or control plots (Figure 3), with rates of parasitism nearly doubling. Other studies have shown *D. rapae*, the parasitoid of the cabbage aphid, to be distributed widely, so the effects demonstrated in this study could have implications across many areas.

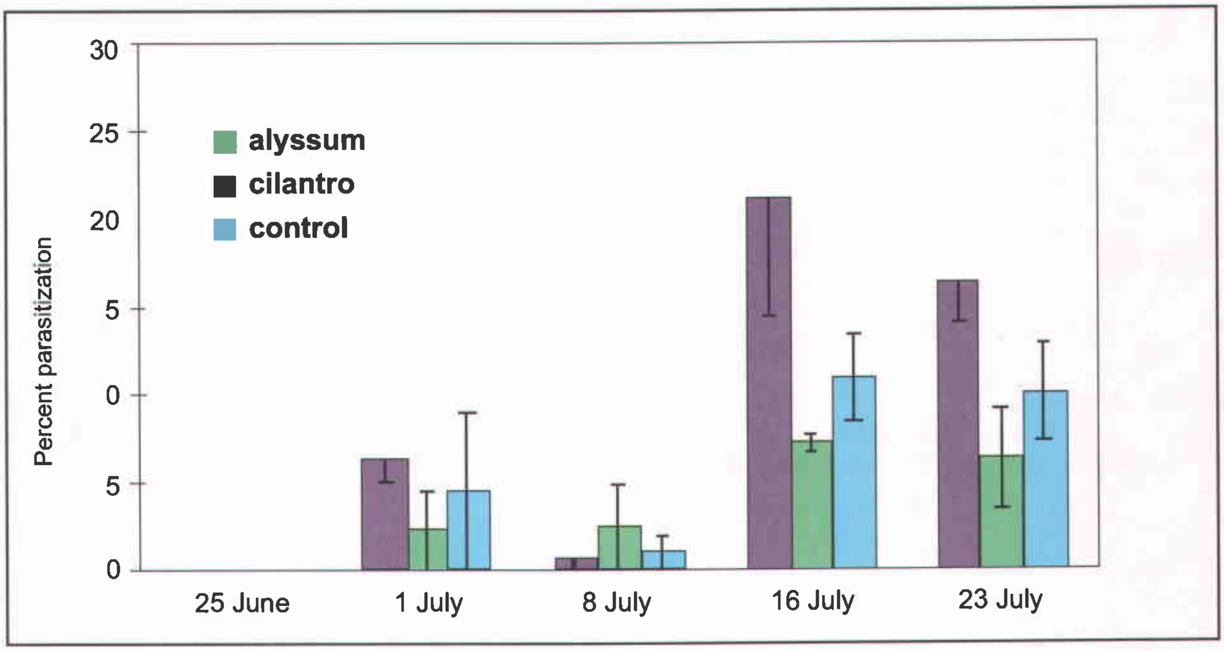

Figure 3. The percentage of aphids parasitized by *Diaeretiella rapae* on broccoli leaves in treatment and control plots from 25 June to 23 July 1997. (Bars indicate standard errors.)

Conclusions

This work shows clear evidence of selectivity of potential insectary flowers by both hoverflies and parasitic hymenoptera. Some flowers appear to be strongly attractive to these natural enemies, some were distinctly less attractive, and some exhibited no attractiveness whatsoever. Interpretation of these data must be tempered by the limitations of a single time-of-day sampling period which could miss key periods of feeding behavior by some hoverfly species. It can be concluded, however, that insectary plants in these trials clearly serving as food resources for hoverflies include annual alyssum, cilantro, buckwheat, mustard, phacelia, fennel, and yarrow.

The results also reveal a differential attraction among hoverfly species to various insectary plants. In addition, the predominant species of hoverflies ocurring in western Oregon have been identified and a taxonomic reference collection developed, housed in the Department of Horticulture at OSU. This collection is available to anyone interested in hoverfly identification.

In the on-farm interplanting study, there was strong evidence that annual alyssum attracted more hoverflies into the experimental plot areas and more hoverfly eggs were laid on the broccoli plants. There was also an "alyssum" effect extending up to 45 feet outside the edge of the treatment blocks which increased numbers of hoverflies trapped.

In this trial, there was no apparent effect of the interplanted flowers on abundance of aphids on the broccoli plants. Aphid population levels were generally low throughout the experimental plots.

These experiments clearly demonstrate the potential of insectary plantings for increasing natural enemy abundance and behavioral response (increased egg laying and parasitism) in a commercial-scale field setting. The experiments have not, however, shown evidence of pest reduction through the use of insectary plants. Merely increasing natural enemy abundance or even actually increasing parasitism rates (as in the case of increased rates of parasitism of the cabbage aphid by *D. rapae* in this experiment) doesn't necessary translate to a "biologically significant" level of improved pest control which reduces or eliminates the need for insecticidal control.

Acknowledgments

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Evaluation of Potential Fall-Seeded Cover Crops for Weed Suppression and Beneficial Insect Habitat

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Objectives

1. Identify broadleaf plants with pollen and nectar attractive to a variety of beneficial insects, which can establish well after fall seeding and begin to flower early the next spring.
2. Establish replicated plots of these plants, alone and in a mix, for the purpose of observing growth and management characteristics.
3. Identify the various insects attracted to each plant.

Ultimate goal

Find a well adapted, easily grown cover crop mix which would host sufficient population of beneficial insects/mites for natural suppression of twospotted spider mite and orange tortrix populations in raspberry.

Progress

Plots of the following plants were seeded and irrigated on September 23, 1997 at North Willamette Experiment Station (NWREC): *Achillea* sp. (yarrow); *Hesperis matronolis* L. (dame's rocket); *Cherianthus allonii* (wallflower); *Phacelia tanecetifolia*; *Carum carvi* (caraway); *Avena sativa* (Amity oat); and a mixture of all six. Germination, establishment, weediness, winter survival, and time of flowering were monitored. Insects were vacuumed from blooms on sunny afternoons (noon to 2:00 pm) from early April to early June.

With the exception of the achillea and oats, all plots became quite weedy. Wallflower was the first to flower (early April through May), followed by hesperis (mid-April through May), phacelia (late-April through May), 'Amity' oat (mid-May through mid-June), and achillea (early June through September).

Insects were vacuumed from blossoms, identified, and classified as being potentially harmful, benign, or potentially beneficial. Because parasitic wasps are of special interest as potential biocontrol agents of the orange tortrix, parasitic wasps were identified to family. Dogfennel (*Anthemis cotula* L.) and hairy vetch (*Vicia villosa* Roth) were the primary weeds in all plots. Blossoms from these weeds also were vacuumed and associated insects identified. Because of time constraints, June 9 was the last sampling date; therefore, insect counts are based on five sampling dates in the oats and dogfennel, two sampling dates in the vetch, and one sampling date in the achillea. A summary of all insects retrieved appears below.

Potentially harmful insects most often associated with the cover crops were leafhoppers, aphids, and plant bugs. Of the plants evaluated in this trial, the 'Amity' oat appeared particularly attractive to leafhoppers, and phacelia appeared most attractive to plant bugs. Benign insects most often associated with the cover crops included flies (mostly long-legged), midges, fungus beetles, fungus gnats, and seed beetles. A total of 36 braconid and 26 ichneumonid wasps were recovered from nine sample dates in *Cherianthus*, with the highest proportion recovered in early May. In all, 65 braconid and 24 ichneumonid wasps were recovered from 11 sample dates in *Hesperis*, with the highest proportion recovered in early-mid-May. The *Phacelia* drew a great number of bees and also appeared more attractive to syrphid flies than the other plants. A total of 23 braconid, 10 ichneumonid, and 25 chalcid wasps were recovered from five sample dates in 'amity' oat. The dogfennel appeared attractive to ground beetles and ichneumonids. Because Achillea did not flower until June, it was only sampled once. However, observations during the summer showed considerable insect activity, and achillea is reported to be attractive to parasitic wasps and syrphid flies.

Insects Associated with Flowering Cover Crops, NWREC, 1998

Plant	Potentially Harmful	Benign	Potentially Beneficial
Cherianthus 4/20-6/9 9 sample dates	leafhoppers 93 aphids 60 plant bugs 15 thrips 15 cucumber beetles 3	flies* midges fungus beetles seed beetles	braconids 36 (5/4 18) ichneumonids 26 (5/4 9) chalcids 3 (all on 6/1) ladybird beetles 6; spiders 10; ground beetles 25; bees 24; lacewings 6
Hesperis 4/20-6/9 11 sample dates	leafhoppers 134 aphids 86 plant bugs 22 thrips 14	flies fungus gnats fungus beetles midges	braconids 65 (5/6 34) ichneumonids 24 (4/20-5/28) chalcids 4; other hymenoptera 1; ladybird beetles 6; spiders 26; ground beetles 19; bees 28
Phacelia 4/30-6/9 8 sample dates	plant bugs 84 leafhoppers 66 aphids 47	flies fungus beetles midges	braconids 22 (5/4 13) ichneumonids 6 chalcids 2; other hymenoptera 2 ladybird beetles 3; spiders 20; ground beetles 25; bees 72; syrphid flies 9; lacewings 1; soldier beetle 1
'Amity' oat 5/26-6/9 5 sample dates	leafhoppers 265 aphids 84 plant bugs 13 thrips 18	midges flies fungus gnats fungus beetles	braconids 23 ichneumonids 10 chalcids 25; other hymenoptera 6; ladybird beetle 5; spiders 16; ground beetles 3; bees 10
Dogfennel 5/18-6/3 5 sample dates	leafhoppers 30 aphids 17 plant bugs 9 cucumber beetles 4	flies fungus beetles midges	braconids 5 ichneumonids 24 (5/26 & 5/28) ladybird beetles 3; spiders 4; ground beetles 54; bees 26 lacewing 1
Hairy vetch 5/26 & 5/21 2 sample dates	leafhoppers 27 plant bugs 7 thrips 17 aphids 3	flies seed beetles fungus beetles midges	braconids 9 ichneumonids 2 ground beetles 3; bees 15; spiders 2
Achillea 6/9			syrphid fly 1; spiders 7; ground beetle 1; bees 1

*flies = mostly long legged flies
bees are a total of halictid, bumble, and honeybees

Field Evaluations of Meadowfoam Seedmeal to Control Clubroot Disease (*Plasmodiophora brassicae)* in Cruciferous Crops

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Introduction

Clubroot disease (caused by *Plasmodiophora brassicae)* is one of the most serious soil-borne diseases of cruciferous vegetable crops in the Pacific Northwest. It occurs in most of the major crucifer growing regions and is a serious threat to fresh market and processing industries. Furthermore, soil-borne diseases like clubroot *(Plasmodiophora brassicae)* and soft rot *(Sclerotinia sclerotiorum)* force growers to avoid growing cruciferous crops on the same land once infested. For example, the considerable longevity of clubroot disease pathogen (resting spores of *P. brassicae)* in the soil (18 or more years) means that the major effect is often one of restricting the flexibility of crop rotations, as contaminated land cannot be used for cruciferous crops for fear of increasing the inoculum to grossly damaging levels. With the reduction in number of registered pesticides that are effective in vegetables, growers are under pressure to find economic alternatives to manage these pests.

Meadowfoam, *Limnanthes alba*, is a herbaceous winter-spring annual, grown as a commercial oilseed crop in the Willamette Valley of Oregon. Its unique oil consists almost entirely of long-chain fatty acids which are used in the manufacture of lubricants, plastics, and cosmetics (Kleiman and Princen, 1991; Seddigh and Jolliff, 1994; Savonen, 1997). Meadowfoam also has become a valuable rotation crop for grass seed growers. As a rotational crop, meadowfoam allows for a "resting period" on heavily cropped soils, is an alternative to field burning, and has become an important tool in seed certification programs (O. Gutbrod, OSU Seed Certification, personal communication). The seedmeal remaining after oil extraction typically was discarded.

Limnanthes species produce large amounts of secondary metabolites such as glucosinolates and phytoecdysteroids, which have allelochemical activity. Glucosinolate degradation products have been shown to be potent biocides (Baratelt and Mikolajczak, 1989; Brown et al., 1991; Gamliel and Stapleton, 1983; Delaquis and Mazza, 1995). Glucosinolate products also have been shown to influence bacterial and fungal populations (Brown and Morra, 1997). Use of glucosinolate-containing plants as green manures or soil amendments to suppress weeds and soil-borne pathogens may provide alternatives to soil fumigants such as methyl bromide (Vaughn, 1999).

Experiments conducted in greenhouses at Northwest Transplants, Molalla, Oregon, and Oregon State University (OSU) in 1998 examined the effect of meadowfoam residues (seedmeal and screenings) for controlling clubroot disease in cauliflower and Chinese mustard grown in pots (Deuel and Svenson, 1999). All treatments with meadowfoam residue incorporations resulted in 100 percent control of clubroot, compared to 70 to 90 percent disease presence (clubbing of root system) in controls for both plant species. In addition to complete control of clubroot, treatments containing low rates of meadowfoam resulted in taller plants. The potential of meadowfoam seedmeal (MSM) for controlling clubroot of cauliflower and mustard was examined in field trials during the summer/fall growing season of 1999.

Materials and Methods

Two field trials were conducted during the summer/fall (August-November) growing season of 1999. Each trial was a completely randomized block design of nine replicate plots 8 m x 1.6 m (three rows per plot). Both trials were conducted at a site naturally infested with clubroot on crucifer growing property of Big "B" Farms, Aurora, Oregon. Meadowfoam treated plots were prepared by hand, spreading dry seedmeal uniformly within designated plots at rates of 15,000 and 30,000 kg ha^{-1} followed by tiller cultivation for incorporation at 20 to 30 cm depth. All plots were irrigated and allowed to stand fallow for a 10 day "activation period." Cauliflower seedlings *(Brassica oleracea* var. *botrytis* 'Snowball

Y Improved') were transplanted at the local planting density (maximum 60,000 plants ha^{-1}). Mustard *(Brassica campestris* var. *chinensis* 'Southern Curl') was seeded using a similar planting density. At 5 days post-transplant of cauliflower and 14 days post-seeding of mustard, a comparative treatment of ionic surfactant (Aqua Gro 2000® at a surfactant-to-water ratio of 1:125) was applied as a drench in a continuous band at the base of transplants/seedlings in specified plots. Fertilizer (16-16-16) and granular insecticide (Lorsban® for cutworm control) was applied in a continuous band along the rows at 5 days post-transplanting at manufacturer suggested rates. Irrigation regimes were applied according to grower's discretion. At 90 and 70 days post-planting of cauliflower and mustard (respectively), six plants were chosen randomly from the center row of each plot and evaluated for clubroot severity. Cauliflower also was evaluated for yield (head mass) while mustard was evaluated for overall height. The fresh weight yield of cauliflower and overall height of mustard was recorded, and disease severity (root galling) was assessed visually on a four point scale (1 = no galling; 2 = less than 10 percent roots galled; 3 = 10 to 50 percent roots galled, and 4 = more than 50 percent roots galled). Data were subject to analysis of variance.

Results

MSM treatments significantly (p-value <0.01) reduced the severity of clubroot in cauliflower and significantly increased marketable yields compared with untreated controls and plots treated with a surfactant drench (Table 1). MSM treatments significantly (p-value <0.01) reduced the severity of clubroot in mustard but did not increase plant height compared with untreated controls and plots treated with a surfactant drench (Table 2). Treatments with a surfactant drench generally reduced severity of clubroot (p-value <0.05) in cauliflower transplants, but generally did not reduce clubbing in seeded mustard. Furthermore, the surfactant drench had no apparent effect on cauliflower yields or mustard plant heights.

Higher rates of MSM resulted in some phytotoxicity in both cauliflower transplants and mustard seedlings. Moreover, emergence of mustard seedlings was delayed by all treatments of MSM. In addition, reduced weed populations were observed in MSM treatments compared with untreated and surfactant treated plots. Statistical data was not gathered for the phytotoxicity, emergence delay, or weed suppression parameters.

Table 1.
Evaluation of Meadowfoam Seedmeal (MSM) for Control of Clubroot in Cauliflower

Treatment	Disease severity (104)	Yield - kg/head
Untreated	2.25	0.66
MSM x 1	1.15 *	1.06 *
MSM x 2	1.52 *	1.05 *
Surfactant	1.85	0.73

*Significant at the 1% level

Table 2.
Evaluation of Meadowfoam Seedmeal (MSM) for Control of Clubroot in Mustard

Treatment	Disease severity (104)	Yield - kg/head
Untreated	2.5	55.57
MSM x 1	1.31 *	55.9 *
MSM x 2	1.38 *	58.33 *
Surfactant	2.39	58.09

*Significant at the 1% level

Discussion

The potential of MSM treatments to reduce the severity of clubroot in cauliflower and mustard was demonstrated in these trials. In addition, marketable yield of cauliflower was increased significantly with MSM treatments. A comparative treatment of surfactant drench generally reduced severity of clubroot in cauliflower transplants but had minimal effect on clubbing of seeded mustard. The efficacy of a surfactant drench applied to a transplant compared to a seeding may be a determining factor for clubroot suppression. There were no significant differences between rates of MSM on clubroot severity, plant height, or yield. However, the higher rate of MSM resulted in greater phytotoxicity and delay of mustard seedling emergence (data not shown). Further field trials using reduced rates of MSM should be conducted to determine optimal rates for avoiding phytotoxic effects in desired crop while providing maximum control of clubroot.

Clubroot (caused by *Plasmodiophora brassica)* is a complex and difficult disease to culture and/or maintain in a controlled environment. Thus, the complexity of this disease limits our understanding of factors controlling disease severity. Differences in glucosinolate patterns between susceptible and resistant crop varieties are thought to play an important role in host-pathogen interactions (Ludwig-Muller et al., 1997; Mithen et al., 1996). We suspect pre-plant stimulation (fungistasis) of the pathogen resting spores by glucosinolate products present in the meadowfoam residue as the primary control mechanism. Discovery of a plant exudate mimic that effects fungistasis in a major plant disease pathogen has far reaching implications. However, further investigation is needed to determine the factor(s) in MSM responsible for reduced severity of clubroot.

The high rates of MSM used in these trials may represent a cost prohibitive control of clubroot. Furthermore, the use of meadowfoam as a cover crop and/or green manure to obtain similar control of clubroot is currently unknown. In many cruciferous production systems, few growers use green manure crops prior to planting cole crops in the spring. Most sites are left fallow during the winter. Growers and processors alike have voiced concern over this present situation and are also becoming increasingly interested in finding sustainable systems that have additional benefits, such as those that improve soil tilth, increase yields, and reduce pests. Meadowfoam cover crops and seedmeal applications show great promise as cost effective weed management tools in many agriculturally important crops, and may offer additional benefits such as increased soil nutrients, plus suppression of insects, slugs, nematodes, bacterial pathogens, and other soil-borne organisms. The use of meadowfoam cover crops, green manures, defatted seedmeal applications, or in combination within multiple commodities, also could minimize synthetic pesticide use, reduce the associated potential for environmental contamination, and contribute to sustainable agricultural production systems on a large scale.

Acknowledgments

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Banker Plants: Strategies for Release of Predaceous Mites to Control Spider Mites in Outdoor Ornamental Nurseries

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Introduction

Mites in the Tetranychidae, Eriophyidae, and Tarsonemidae are major pests of commercial ornamental nurseries. Historically, ornamental producers have relied on chemical applications to suppress pest mites in these high-value plants (Brushwein, 1991; Mizell and Short, 1992). An alternative to chemical control of pest mites is the introduction of predaceous mites (Phytoseiidae) into nursery crops. Recent studies have evaluated the use of *Neoseiulus fallacis* (Garman) to control pest mites on ornamentals and have demonstrated that inoculative releases can reduce populations to the extent of eliminating miticide applications (Pratt and Croft, 1999; Pratt and Croft, 1998).

Unfortunately, only limited attention has been given to identifying methods of releasing predatory mites into nursery systems. Although other methods occasionally have been used (McMullin, 1995), introduction of predatory mites usually consists of purchasing predators and distributing them, by hand, into infested foliage (Pratt, personal observation). This procedure can be labor intensive and expensive, especially when multiple releases per season are required (Cashion et al., 1994; Brushwein, 1991). In addition, improper timing of releases has been implicated in many biological control failures (Stiling, 1993; Beirne, 1975). In ornamental systems, releases of predatory mites in the absence of prey might result in starvation of the predator, and release of predators in abundance of prey might cause unacceptable damage on the ornamental crop.

Ramakers and Voet (1996) described an alternative method of rearing and dispersing predatory mites from banker plants in greenhouse systems. Banker plants are any plant addition that aids in development and dispersal of predators for control of herbivorous pests. In castor bean banker plants, predatory mites fed on pollen and extrafloral nectaries and dispersed from the host plants to other plants, suppressing pests such as thrips and spider mites for several months. To our knowledge, banker plants have not been evaluated for production and release of predatory mites in outdoor ornamental plants.

Banker Plant Concepts

To give perspective to our research, it is important to describe a "banker plant system." The three basic components are the predatory mite, the banker plant and the prey or alternative food. Each is dependent and influences the others in complex ways (Fig. 1).

The Predator

Does the predator suppress the pest in the nursery crop? The ultimate objective is to control spider mites in ornamental crops. Thus, the initial criteria for selecting a predatory mite must be that it responds and can suppress the spider mite pest in the crop(s) of interest. Initial tests of predator-crop plant interactions must be conducted prior to incorporating a predator into a banker plant system.

Is the predator oligophagous? Preferably, the prey or the alternative food on the banker plant will be different than the mite pest that feeds on the ornamental crop. Thus, phytoseiid predators possessing a wide prey or food range might be more easily integrated into a banker plant system (Pratt et al., 1999).

Will the predator numerically respond to the prey or alternate food in the banker plant? The banker plant and associated foods can potentially serve as a rearing unit for the predatory mite. Therefore, initial inoculations of the predator into the banker plant system might be quite low if the predator numerically responds greatly to the prey or alternate foods. The extent of onsite rearing of the predatory mite often will reduce the costs of purchasing, transporting, and dispersing the predators appreciably.

Will the predator remain on the banker plant? Most arthropods are influenced by substrate types. For instance, predatory mites are affected by leaf domatia, indumentum, plant turgor, pollen availability, extrafloral nectaries, overwintering sites, etc. (Walter and O'Dowd, 1992; Pemberton, 1998). For this reason, selection of a banker plant must account for the acceptability and long-term colonization by the predator.

Is the predator a good disperser? Aerial dispersal among predatory mites is accomplished by entering the air currents and dropping to foliage downwind (Helle and Sabelis, 1985). Behavioral and morphological adaptations among predatory mites might increase the dispersal distance of some species (Johnson and Croft, 1979; Pratt et al., 1998). For example, body size, body shape, setal length, and behavioral adaptations such as different forms of "posturing" are believed to affect rates and distance of dispersal of these mites (Jung and Croft, 1999). Knowledge of the distance and rate of dispersal by the predatory mite will influence the location and number of banker plants that are necessary in the nursery system.

The Banker Plant

Is the banker plant an adequate host for the prey? A suitable prey for the predator must develop and reproduce on the banker plant. If prey densities are greatly affected by inferior banker plant quality, then the densities of dispersing predatory mites will be affected similarly. Degradation of the banker plant to an inadequate state will reduce the longevity of the system.

Is the banker plant tall (or can it be maintained in an elevated position)? Because dispersal of phytoseiid mites is determined in part by the height of the take-off location, tall banker plants might aid in long-distance dispersal of the predatory mite. Increasing the height or elevation of the banker plant might increase the distance between banker plants and thereby decrease the number of plants that are required to achieve coverage with predators in the nursery system.

Does the banker plant provide spatial refugia? Population reductions or extinction of prey or alternate food by overexploitation by the predator will affect longevity of the banker plant system (continued dispersal of predators). One method to maintain the dispersing predator population is if the banker plant possesses refugia for the prey (Hawkins et al., 1993). For instance, the stems on new shoots of some rhododendron varieties possess a sticky material that impedes colonization by predators of the new leaves. In contrast, *Oligonychus illicis* (McGregor), the prey mite, does not seem to be as negatively affected, and consequently it can develop large populations in a refuge on new leaves (Pratt, unpublished data).

The Prey or Alternate Food

Can the prey negatively affect the ornamental crop? If spider mites are used, it is quite probable that the prey on the banker plant will disperse to the surrounding environment. Therefore, the prey must not cause any negative effects on the ornamental crop of interest. If information on host range of the banker plant prey is not available, preliminary studies must be performed to determine this risk.

Is the prey synchronized with the predator? Prey or alternate food must be available to the predator for development and reproduction. Data suggest that some spider mites have lower developmental thresholds and therefore can develop appreciably while the predator is unable to develop (Helle and Sabelis, 1985). Similarly, pollen and other foods might be available or acceptable only for specific intervals. This asynchrony might negatively affect the densities of predators produced and dispersed from the banker plant.

Does the prey or alternate food have temporal refugia from the predator? As previously mentioned, long-term production of prey might be accomplished with refugia. Stages of the prey or alternate food that are not available for predation might serve as refugia for the prey. For instance, it has been documented that the egg stages of some spider mites are inaccessible to the predator (Helle and Sabelis, 1985). Refugia of this type might reduce overexploitation of the food source and improve continued predator dispersal.

In the experiments described hereafter, we sought to evaluate several of the criteria for a good banker plant system that were raised in this general section. Specific objectives of our studies included to: 1) measure the ability of *N. fallacis* to numerically increase on banker plants and disperse to mite-infested leaves downwind, and 2) determine whether reintroduction of spider mites into the banker plants would increase the duration and quantity of dispersed *N. fallacis*.

Materials and Methods

Mite Sources, Greenhouse Facilities, and Receiver Plants

Predatory mites used in these studies were provided by Biocontrol Works of Jefferson Oregon, USA. Predatory mites were reared on bean plants that had been infested with *T. urticae* and collected just prior to extinction of the prey (Pratt et al., 1998). Bean leaves containing all life stages of

N. fallacis and a few individuals of *T. urticae* were placed in the canopy of each respective banker plant at rates described below. The prey mites, including *Oligonychus illicis* (McGregor) and *O. ununguis* (Jacobi), were collected in mid May from field-grown ornamental plants. *T. urticae* was taken from a laboratory culture that was periodically mixed with field-collected specimens.

In the initial three studies, a pair of identical 10 x 4 m greenhouse rooms with internal conditions of 26:21 (±10) °C (D:N), photoperiod 16:8 (L:D) h, and 75% (±10) R.H. were used. Four 1 x 3 m benches were placed 1.5 m apart in each of the greenhouse rooms. A 1.5-m-high muslin curtain was hung above each bench so that the curtain created two isolated cubicles (1 x 1.5 x 1.5) on top of each bench. The bottom 10 cm of the curtains rested in a 10-cm-deep water moat within the benches, thus saturating the 4 muslin walls of each cubicle with water. A fan, placed against one of the walls of each cubicle, produced wind speeds of approximately 2.4 m/s .

Receiver plants consisted of a dense canopy of lima bean (*Phaseolus lunatus* L.) leaves covering a circular area of 0.3 m diam (±5 cm) each. These receiver plants were designed to catch predatory mites as they dispersed from banker plants (Pratt et al., 1998). To make the receiver plants, a total of 55 (±3) seeds were planted into a polyethylene bag (30 cm diam) that was filled with a potting mixture of pumice, sand, peat moss, and soil (2:1:1:1) (Strong and Croft, 1995). Seeds germinated in 1 week, and 1 week later each leaf of each plant was inoculated with 50-100 mixed life stages of *T. urticae*.

Dispersal from Banker Plants and Reintroduction of Prey

To determine whether the predator *N. fallacis* would numerically respond to prey on a banker plant and disperse downwind to receiver plants, we used the greenhouse system as described above. Sixteen arborvitae plants (*Thuja occidentalis* 'Pyramidalis'; height: 1 m ±5 cm, diam: 23 cm ±3 cm, potted in 3.8 L plastic containers) were inoculated with 2,000 (±150) *O. ununguis,* and 30 days later populations had increased to 450 (±23) spider mites (all stages) per 6 cm terminal. Two arborvitae (placed in close proximity to each other) and three receiver plants were randomly assigned each of eight cubicles that served as replicate environmental units. The arborvitae banker plants were placed in the trajectory of the wind between the fan and the receiver plants. The lateral distance separating the fan and the receiver plants from the banker plants was 30 cm. Five hundred mixed life stages of *N. fallacis* were inoculated into each of the banker plants. Leaves of the receiver plants were viewed every day for 37 days, and the number of predatory mites found in receiver plants per replicate was recorded. When predatory mites were found on leaves of the receiver plants, the leaf was excised and taken out of the greenhouse. Receiver plants were sufficiently dense with bean leaves that vacant areas in the canopy were not created by destructive sampling. Because of possible oviposition from a few dispersing female predators that were not removed in sampling, receiver plants were replaced every 5 days (minimum development time of predator from egg to adult; Pratt et al., 1998). Life stages of dispersing *N. fallacis* were only recorded 1 day after receiver plants were replaced. Relative densities of predator and spider mites on each banker plant were estimated by removing the terminal 6 cm of foliage from three randomly selected branches each week and recording mites under a 40X microscope.

Eight rhododendron plants ('Ana Krushke'; height: 0.5 m ±6 cm, diam: 30 cm ±5 cm, 3.8 L plastic containers, and 45 (±6) leaves per plant) were inoculated with ca. 500 *O. illicis,* and 30 days later populations had increased to 125 (±32) per leaf. Two plants were randomly placed in each of 4 cubicles, as explained above, and 250 predatory mites (of all life stages) were released onto each rhododendron. Sampling and replacement of receiver plants were preformed as in the arborvitae study. Relative densities of predatory and spider mites on the rhododendrons were estimated by scanning five randomly selected leaves on each plant once a week under a 40X microscope.

Without the presence of any alternative foods such as pollen or plant fluids, *N. fallacis* is dependent on spider mite prey for continued reproduction and development (McMurtry and Croft, 1997; Croft et al., 1998). For this reason, we suspected that dispersal of *N. fallacis* individuals into receiver plants would be minimal at the onset of the experiment, increase as predators depleted the prey source, and would again decline as prey were driven to extinction. We questioned whether the number and interval of *N. fallacis* dispersants could be extended by reintroducing prey. We randomly selected 4 arborvitae banker plants from the previous study and reinoculated each with ca. 50,000 *T. urticae* (mixed life stages) 21 days after release of *N. fallacis* into the banker plant. Reinoculation was accomplished by placing spider-mite-infested bean leaves (*P. lunatus*) directly into the arborvitae foliage. Dispersal of *N. fallacis* from reinoculated banker plants to receiver plants was compared to that of the remaining four untreated banker plants.

Statistical Analysis

Repeated measures analysis of variance (ANOVA) was used to compare the dispersants recovered in receiver plants over time (von Ende, 1993). The Huynn-Feldt adjustment was used when the covariance matrix of the data did not meet the assumption of sphericity (SAS Institute, 1990). The dispersal index was calculated by dividing the number of individuals dispersed per day by the total number of *N. fallacis* inoculated into the system.

Results

Dispersal from Banker Plants and Reintroduction of Prey

In tests run in replicated greenhouse cubicles, an average of 25 (± 6.08) *N. fallacis* individuals dispersed from arborvitae banker plants into receiver plants on day 7, and 10 days later the average increased to 180 (±12.77) (Fig. 2). The number of *N. fallacis* found in receiver plants decreased to 18 (±4.83) over the next 5 days, and the cumulative number of dispersed individuals over the first 21 days was 1,620 (±8.09). The dispersal index was 0.02 or greater for days 7-21. After reintroduction of spider mites into arborvitae banker plants on day 21, a 5-day decrease in dispersal of *N. fallacis* occurred, which was followed by a second dispersal event, peaking at 66 (±5.15) individuals. In the banker plants where spider mites were reintroduced, the dispersal index was 0.02 or greater for 8 days as compared to 3 days for the control. When compared with a repeated measures ANOVA, the reintroduction of *T. urticae* into the arborvitae banker plants significantly increased the number of *N. fallacis* found in receiver plants as compared to the control (P=0.023, F= 41.89, df=1).

The number of dispersing immatures seemed to increase over time, but in a delayed way compared to the adult females (Fig. 2). Less than 1 percent of the total population of dispersing *N. fallacis* were immatures in the first 10 days of the experiment (Fig. 14). As the prey density decreased in the arborvitae banker plants during the next 10 days, the proportion of immatures dispersing increased to 75 percent of the total mites collected in receiver plants.

The number of *N. fallacis* dispersing from rhododendron banker plants into the receiver plants in small greenhouse cubicles increased to 27 (± 4.58) individuals on day 15 and remained above 20 individuals dispersed for 4 days (Fig. 3). The cumulative number of *N. fallacis* dispersed from rhododendron plants during the entire study was 368 (± 10.30). The dispersal index was 0.02 or greater for days 12-25. During this study, new plant growth developed and was determined to be unsuitable for *N. fallacis* due to the sticky substance on the branches and leaves. This substance slowly deteriorated and on day 28 spider mites were found on the new growth of the rhododendron. Predators were not found on this new growth.

Again, the ratio of immatures to adult females dispersing from rhododendron plants increased over time (Fig. 3). When prey densities were high in the banker plants in weeks 1 and 2, only 4 percent of the dispersants were immatures. As prey densities decreased in banker plants on weeks 3 and 4, 81 percent of the predators found in receiver plants were immatures.

Discussion

The inoculation of *N. fallacis* into spider-mite-infested arborvitae and rhododendron banker plants resulted in an increase of predatory mites and dispersal of biological control agents to spider-mite-infested plants downwind. With respect to rearing of predators, approximately 1,000 more *N. fallacis* were collected from receiver plants than were initially inoculated into arborvitae banker plants. These increases in predators produced are conservative when considering that some individuals might have been lost in water or muslin barriers. In addition, >5 *N. fallacis* per day dispersed from arborvitae and rhododendron plants for 28 and 13 days, respectively. This long period of predatory mite release into plants might aid in synchronization of predator-prey interactions for control of spider mites.

The reintroduction of prey into the arborvitae banker plant increased the dispersal duration of

N. fallacis (Fig. 2). Further field studies are needed to determine whether reinoculation of spider mites is necessary or whether repeated introductions of spider mites or alternate food might create a perpetual, season-long banker plant. Also of interest was the 5-day reduction in dispersal of *N. fallacis* directly after reintroduction of spider mites. Possibly, starving *N. fallacis* stopped dispersing in response to spider-mite-induced plant volatiles, or the physical presence of prey might have caused them to start feeding again and stop dispersing (Sabelis, 1985; Maeda et al., 1998). *Neoseiulus fallacis* also has been shown to develop and reproduce when held with pollen and other alternative foods (Pratt et al., 1999; Zhang and Li, 1989). Addition of pollen might increase the number and duration of *N. fallacis* in the banker plant similarly as when spider mites were added.

Immatures of *N. fallacis* seemed to increase their rate of movement from plants as spider mite prey decreased in banker plants. These studies in a small cubicle with a short distance between the banker plants and receiver unit do not distinguish between active dispersal and dislodgment of immatures from the plant substrate. Immature stages become more active in searching for food as prey levels decrease and subsequently might have higher rates of dislodgment from the banker plant. This explanation is consistent with within-plant movement studies of *N. fallacis* immatures (Croft et al., 1995). Another possible explanation, but a less likely one, is that immatures might enter an active aerial dispersal phase, similar to that of the adult females.

Integration of a banker plant system into an ornamental nursery operation is a site-specific phenomenon. Although similarities exist among all such systems, each nursery facility has a unique set of factors that must be considered. For instance, the ornamental crops for which control is needed, cultural practices, and physical layout must be considered in the banker plant design. One attribute of banker plants that is highly desirable is plant mobility. By producing the banker plants in plastic containers, the system can be redistributed spatially or elevated to increase long-range dispersal of the natural enemy. Also, mobility of the banker plants might allow them to be removed from direct application of fertilizers or harmful pesticides (Croft, 1990). Banker plants also can be developed from existing hedgerows within the ornamental production facility. Various commercial nurseries have arborvitae surrounding portions of the production site, and, assuming these hedgerows contain spruce spider mites, *N. fallacis* can be inoculated into the hedgerow. The use of an existing hedgerow would require fewer adjustments to current cultural practices of the nursery.

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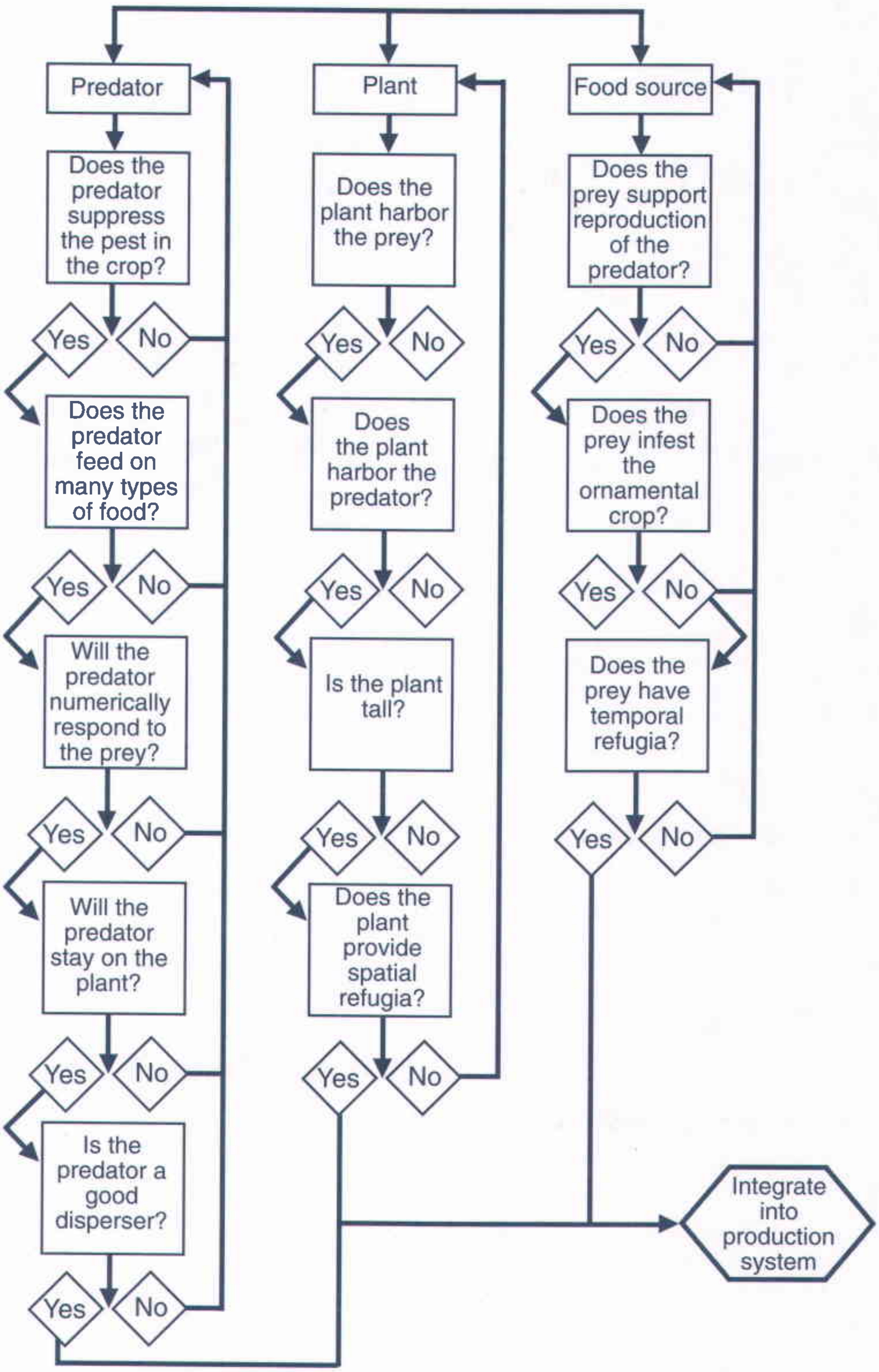

Figure 1. Flow chart describing attributes of three main components in a banker plant system. Components are not mutually exclusive, and evaluations of each should consider impacts on the other components.

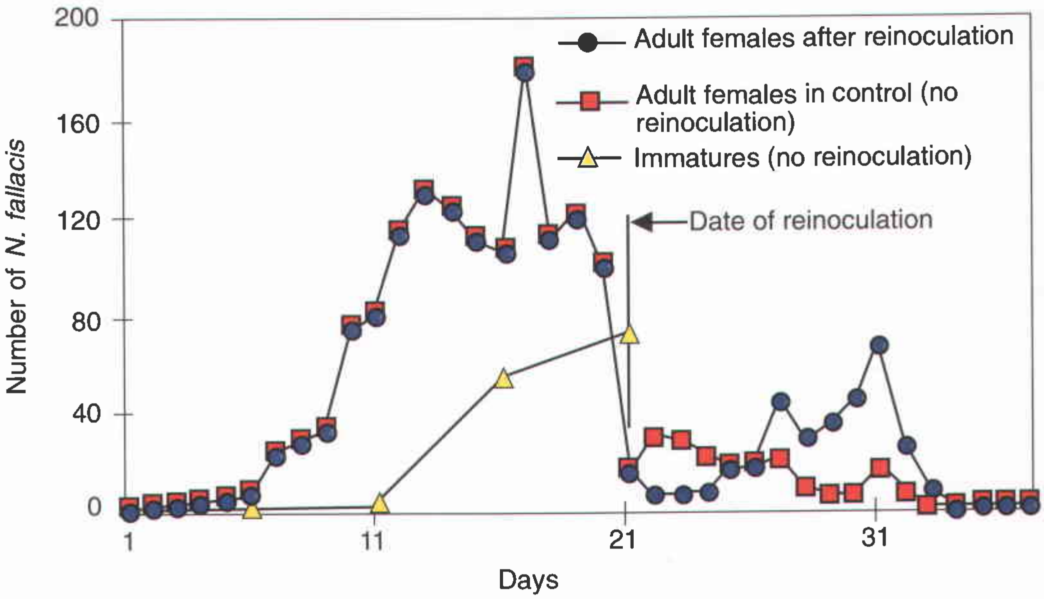

Figure 2. Dispersal of the predatory mite *N. fallacis* from *T. occidentalis* 'Pyramidalis' banker plants to spider-mite-infested bean plants downwind. Reinoculation of the banker plant was performed on day 21 and resulted in extending the dispersal interval and number of dispersants of the predatory mite.

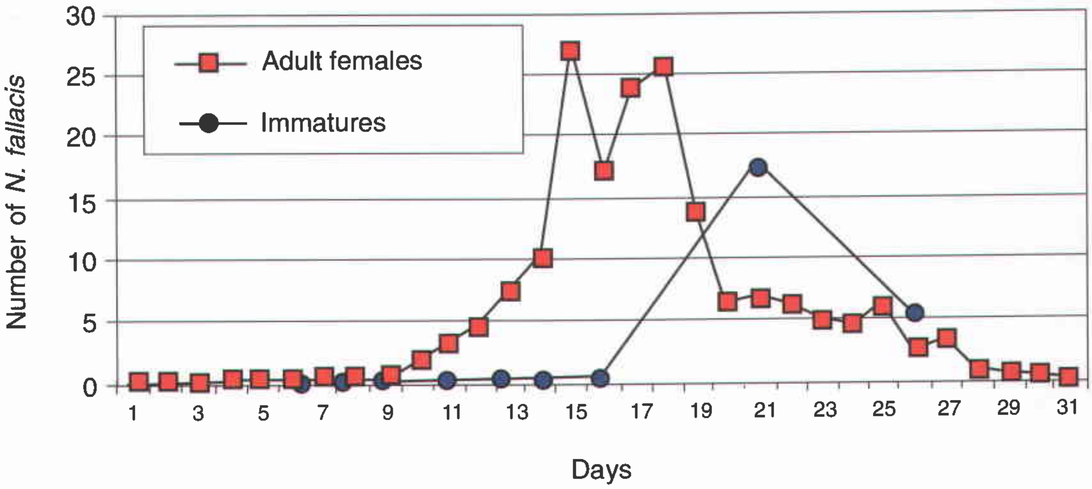

Figure 3. Number of *N. fallacis* dispersing from a rhododendron banker plant to receiver plants downwind.

Efficacy of Insecticide Mixtures to Control Lygus Bug in Alfalfa Seed

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Introduction

The objective of this trial was to evaluate and compare the performance of single treatments against tank mixes of currently registered insecticides for the suppression of lygus bug (*Lygus hesperus*) in alfalfa seed. Evaluations included treatment mixtures of organophospate and synthetic pyrethroid materials. The rates and tank mixes used were common industry recommendations for lygus bug control treatments during the critical bloom or pollination period of crop development.

Material and Methods

Small 0.01 acre plots were established using a randomized complete block design with three replications in a commercial alfalfa seed field. Treatments evaluated in the trial (Table 1) were applied using a CO_2 backpack sprayer calibrated to deliver 20 GPA at ~30 psi. Tee Jet 8002 VS nozzles were utilized. Lygus bug control was evaluated 3 and 14 days post-treatment using a standard insect sweep net to collect insect samples. Sweep samples were preserved in small canning jars containing 70 percent ethanol, and collected insects were counted in the lab. Population levels of all stages of lygus bug, pea aphids, and beneficial insects were counted and recorded. Insecticides were applied on May 15, 1998, timed to coincide with the first spring hatch of insects and when most of the population was in the small nymph stage of development (instars 1 and 2) (Figure 1). The trial was established targeting the first May hatch to avoid conflict with the grower's lygus bug spray schedule. Insecticide treatments simulated the rates and tank mixes typically used against the second, late June, or July pollination period lygus bug hatches.

Results and Discussion

At 3 days post-treatment, all treatments provided significant suppression compared to pretreatment counts. There was no treatment separation. Control ranged from 97 to 100 percent. At 14 days post-treatment, sweep samples indicated continued good suppression of lygus bug when compared to the untreated check plots. Control for the treatments ranged from 94 to 100 percent (Tables 2 and 3). There was no significant difference in the efficacy of the single treatments compared to the tank mixes for lygus bug control. All treatments provided a high level of control of pea aphid at 3 days post-treatment. At 14 days post-treatment, Dibrom, at 1 pt/acre formulated material, was significantly inferior to the other treatments in the control of pea aphid. Beneficial populations were at only trace levels in the pretreatment count,s so impact of the treatments on predators and parasites could not be evaluated effectively. Under the conditions of this trial, it appeared that all the treatments were effective when applied to populations of small lygus bug nymphs in a timely manner. These observations support the conclusion that successful control of lygus bug hatches depends on frequent sweeping schedules and timely insecticide sprays in addition to judicious selection of active ingredients. No data were collected on residual toxicity toward pollinators of the treatments, particularly of the active ingredient tank mixes.

Table 1. Lygus bug insecticides, tank mixes, and treatment costs, Sutton Farm, Ontario, OR, 1998.

Treatment[1]	Rate ai/acre	Rate formulated/acre	Cost $/acre
Dibrom	1.0	1 pt	9.13
MSR	0.5	2 pt	16.25
Capture	0.03	2 oz	7.83
Warrior	0.016	2 oz	5.05
Dibrom + MSR	0.5 + 0.375	½ pt + 1½ pt	16.75
Dibrom + Warrior	0.5 + 0.16	½ pt + 2 oz	9.61
MSR + Warrior	0.375 + 0.016	1½ pt + 2 oz	17.25
Untreated Control			

[1] Registered Trademarks

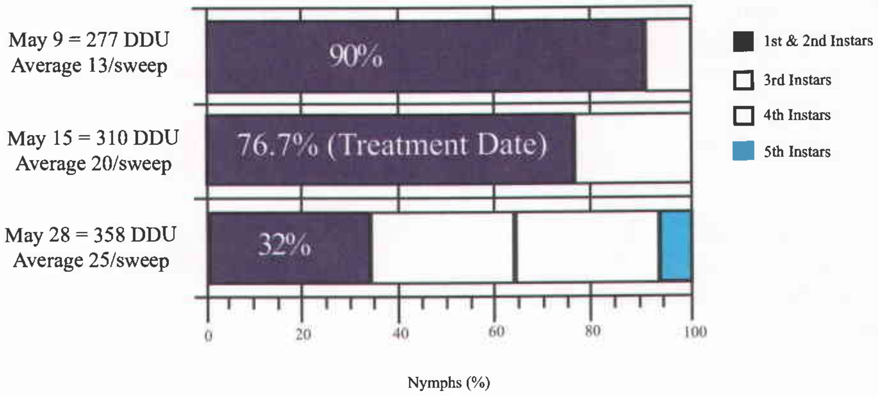

Figure 1. Lygus bug instar profiles at treatment date and two subsequent dates, Sutton Farm, Ontario, OR, 1998.

Table 2. Efficacy of commercial insecticides on lygus bug in alfalfa seed, 3 days post-treatment, Sutton Farm, Ontario, OR, 1998.

Treatment	Rate (volume/acre)	Average lygus per 5-sweep sample	Control compared to pretreatment population† (%)
Dibrom	1 pt	3.3	96.7
MSR	2 pt	0.7	99.3
Capture	2 oz	1.3	98.7
Warrior	2 oz	1.3	98.7
Dibrom + MSR	½ pt + 1½ pt	3.3	96.7
Dibrom + Warrior	½ pt + 2 oz	1.7	98.3
MSR + Warrior	1½ pt + 2 oz	0.3	99.7

†Pretreatment lygus bug population, 101 per 5-sweep sample.

Table 3. Efficacy of commercial insecticides on lygus bug in alfalfa seed, 14 days post-treatment, Sutton Farm, Ontario, OR, 1998.

Treatment	Rate	Average lygus per 5-sweep sample	Percent lygus control compared to untreated check
	volume/acre		
Dibrom	1 pt	7.0	94.5
MSR	2 pt	5.0	96.1
Capture	2 oz	2.0	98.4
Warrior	2 oz	0.0	100.0
Dibrom + MSR	1/2 pt + 1-1/2 pt	2.7	97.9
Dibrom + Warrior	1/2 pt + 2 oz	1.3	99.0
MSR + Warrior	1-1/2 pt + 2 oz	1.0	99.2
Untreated Check		127	

Integrated Insect Management in Mint

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Abstract

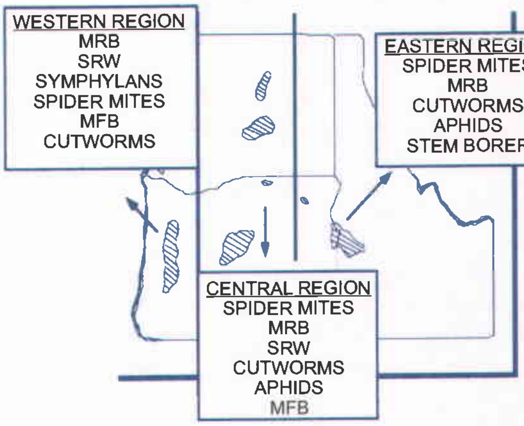
Successful insect pest management in mint depends on at least three components: sampling and monitoring, using treatment thresholds, and integrating multiple control tactics when possible.

It is imperative that insect pest management programs be developed that employ insecticides and acaricides only when necessary. It also is necessary to integrate other tactics, such as cultural practices (flaming, plowing/tillage, crop rotation, planting pest free roots), biological control, etc., into a comprehensive and regional integrated pest management program. Successful implementation of insect pest management on mint depends on accurately sampling and monitoring pest populations to determine pest densities and the need for intervention. The use of treatment thresholds to avoid the unnecessary use of insecticides and acaricides is equally important, not only to reduce production costs and environmental impacts, but to delay the development of pest resistance to insecticides and acaricides.

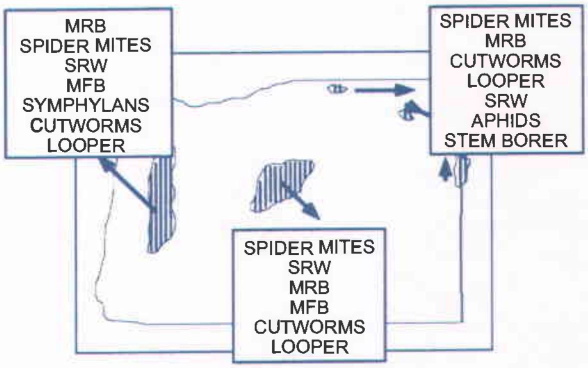
Decisions on how best to manage insect and mite pests on mint should be based on the best available knowledge with the goal of integrating as many tactics as possible into the mint production system. Each pest is unique and may require different management strategies, but, in many instances, careful employment of multiple tactics can reduce pest populations significantly below economic levels. The use of insecticides and acaricides likely will continue in the near future; but they should be used judiciously, to manipulate pest populations so that other more permanent management tactics can be implemented.

Insect and mite pests on peppermint can be separated into three distinct regions in the Pacific Northwest (PNW) according to their abundance and severity. The major pests in the western region, which includes western Oregon and Washington, are primarily soil insects such as mint root borer (MRB), strawberry root weevil (SRW), garden symphylan, mint flea beetle (MFB), and cutworms, although spider mites are becoming more serious. The central region includes areas east of the Cascade Mountains, particularly central Oregon and Washington. The major pests in this region are spider mites, mint root borer, and, to a lesser extent, cutworms (redbacked cutworm species complex), mint flea beetle, and strawberry root weevil. The eastern region includes eastern Oregon and Washington and western Idaho. The major pests in this region are spider mites and mint root borer; and, to a lesser extent, mint stem borer, aphids, and cutworms.

Pests on Mint in the PNW

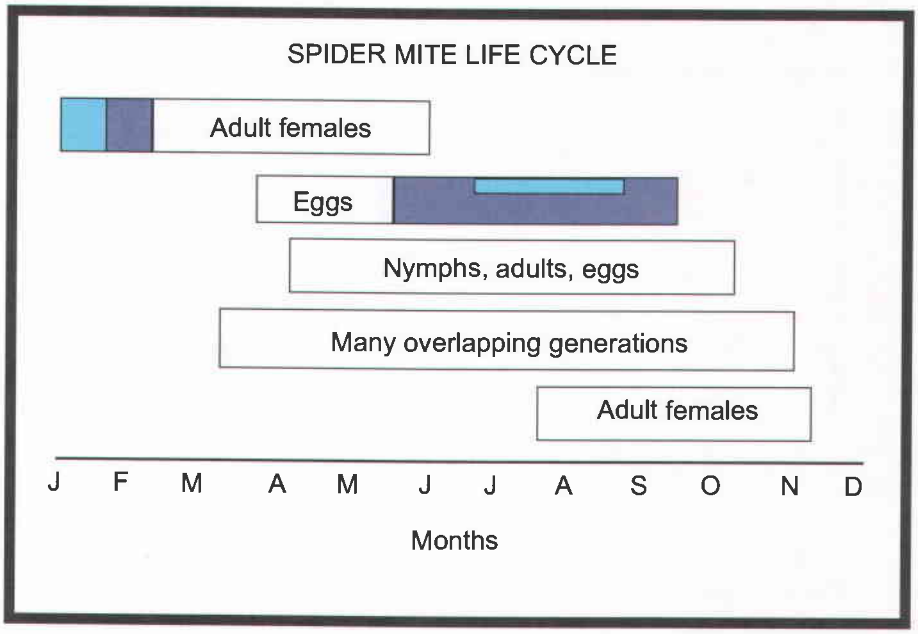


Similarly, insect and mite pests in Oregon are important in the state's western, central, and eastern regions. In general, two important pests dominate in all Oregon production regions: spider mites and mint root borer. The design of an IPM program on mint must take into account these regional differences as well as differences in pest biology, growing conditions, and production practices in the different regions.



The major insect and mite pests on mint are: spider mites, mint root borer (MRB), strawberry root weevil (SRW), mint flea beetle (MFB), and several species of cutworms. Interestingly, most of the serious insect pests on mint are soil insects: MRB, SRW, MFB, and cutworms (redbacked cutworm species complex, RBC), a phenomenon most likely associated with the nontillage practices used in mint production. Also, it is interesting to note that spider mites were not a serious problem in western Oregon until about 20 years ago.

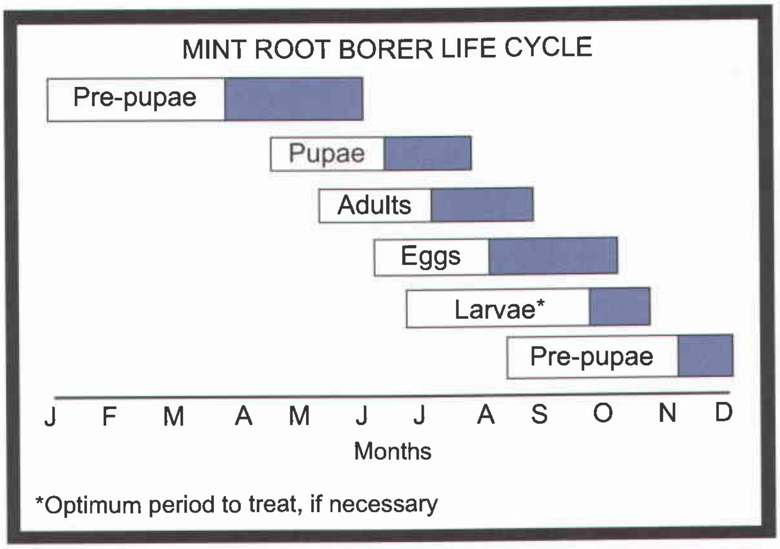
Following is a brief description of the life cycles of the major pests on mint to illustrate the damaging stages and current management strategies. There are several other pests that occur on mint that are not discussed here: cabbage and alfalfa loopers, wireworms, aphids, mint stem borer, and garden symphylan (see Berry, R. and G. Fisher, 1993: *A Guide for Peppermint Insect and Mite Identification and Management* for a complete discussion of pests on mint).



Twospotted Spider Mite (TSSM)
This pest is a major threat to mint production in the Northwest because growers currently rely almost exclusively on two acaricides. M. Morris (1998) has documented TSSM resistance to Kelthane® in western Oregon, central Oregon, and Montana. TSSM resistance to Comite® has not yet been documented fully. TSSM overwinter as females in soil debris in and around mint fields. In milder climates, TSSM may be found feeding on the lower foliage year around. Populations begin increasing in the spring and may reach damaging levels as early as April or May in some regions. During the summer, a complete generation from egg to egg may be completed in 1 to 3 weeks, and there may be as many as six to eight generations each year.

Currently, control of TSSM is based on the use of Comite® (1.6 - 2.0 lb ai/acre). Recommendations are that growers not use Kelthane® because of the resistance problems and because it is extremely disruptive to predator mites. M. Morris found predator mites (principally *Neoseiulus fallacis*) in all production areas (even during the winter), and he has documented their effectiveness in suppressing TSSM for the entire season, if managed properly. One of the goals of his research is to develop a management program in which predator mites play a key role in the management of TSSM on mint. Management of predator mites on mint will depend on careful management and the registration of an acaricide that is "soft" on predators. M. Morris (1996) also found that spring applications of Vydate® against nematodes disrupts predator mites, but Orthene® does not. His observations are important to an understanding of how best to manage predator mites to increase their effectiveness against TSSM. In western Oregon and

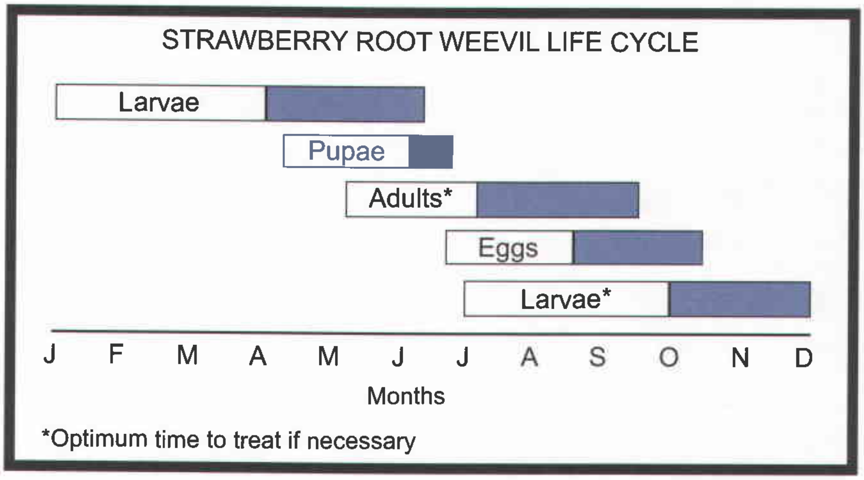
Washington, spring and fall propane flaming for rust control reduces the population of TSSM. Flaming in the spring often delays the development of TSSM populations, and in many years no acaricide treatments are necessary during the growing season. However, propane flaming is not a common practice in other production areas and TSSM populations begin developing early in the spring and usually reach outbreak populations sometime during the growing season. Integration of cultural practices such as flaming and careful management of predator mites may provide season long control of TSSM without the use of acaricides.



*Optimum period to treat, if necessary

Mint Root Borer (MRB)

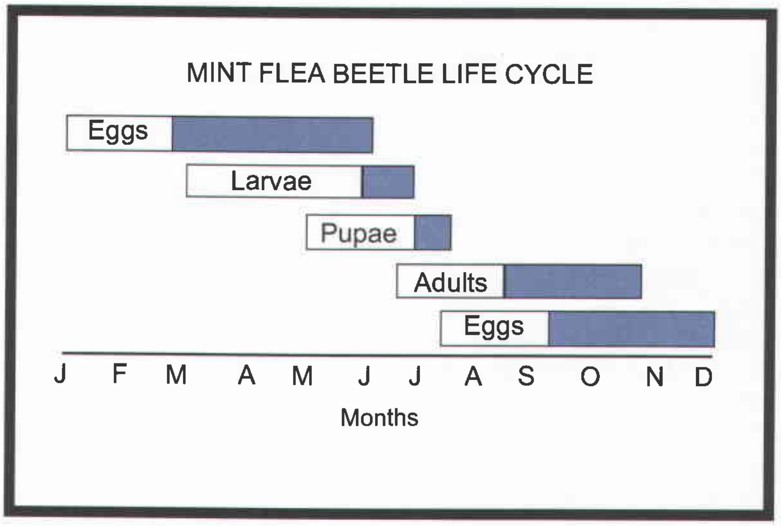
MRB first was identified as a pest on mint in western Oregon in 1973 and in north central Oregon in 1974 (Berry, 1993). MRB is currently one of the principal insect pests on mint in all production areas in Oregon, Washington, Idaho, and Montana. MRB produces one generation each year. Larvae are present in mint fields beginning in July and continuing through September. The most severe damage occurs when larvae feed within rhizomes in the fall, usually after harvest in August and early September. Larval feeding damage kills plants and weakens the stand, which often results in substantial plant mortality during the winter. Currently, control of MRB is based on the use of Lorsban® (2.0 lb ai/acre) or entomopathogenic nematodes applied at 1.5 to 2.0 billion infective juveniles per acre (IJs/acre) against larvae after harvest. In both instances, materials are applied through the irrigation system prior to the time larvae form the overwintering stage. J.Takeyasu (1994) has shown that both products effectively reduce MRB populations. However, preharvest applications of beneficial nematodes at 2.0 billion IJs/acre have the added advantage of reducing MRB larvae before the most serious damage is done to rhizomes in the fall. Research on how to use MRB sex pheromone traps (available commercially from Trece, Inc.) to time preharvest applications of BioVector is currently underway. Previous research in Oregon (Talkington and Berry, 1986) and Washington (Pike and Glazer, 1982) showed that tillage (strip tillage in Washington, plowing and discing in Oregon) effectively reduced MRB; however, because of the danger of spreading verticillium wilt, growers have been reluctant to adopt this practice.



Strawberry Root Weevil (SRW)

SRW is a serious soil pest in western Oregon and Washington and to a lesser extent in central Oregon. SRW has one generation each year and overwinters either as adults or larvae. Damage is most evident in the early spring as larvae feed on the roots and rhizomes. Adults emerge in May and lay eggs beginning in mid-June and into the fall, usually until the first frost. Larvae are present from early July until the following spring.

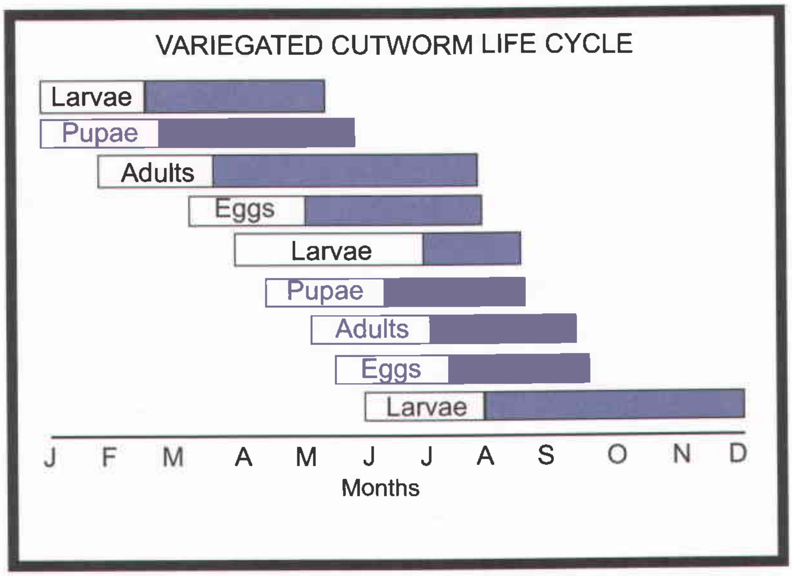
Currently, control of SRW is based on applications of Orthene® (1 lb ai/acre) in the evening in late May or early June to reduce adult populations before egg laying begins. Since timing of the Orthene® application is so critical, a predictive model has been developed using accumulated temperature to predict adult emergence. This model was used in central Oregon in 1992 to predict adult emergence on May 27 after 700 degree-days (°F) (DD) had been accumulated. Research is continuing on the use of BioVector® to control SRW larvae. Spring applications have met with limited success because of low soil temperatures (< 55°F) when larvae are present (April). Applications of beneficial nematodes after harvest are more effective, but the recommended rates of application are higher for SRW than for MRB (3.0 billion IJs/acre for SRW, 1.5 to 2.0 billion IJs/acre for MRB). Timing applications of beneficial nematodes to coincide with the occurrence of MRB and SRW may control both pests, but applications should not be delayed beyond early to mid-September.



Mint Flea Beetle (MFB)

MFB is a serious pest in western Oregon and Washington and to a lesser extent in central Oregon. MFB has a single generation each year and damage occurs in the spring (early April to early May) when larvae feed and tunnel in roots and rhizomes. Adults emerge in late June and early July and begin laying eggs in mid-July through the fall or until the first frost. Eggs overwinter and hatch in early March

Currently, control of MFB depends on using Lannate® (0.68 - 0.9 lb ai/acre) against the adults prior to the beginning of egg laying. Since timing is critical for successful adult suppression, a model to predict adult emergence has been developed. In 1992 in central Oregon, the model predicted peak adult emergence on June 14 after an accumulation of 1,475 degree-days. Lannate® must be applied within 14 days after adult emergence to prevent oviposition. Entomopathogenic nematodes also have been evaluated to control MFB larvae, but because of low soil temperatures (< 55ºF) in the spring when MFB larvae are present, the practice has met with limited success. Also, the availability of irrigation water in the spring is a limiting factor in most production areas. Finally, Vydate® applied in the spring to suppress plant parasitic nematodes also may provide control of MFB larvae, but timing of application is critical. The model developed to predict MFB development showed that susceptible stages of MFB larvae were present in late March and mid-April after an accumulation of 400 to 600 DD.



Cutworms (Variegated and Redbacked)

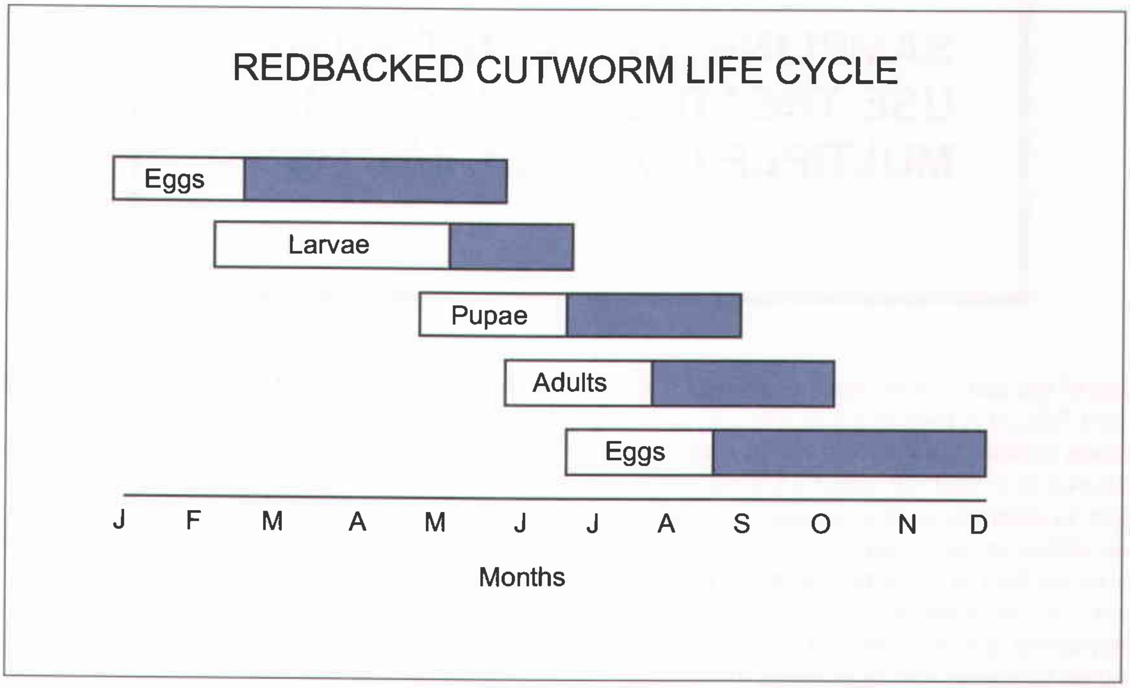
The variegated cutworm (VC) is principally a pest in western Oregon and Washington, whereas the redbacked cutworm complex (RBC) (a complex of at least eight different species) occurs in central and eastern production areas.

Variegated Cutworm

This cutworm has two generations each year, with the second generation causing the most damage on mint during July. Adults emerge as early as February in some areas and begin laying eggs as early as mid-March. Adult emergence can be monitored using sex pheromone traps placed in mint fields in late March or early April. Larvae may be present in early April, but the majority of damage to the mint foliage occurs in July. Larvae overwinter in crop debris around field margins or in other crops.

Control of VC is accomplished with foliar applications of Orthene® (1.0 lb ai/acre) or Lannate® (0.9 lb ai/acre) timed to coincide with the occurrence of third or fourth stage larvae. Both insecticides provide excellent control if timed for the early stages; however, as larvae reach maturity, the effectiveness of both insecticides declines. Timing applications of Orthene® with emergence of adult

SRW may offer an opportunity to control both pests in some areas. Beneficial nematodes to control VC have not been satisfactory, possibly because of the large amount of foliage present in July and the requirement to "wash" the nematodes through the foliage. It also has been observed that a large number of VC are parasitized, and treatment with insecticides may not be required (Coop and Berry, 1986).



Redbacked Cutworm Complex

There are at least eight species of cutworms that occur in the redbacked cutworm complex. Most of the species have one generation each year and overwinter either as larvae or eggs in the mint fields. Larvae feed on the roots and rhizomes of mint in the spring, usually from late April through early June. Adults begin emerging in July and continue through early September. Eggs are laid in the fall and form the overwintering stage.

Presently, control of the redbacked cutworm complex is with a spring application of Orthene® (1.0 lb ai/acre) or Lorsban® (1.0 to 2.0 lb ai/acre) timed to coincide with early stages of larvae before severe defoliation occurs. There are no insecticides registered to control larvae feeding on roots and rhizomes beneath the soil surface, although BioVector may have some effect if applications can be applied by irrigation after soil temperatures reach 55°F. Previous research has shown that a large percent of RBC larvae are parasitized, and, in some fields, the use of insecticides is not required.

Successful insect pest management on mint depends on at least three components: sampling and monitoring, using treatment thresholds, and integrating multiple control tactics when possible.

Sampling and monitoring programs have been developed for the majority of insect and mite pests on mint. For example, for spider mites, leaf samples taken from different locations in the field provide an estimate of the TSSM population (Hollingsworth and Berry, 1986). For a 30-acre field, at least 14 locations should be selected, and 45 leaves should be examined at each location (15 mint stems per location; examine one leaf from the top, middle, and bottom portions of the plants). Leaves should be categorized as infested if the number of TSSM exceeds 5 mites/leaf. Also, the number of TSSM eggs and the number of predators and their eggs should be counted. If the ratio of TSSM to predator mites is about 10:1, suppression of TSSM by predators may be adequate to avoid the use of acaricides.

IPM ON PEPPERMINT

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SAMPLING AND MONITORING
USE TREATMENT THRESHOLDS
MULTIPLE CONTROL TACTICS

For most of the soil insects, such as MRB, SRW, MFB, and RBC, it is necessary to take soil samples to estimate population density. Typically, square foot samples to a depth of about 2 inches are adequate to estimate most soil insect populations. In some instances, soil samples may be examined directly in the field to estimate the insect density; however, the use of Berlese funnels increases the accuracy of the sample. Detailed sampling procedures for these and other pests are outlined in the publication *A Guide for Peppermint Insect and Mite Identification and Management,* Oregon State University Extension Service, Corvallis, OR (Berry and Fisher, 1993).

The use of insecticides and acaricides as part of an overall insect/mite pest management program on mint undoubtedly will continue. However, the number of insecticides registered on mint is likely to decline during the next several years as the re-registration process progresses. Also, it is unlikely that there will be a significant number of "new" insecticides or acaricides available for registration on mint, largely because of the high costs of registration and the reluctance of some manufacturers to pursue registration on minor crops. Therefore, it is imperative that insect and mite pest management programs be developed that employ insecticides and acaricides only when necessary. It also will be necessary to integrate other tactics, such as cultural practices (flaming, plowing/tillage, crop rotation, planting pest free roots), biological control, etc., into a comprehensive and regional IPM program. Successful implementation of pest management in mint depends on accurately sampling and monitoring pest populations to determine pest densities and the need for intervention. The use of treatment thresholds to avoid the unnecessary use of insecticides and acaricides is equally important, not only to reduce production costs and environmental impacts, but to delay the development of pest resistance to insecticides and acaricides.

USE ONLY WHEN JUSTIFIED

BASED ON SAMPLING AND THRESHOLDS

INSECTICIDES	PESTS CONTROLLED
ORTHENE	SRW, CUTWORMS/LOOPERS
LORSBAN	MRB, RBC, SYMPHYLANS
LANNATE	MFB, CUTWORMS/LOOPERS
COMITE	SPIDER MITES
KELTHANE	SPIDER MITES
DYFONATE	SYMPHYLANS
MALATHION	APHIDS, MFB, SRW ADULTS
BIOVECTOR	MRB, SRW, MFB LARVAE

Numerous insect and mite management tactics are available to mint growers. For example, as previously noted, use cultural controls, such as: spring flaming, which reduces spider mites; and fall or spring plowing or strip tillage, which reduces mint root borer. Planting disease, insect, and nematode free mint roots may be the single most effective pest management tactic available to mint growers. Many pests are spread from field to field in the root stock; verticillium wilt, nematodes, weed seed, mint root borer, mint flea beetle, strawberry root weevil, symphylans, redbacked cutworm, etc. The use of biological control tactics also is an important consideration in pest management on mint. For example, cutworms and loopers are parasitized heavily, and, in many instances, insecticides are not required. Spider mite predators are abundant in mint fields in all production areas, and, in many instances, they successfully suppress populations of TSSM without the use of acaricides. The use of entomopathogenic nematodes is proving to be an effective biological control for mint root borer and shows promise for control for strawberry root weevil and mint flea beetle as well. Other entomopathogenic nematode species need to be evaluated. A 4- to 5-year crop rotation program also can reduce effectively many of the pest problems associated with mint production, especially those pests that build-up in the soil, such as verticillium wilt, perennial weeds, soil insects, nematodes, etc.

IPM TACTICS

PLANT PEST FREE ROOTS
CONTROLS MRB, SRW, MFB, SYMPHYLANS, CUTWORMS

4- OR 5-YEAR CROP ROTATION
CONTROLS MRB, SRW, MFB, WILT, WEEDS, NEMATODES

PLOWING / TILLAGE
CONTROLS MRB, WEEDS, ENHANCES SOIL / NUTRIENTS

SPRING / FALL FLAMING
CONTROLS TSSM, RUST, WILT, WEED SEED

BIOLOGICAL CONTROL
PARASITES CONTROL VC, RBC, LOOPERS
PARASITIC NEMATODES CONTROL MRB, SRW, MFB

Decisions on how best to manage insect and mite pests on mint should be based on the best available knowledge with the goal of integrating as many tactics as possible—and practical—into the mint production system. Each pest is unique and may require different management strategies, but, in many instances, careful employment of multiple tactics can reduce pest populations significantly below economic levels. The use of insecticides and acaricides likely will continue in the near future, but they should be used judiciously to manipulate pest populations so that other management tactics can be implemented. In insect and mite management, biological control may be one of the most useful tactics, if properly integrated into a comprehensive pest management program.

DECISION MAKING IN MINT IMP

PEST	SAMPLE	THRESHOLD	MANAGEMENT
VC	SWEEP/GROUND	1-2 / SAMPLE	ORTHENE / LANNATE
TSSM	45-LEAF SAMPLE	5-LEAF	COMITE / KELTHANE
MRB *	SOIL / RHIZOMES	2 - 3 /SAMPLE	BIOVECTOR / LORSBAN
ADULTS	PHEROMONES		
SRW *	700 - 900 DDSOIL	1 - 2 SAMPLE	BIOVECTOR
ADULTS			ORTHENE
MFB *	SOIL	0.5 / SAMPLE	BIOVECTOR / VYDATE
ADULTS	1,400 DD		LANNATE

*SPREAD IN PLANTING STOCK

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The Importance of Integrated Pest Management (IPM) for the Successful Use of Predator Mites to Control Spider Mites in Peppermint

M.A. Morris and J.Y. Takeyasu, Consultants

Keywords: Tetranychus urticae, Neoseiulus fallacis, Phytoseiid, Mentha piperita

Introduction

Peppermint (*Mentha piperita* L.) is a perennial herb in the family Labiatae (Laminacea). During 1998, peppermint was grown on approximately 123,000 acres in the U.S., mostly in Oregon, Washington, Idaho, Indiana, and Wisconsin. The majority of peppermint is produced for its oil, most of which is used for flavoring chewing gum, toothpaste, and other oral care products.

Peppermint is also a host for many arthropod species, several of which are economically important pests (Berry and Fisher, 1993). Presently, spider mites are the most common arthropod pest on mint (Morrell et al., 1995; Morris and Lundy, 1995), but this was not always the case. Prior to the late 1970s, spider mites were not a serious threat to peppermint production and seldom reached damaging levels. By the early 1980s, spider mites had become a more severe problem to this crop, especially in arid growing regions. In 1981, for example, over 90 percent of the peppermint acres in central Oregon were treated for spider mites, and 21 percent of those acres were treated twice. Research conducted by DeAngelis et al. (1983a) suggested that nighttime water loss and daytime water stress, resulting from damage to epidermal cells and cuticle, were the most significant type of spider mite injury to peppermint. Despite the advances made in spider mite management during the 1980s (Hollingsworth and Berry, 1982 and 1983), the severity of spider mites on this crop continued to increase. Because of the economic burden that spider mite management was placing on mint growers, and because miticides labeled for peppermint could be lost through pesticide resistance or regulatory concerns (Glass, 1986), the U.S. Mint Industry, U.S. Department of Agriculture, and Environmental Protection Agency supported research into biological control of spider mites on peppermint during the 1990s.

We begin this paper by discussing the suitability of peppermint as a crop for implementing spider mite biological control and why integrated pest management (IPM) is needed if biological control is to succeed on this crop. Next, the biological control program for spider mites conducted by the U.S. Mint Industry during the 1990s is evaluated. Finally, constraints to further adoption of biological control by mint growers is discussed.

The Biological Control Option

Peppermint is a suitable crop for implementing biological control of most arthropod pests, probably because many natural enemies are well adapted to mint. Frequent irrigation often results in lush foliage and high humidity, which many natural enemies prefer. Mint is also a perennial crop that allows time for natural enemies to colonize and establish themselves. Another reason is that cosmetic appearance is not an issue in peppermint grown for oil. Therefore, higher pest levels may be tolerated before potentially disruptive management practices become necessary. Finally, mint pests have not been shown to vector pathogens that economically damage peppermint under commercial field conditions.

The potential for biological control of spider mites on peppermint was first explored in the early 1980s, although this strategy did not seem practical at the time. Of the 18 spider mite predators (including four phytoseiid species) identified from Oregon peppermint fields, none were present in sufficient numbers to control spider mites (Hollingsworth, 1980; Hollingsworth and Berry, 1983; Hadam et al., 1986). Hollingsworth and Berry (1983) suggested that agricultural practices may have been responsible for low predator levels. Sampling data obtained from 1989 to 1995, however, showed that phytoseiid predator mites were distributed more widely on peppermint in the western U.S. than was previously reported (Morris et al., 1999a). Of the phytoseiids collected, 99 percent were *Neoseiulus fallacis*. Although other species were detected, their levels were too low to control spider mites. Perhaps mint growers had modified their agricultural practices in ways that enhanced the survival of *N. fallacis*, or it adapted to peppermint agricultural practices. Results of cage and pesticide exclusion studies showed *N. fallacis* was capable of controlling spider mites in peppermint (Morris et al.,1999a). Moreover, this species was able to overwinter and provide control of spider mites for several seasons (Morris et al., 1996). Other attributes which make *N. fallacis* a good candidate for biological control include high fecundity, short development time, high prey consumption, and good dispersal ability (Johnson and Croft, 1975; Smith and Newsom, 1970a and 1970b; Croft, 1975; Ball, 1980; Raworth, 1990; Coop and Croft, 1995; McMurtry and Croft, 1997).

Based on the suitability of peppermint as a crop for implementing biological control, and the potential of *N. fallacis* as a natural enemy of spider mites, the U.S. Mint Industry established a spider mite biological control program in 1993. The goals of this program were to reduce to 25 percent the number of peppermint acres treated for spider mites in the western U.S., and to eliminate the need to treat mint fields for spider mites twice in a single season.

The importance of Integrated Pest Management (IPM)

Although *N. fallacis* is an effective natural enemy of spider mites, IPM tactics are necessary if biological control of this pest is to succeed on mint. The U.S. Mint Industry defines IPM to be "the intelligent selection of all available pest control tactics in a manner that is both cost effective and least harmful to non-target species and the outside environment" (Morris and Lundy, 1995). The IPM tactics considered crucial for the success of spider mite biological control are grower education and training, the use of critical densities for spider mites and *N. fallacis*, intensive field monitoring, strategic use of predator mites and pesticides, and using a systems approach to mint pest management.

Grower Education and Training

The first step of this program was to explain clearly the program goals to mint growers. For example, one goal was to reduce the use of miticides, not eliminate them. By discussing the capabilities and limitations of biological control, including the impact of agricultural practices on predators, mint growers were less likely to become disenchanted when the progress of biological control was slower than expected. Moreover, when growers were trained to identify spider mites and predator mites on mint leaves with a hand-lens, they were often more supportive of spider mite biological control. They also tended to be more patient and more likely to reduce disruptive agricultural practices, allowing predators the time to reduce spider mite levels effectively. Finally, growers who can identify pests and their natural enemies under field conditions are better able to determine the need for, and quality of, biological control products and services.

Critical Densities and Field Monitoring for Spider Mites and Predator Mites

Determining a pest's critical density (CD) is needed before an effective monitoring program can be implemented (Nyrop, 1998). If an effective CD is not established, growers have no way of knowing whether or not a particular pest density is causing economic injury. This lack of knowledge can lead to unnecessary pesticide use. For peppermint, laboratory studies by DeAngelis et al. (1983b) showed that a density of 20 *Tetranychus urticae* per leaf could result in complete leaf loss. Because other factors such as temperature, duration of feeding, and soil type can affect the CD for spider mites, a conservative CD of 5.0 spider mites per leaf was established (economic threshold) for peppermint (Berry and Fisher, 1993). When temperatures are cool, or when the peppermint crop is strong and vigorous, higher spider mite levels may be tolerated without economic injury (Morris, personal observation).

The critical ratio (CR) of a pest to its natural enemy also may help growers decide whether or not to intervene with a pesticide (Helle and Sabelis, 1985; Nyrop, 1994). For several phytoseiid species on various crops, including *N. fallacis* on peppermint, a CR of 10 spider mites to 1 predator is often sufficient to control spider mites (Croft, 1975; Croft and McGroarty, 1977; Morris et al., 1999a). Growers must be cautious, however, because sometimes the CR may not adequately predict predator/prey interactions. For example, the effectiveness of a CR may vary depending on differing densities of the pest and its natural enemy (Nyrop, 1994).

Once the CD and CR are determined, monitoring is needed to determine pest and predator levels in the field (Kogan and Herzog, 1980; Binns and Nyrop, 1992; Pedigo and Buntin, 1994). A spider mite sampling program has been developed for peppermint by Hollingsworth and Berry (1992). To determine the CR for this crop, the number of predator mites per leaf may be counted and reported along with spider mites (Morris, personal observation). Once the decision is made to intervene with miticides or predators, periodic monitoring is necessary to determine the treatment's effectiveness. Although it is theoretically possible to predict the outcome of biological control from one sample (Croft, 1975; Nyrop, 1994), periodic monitoring provides insurance against the risk of being incorrect. Monitoring mint fields for other pests also may benefit spider mite biological control; for example, by reducing the use of non-selective pesticides applied for pests other than spider mites.

Augmentation with Predator Mites

Resident populations of *N. fallacis* often are present in mint fields at levels capable of controlling spider mites (Morris et al., 1999a). In situations where predator levels are not adequate, augmenting with low rates of commercially produced *N. fallacis* (500 to 2,000 per acre) may be an economical approach for re-establishing biological control. This approach assumes, however, that enough time is available for predator levels to increase and adequately disperse throughout the field (Coop and Croft, 1995; Croft and Coop, 1998). Another possible limitation of using *N. fallacis* in this manner concerns the timing of predator mite release. For example, applying low rates of predator mites in the spring when spider mite populations are above 0.1 per leaf and temperatures are cool, usually will not stop spider mites from reaching damaging levels, although this strategy usually avoids multiple miticide applications during a single season. Releasing low rates of predators into newly established fields has been the most successful approach in peppermint. By applying predators when spider mites first begin to colonize new mint fields, usually May through July, problem levels of spider mites the following spring usually are avoided (Morris, personal observation). The success of this approach assumes that growers can avoid disruptive agricultural practices after predators are released. The practice of inundating mint fields with high rates (10,000 to 60,000 per acre) of *N. fallacis* is not cost effective presently.

Strategic Use of Pesticides

Because biological control is not completely reliable, pesticides are needed in those situations where natural enemies are not effective enough (Croft, 1990; Metcalf, 1994). For this reason, pesticides are likely to remain an important IPM tactic for mint in the foreseeable future; so, a pesticide strategy that is compatible with natural enemies was developed by the U.S. mint industry (Morris and Lundy, 1995). Important features of this strategy include: the use of pesticides only as a backup to biological control; when pesticide intervention is necessary, use only selective components as economically feasible; and, when selective pesticides are not available, use least toxic ones selectively. This strategy applies to all kinds of pesticides used on mint, including miticides, insecticides, fungicides, and herbicides. Selective use of pesticides other than miticides is discussed in the following section on system interactions. Another part of the mint pesticide strategy is to maintain pesticides currently labeled selective. For example, the U.S. mint industry successfully has maintained propargite, the only selective miticide registered for use on mint. In the event that propargite is lost, and for resistance management purposes, mint labels for two additional selective miticides, hexythiazox and cyhexatin, are being pursued. Through educational efforts, fewer mint growers now are using dicofol or oxydemeton methyl, two miticides which are not selective to *N. fallacis* (Croft, 1990; Kaufman et al., 1999). To determine whether or not a pesticide is selective to important natural enemies of a particular crop, commodity groups probably should test the pesticides themselves. Relying on pesticide selectivity data gathered for natural enemies of one crop may not adequately predict the effect of pesticides to the same or other natural enemies on another crop (Morris, 1998).

Systems Approach to Mint IPM

A systems approach to IPM is necessary for understanding the interactions that take place within agro-ecosystems (Croft and Hoyt, 1983; Ruesink and Onstad, 1994). Spider mite levels in peppermint often are influenced by factors such as (1) the management of other pest complexes (e.g., arthropods, diseases, nematodes, and weeds), (2) mint cultural practices (e.g. flaming and irrigation), and (3) the surrounding crops and other vegetation. By understanding these factors, farm management practices sometimes can be adjusted to reduce the negative impact on spider mite natural enemies.

The use of non-selective pesticides to control mint pests other than spider mites frequently results in spider mite outbreaks (Morris, 1998). For example, fall applied carbofuran, used for 8 years in peppermint under an emergency exception for rootweevil control, severely can reduce predator mite levels and cause spider mite outbreaks the following spring (Morris et al., 1996). Another example concerns the use of chlorpyrifos in mint to control soil cutworms and the mint rootborer. Broadcast applied liquid formulations of chlorpyrifos are very toxic to *N. fallacis*, whereas granular chlorpyrifos is less toxic (Morris, personal observation), probably because granular formulations leave fewer residues on mint leaves. Similarly, changing the application of liquid bromoxynil from broadcast to herbigation greatly improves the selectivity of this broadleaf herbicide. Timing of pesticide application is another way to enhance pesticide selectivity. In addition to bromoxynil, several other mint herbicides are toxic to *N. fallacis*. Three of these—paraquat, oxyflorfen, and pendimethalin—usually can be applied safely during the dormant season when predators are inactive and protected in soil debris. The insecticide acephate, used in mint to control cutworms, is often less toxic to *N. fallacis* when applied in early spring than when applied later in the season (Morris, 1998). In early spring, temperatures are often cool and *N. fallacis* usually is found feeding on abundant spider mites on the underside of lower mint leaves. This provides a kind of protective umbrella. Later in the summer, however, predators are seeking actively to disperse or locate food higher in the canopy, rendering them more vulnerable to contact with pesticides.

Mint cultural practices also can affect spider mite and predator mite levels. One example is the irrigation program used. Surprisingly, *N. fallacis* was detected at high levels in arid mint growing regions of the western U.S. (Morris et al., 1996). Although *N. fallacis* is affected adversely by low humidity and high temperature (Kramer and Hain, 1989; Croft et al.,1993), it may survive on peppermint in arid regions because frequent irrigation provides a suitable microenvironment (Morris et al., 1996 and 1999a). Flaming mint fields for disease control in the fall is another practice that can impact spider mite control. Peppermint fields in central and western Oregon often are fall-flamed to reduce levels of the soil pathogen *Verticillium dahliae*, one of the major limiting factors to mint production in the U.S. (Horner and Dooley, 1965; McIntyre and Horner, 1973). Fall-flaming mint is also detrimental to predator mites and can result in spider mite outbreaks the following spring (Morris et al., 1999b). Reasons why flaming is harmful to *N. fallacis* include direct contact with flame, reduced humidity, and destruction of overwintering habitat.

The other crops and surrounding vegetation found in the agro-ecosystem where mint is grown also can affect spider mite management. For example, spider mites often increase on corn and carrot, then disperse downwind and create spider mite problems in mint (Morris, personal observation). Because sweet corn and carrot seed frequently are treated with non-selective insecticides, few natural enemies disperse along with spider mites.

Program Overview

Presented here are the results of the spider mite biological control program initiated by the U.S. mint industry during the 1990s. This evaluation is based on grower surveys from mint growing regions of the western U.S. Data from the Midwest are not included, because spider mites are presently not a significant problem there.

Between 1990 and 1995, there was a 31 percent decrease in the number of peppermint acres treated with miticides in the major mint growing regions of the western U.S. For individual growing regions, the percent of peppermint acres treated with miticides decreased by 14 percent, 16 percent, 65 percent, and 16 percent, for central Oregon, Idaho, Washington, and western Oregon respectively (Table 1). The large decrease in miticide use in Washington can be attributed to a Washington Mint Commission that effectively disseminated information to their grower community, and to several large mint growers (more than 2,000 acres) who embraced biological control for economic reasons. Mint growers also have curtailed their use of dicofol (Table 2). Because dicofol is highly toxic to *N. fallacis* (Kaufman et al.,1999), reducing the use of this miticide should create a better environment for spider mite biological control.

Table 1. Changes in the percent of peppermint acres treated with miticides in the major growing regions of the western U.S. from 1990 to 1995.

Mint growing Region	1990 mint grower survey [1] Acres	% treated	1995 mint grower survey [2] Acres	% treated
Central Oregon	18,300	100	15,500	86
Idaho	19,800	85	23,200	69
Washington	18,800	92	32,700	27
Western Oregon	25,000	41	25,000	25

[1] Morris and Lundy, 1995; [2] Jepson and Mason, 1996; Morrell et al., 1995; Lundy, 1997.

Table 2. Survey of miticide use (Comite [propargite] and dicofol) on U.S. peppermint from 1990 to 1997.

Mint growing region	1990 Survey[1]		1992 Survey[2]		1995 Surveys[3]	
	% acres treated		% acres treated		% acres treated	
	Comite	dicofol	Comite	dicofol	Comite	dicofol
Central Oregon	100	57	92	<1	86	<1
Idaho	78	7	**	**	64	5
Montana	13	50	**	**	55	5
Washington	66	26	**	**	25	2
Western Oregon	33	8	58	14	25	<1

[1] Morris and Lundy, 1995. [2] Jepson and Mason, 1996. [3] Morrell et al., 1995; Rinehold et al., 1999; Lundy 1997.

A greater reduction was seen in the number of peppermint acres treated twice each season for spider mites than for total spider mite treated acres. This result is observed best in central and eastern Oregon, historically the growing regions with the most severe spider mite problems. From the late 1980s until 1994, over 85 percent of peppermint fields in these two growing regions were treated twice each season for spider mites (Morris and Lundy, 1995). This level has been reduced 50 percent or more from 1996 to 1998 (Table 3). More importantly, when independent mite monitoring programs were implemented based on the methods of Hollingworth and Berry (1982), the number of acres treated twice for spider mites fell below 10 percent (Table 3).

Table 3. Survey of Comite (propargite) use by peppermint growers in Central Oregon.

Information source	1996 Survey			1997 Survey			1998 Surveys		
	% acres treated			% acres treated			% acres treated		
	none	once	twice	none	once	twice	none	once	twice
OSU survey[1]	20	33	47	14	36	50	*	*	*
Cathie Bennett[2]	45	29	25	35	57	8	52	39	9
Bryon Quebbeman[3]	53	46	1	49	45	6	35	64	1

[1] Rinehold et al., 1999. [2] Based on 1,800 acres monitored by Bennett's Scouting Service, Madras, Oregon. [3] Based on 6,500 acres monitored by Quebbeman's Crop Monitoring, LaGrande ,Oregon.

Although miticide use on peppermint has been reduced to levels well below those observed during the early 1990s, the goals of reducing the total acres treated to 25 percent and eliminating the need for multiple applications during a single season have not been met. Perhaps these goals are not realistic. If, however, more peppermint growers adopt intensive field monitoring, augment with *N. fallacis* where needed, and avoid disruptive agricultural practices, further reductions in miticide use on mint probably can be realized. These data do suggest, however, that selective miticides will be needed by mint growers to help control spider mites for some time to come.

Constraints to Adoption of Mint IPM and Biological Control

Despite the advances made in managing spider mites, this pest continues to be a serious problem to mint production in the western U.S. So why have some mint growers failed to embrace the intensive spider mite management tactics outlined above? Several reasons are suggested here. First, the complexity of managing spider mites through field monitoring and biological control is not economically justified in the view of many mint growers. Miticides are perceived to be relatively inexpensive, and fewer than half of the mint growers have experienced miticide failure. Treating a mint field for spider mites costs about $30.00 per acre per miticide application, including the application cost. As long as multiple miticide applications are not necessary, or the price of mint oil remains reasonably high, many growers are unlikely to adopt an IPM program for spider mites.

Second, mint growers often are reluctant to change traditional pest management practices. For spider mites, this often means treating fields with non-selective miticides when mites first are detected. Even when intensive monitoring programs are implemented successfully, such as to manage severe spider mite outbreaks, many growers dropped these programs once the spider mite problem subsided. Innovative mint growers tend to remain with independent monitoring programs despite changes in mint oil prices, while others adopt monitoring programs when prices are high and drop them when prices decline.

Third, depending on field monitoring to make spider mite management decisions is perceived to be too risky. In fact, intensive monitoring has missed spider mite outbreaks in mint, leading to economic damage before action was taken (Morris, personal observation). This may have resulted from erroneous monitoring data. Field scouts often are inexperienced and seasonal employees who, either intentionally or unintentionally, sometimes make mistakes entering monitoring data. Even experienced field scouts who monitor correctly, occasionally miss a spider mite problem due to chance alone. It is nearly impossible to design a sampling plan that is completely reliable (Pedigo, 1994). Treating a mint field with a miticide and not evaluating its performance through field monitoring is also risky. For example, propargite is usually not effective enough to maintain spider mites below damaging levels in fields where predators have been severely depleted (Morris et al., 1999a). Also, dicofol was ineffective for controlling resistant spider mites in mint, and resistance to dicofol was widespread in peppermint throughout the western U.S. (Morris, 1998).

Fourth, a source of high quality predator mites is needed in situations where resident populations of *N. fallacis* are too low, and such sources are difficult to find (Morris, personal observation). Not only was the wrong species of predator mite found in containers, but, in some cases, even the wrong family of mites were the only ones observed in shipments. Mixtures of phytoseiid species were common, as were fewer numbers of the correct species than was reported on the container. Such discrepancies in quality could result in a bad reputation for a pest management program that depends on commercial sources of natural enemies, especially if no one knew the wrong species or count was responsible for the control failure.

Fifth, releasing *N. fallacis* in mint fields to control spider mites is sometimes unreliable (Morris, personal observation), even when the species and the numbers released are correct. Predators may not establish effectively, increase in numbers, and disperse throughout mint fields for reasons other than disruptive agricultural practices. For example, competition with other species may be responsible for the lack of predator performance (MacRae and Croft, 1996). As for evaluating any pest control tactic, follow up field monitoring is a good way to determine if predators are working effectively.

Finally, the lack of effective pesticides or pesticide formulations that are compatible with natural enemies has slowed the progress of biological control in mint. Although the U.S. mint industry is pursuing aggressively the registration of selective pesticides, such alternatives must be effective. To allow natural enemies the time needed to control pest populations successfully, mint growers need a reliable pesticide backup in the event that biological control is not successful. For example, *Bacillus thuringiensis* has never been effective enough at reducing cutworm populations in mint to replace acephate or chlorpyrifos. More effective pesticide formulations also would help encourage the success of biological control. For example, granular chlorpyrifos may be more effective at controlling soil pests in mint than are liquid formulations, and granular formulations are less disruptive to natural enemies on mint leaves (Morris, personal observation). Because the success of biological control cannot be adequately predicted 14 to 30 days before harvest, a miticide or insecticide having a shorter pre-harvest interval (0 to 7 days) would reduce greatly the number of fields treated with miticides and other pesticides.

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Evaluation of the Toxicity of Pesticides to *Neosieulus fallacis* in the Laboratory and in Field Observations

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Objectives

1. To evaluate the toxicity of a directed pesticide spray application to *Neosieulus fallacis*.
2. To complement field implementation research using releases of *N. fallacis* for control of twospotted spider mites.

Progress

Colonies of twospotted spider mites and *N. fallacis* were established in the laboratory at North Willamette Research and Extension Center during the fall of 1996 and '97. For the directed spray trials, a pre-determined number of *N. fallacis*, along with an adequate number of twospotted spider mites to sustain them, were placed on small leaf disks which were sprayed with one of the following pesticides at rates recommended for use in strawberries. In 1996: Vendex, Guthion, Diazinon, Thiodan (applied at the low rate recommended for control of aphids and the high rate recommended for control of cyclamen mites), Lorsban, Metasystox-R, Alert, and Benlate. In 1997: Brigade, Kelthane, Aliette, Captan, Ridomil, Rovral, Thiram, Devrinol, and Simazine. The following additional herbicides were evaluated for toxicity by Mark Morris: Goal, Poast, Sinbar. A summary of our results appears below.

Among the insecticides/miticides, Alert, Brigade, Diazinon, Kelthane, Lorsban, Metasystox-R, and the high rate of Thiodan were most toxic, resulting in 90 percent or greater mortality within 24 to 48 hours of application. Among the fungicides, Ridomil was most toxic, resulting in 74 percent mortality. Although Benlate did not kill many *N. fallacis*, it resulted in a sharp reduction in egg laying among females. This observation supports Brian Croft's previous conclusion that Benlate sterilizes *N. fallacis* females. None of the other fungicides appeared to affect egg-laying. Levels of mortality among the herbicides tended to be fairly low. Of the herbicides, only Goal resulted in reduced egg production by survivors. The rate of Sinbar used in this trial was based on the recommended rate for use in mint and is several times the rate recommended for strawberries.

Results from directed sprays onto small leaf disks reflect the "worst case scenario," because there is no way for *N. fallacis* adults to move quickly to avoid contact as they would be able to do in the natural environment. Spray coverage is also much greater than in a field situation, providing no areas free from direct spray contact. Because of this, sprays of these chemicals would probably not be as disruptive to *N. fallacis* populations in a strawberry field as they are in the laboratory. In an attempt to monitor *N. fallacis* populations in a field situation, populations of *N. fallacis* were released into five strawberry fields with twospotted spider mites (TSSM) in late summer, 1997. Populations of TSSM and *N. fallacis* were monitored in these fields through harvest, 1998. No dramatic changes in TSSM or *N. fallacis* populations were observed following grower applications of Lorsban or Metasystox-R, despite their toxicity in laboratory trials. The same strain of *N. fallacis* was used in the field and the laboratory.

There are several factors (spray coverage, amount of contact of *N. fallacis* with spray residues, etc.) affecting exposure of *N. fallacis* to pesticides in the field. The fact that the weather this spring was cool and wet also would have had a moderating effect on twospotted spider mite populations. The long lapse in time between *N. fallacis* release and strawberry harvest makes it difficult to determine what proportion of *N. fallacis* present in the field in May 1998 were progeny of the original population released in September 1997.

All of these factors make it difficult to draw any firm conclusions from our field observations. Additional work is needed to correlate laboratory results with field conditions.

Summary sheets of observations in the five fields monitored are attached. Four of these fields bore their first crop in 1998; one of these is organic. The remaining field was in its second fruiting year. In general, there were greater numbers and a greater variety of insect predators in the organic field. The organic field also had a significant number of mummified aphids, indicating activity by parasitic wasps. The "ideal" ratio of TSSM to *N. fallacis* for good control is 10:1 or lower. Although we rarely achieved such narrow ratios, TSSM populations remained relatively low in all five fields during spring 1998. The only site to maintain recommended ratios during part of the spring was the organic field. This may be a reflection of the lack of pressure from pesticides. The lack of TSSM population pressure is probably a reflection of cool, wet conditions. Had the weather been warm and dry, it is conceivable that the wide TSSM/*N. fallacis* ratios might not have been adequate to control TSSM populations sufficiently.

Toxicity of Strawberry Pesticides to the Predator Mite, *Neosieulus fallacis*

TREATMENT	RATE (LB I/A)	% MORTALITY
Insecticide/Miticide		
Alert	0.2	96
Brigade	0.1	100
Diazinon	0.5	100
Guthion	0.5	18
Kelthane	1.0	92
Lorsban	1.0	100
Metasystox-R	0.5	96
Thiodan	1.0	47
Thiodan	2.0	91
Vendex	0.5	12
Fungicides		
Aliette	5.0 lb prod/a	1
Benlate	1.0 lb prod/a	6
Captan	6.0 lb prod/a	4
Ridomil	2.0 qt prod/a	74
Rovral	2.0 lb prod/a	14
Thiram	2.5 lb prod/a	9
Herbicides		
Devrinol	4.0	6
Goal	0.5	25
Poast	2.5 lb prod/a	15
Simazine	1.0	10
Sinbar	1.5	26

Field Releases of *N. fallacis* and Twospotted Spider Mite Counts (TSSM), 1997-98

Field #1. Washington County

Date	**2-potsl/leaf**	***N. fallacis*/leaf**	**Ratio**	**TSSM eggs**	**Other**
Aug. 1997					
Lorsban appl.					
Aug. 27, 1997 *	20.0	0.025	800:1		Minute pirate bug
Sept. 24, 1997	3.0	0.100	27:1		
March 25,1998	3.0	0		e	Aphids
Lorsban appl.					
April 9, 1998	0.4	0		E	Aphids
April 22, 1998	4.0	0			Aphids
Agrimek appl.					
May 3, 1998	3.0	0			
May 29, 1998	8.0	0.080	100:1	E	Green lacewing

e=eggs present, E=several eggs present

*Mite Counts within 3 weeks of *N fallacis* release:

Date	**Flagged Release Sites**		**Non-Release Sites**	
	2-spots	*N. fallacis*	2-spots	*N. fallacis*
Sept. 24, 1998	0.6	0.25	4	0
Ratio 2:1				

Field #2. Washington County

Date	**2-spots/leaf**	***N. fallacis*/leaf**	**Ratio**	**TSSM Eggs**	**Other**
Aug. 27, 1997	8.4				Minute pirate bug
Sept. 24, 1997*	0.1	0.0125	8:1		
April 14, 1998					
Lorsban appl.					
April 22, 1998	0.8	0.1250	64:1		
April 31, 1998	0.1			e	aphids
Thiodan appl.					
May 3, 1998	2.0	0.0140	143:1	e	
May 28, 1998	5.0	0.0800	62:1		

e=eggs present, E=several eggs present

*Mite Counts within 3 weeks of *N fallacis* release:

Date	**Flagged Release Sites**		**Non-Release Sites**	
	2-spots	***N. fallacis***	**2-spots**	***N. fallacis***
Sept. 24, 1998	0.1	0.025	0.125	0
	Ratio 4:1			

Field #3 Organic, Yamhill County

Date	**2-spots/leaf**	***N. fallacis*/leaf**	**Ratio**	**TSSM Eggs**	**Other**
Aug. 14, 1997	20.0	0.02	800:1		*MPB, SF, GL, LB
Sept. 23, 1997	9.0	0			*MPB, SF, GL, LB
March 26, 1998	7.0	0		E	
April 9, 1998	0.5	0.01	50:1	E	Aphid mummies
April 21, 1998	1.5	0.4	4:1		Aphids
April 29, 1998	2.0	0.4	5:1		Aphid mummies
May 27, 1998	2.7	0.1	27:1		Aphids

*MPB=Minute Pirate Bug; SF=Syrphid Fly; GL=Green Lacewing; LB=Lady Bird Beetle; adults and larvae present on all predators.
e=eggs present, E=several eggs present

*Mite Counts within 3 weeks of *N fallacis* release:

Date	**Flagged Release Sites**		**Non-Release Sites**	
	2-spots	*N. fallacis*	2-spots	*N. fallacis*
Sept. 23, 1998	8	0	11	0

Field #4 Yamhill County

Date	2-spots/leaf	*N. fallacis*/leaf	Ratio	TSSM Eggs	Other
Aug. 14, 1997*	17	0			
Sept. 23, 1997	3	0			
March 1998 Metasystox-R appl.					
May 5, 1998	5	0.05	100:1	E	Aphids, syrphid flies
May 28, 1998	7	0.14	50:1	E	

e=eggs present, E=several eggs present

*Mite Counts within 3 weeks of *N fallacis* release:

Date	Flagged Release Sites		Non-Release Sites	
	2-spots	*N. fallacis*	2-spots	*N. fallacis*
Sept. 23, 1998	0	0	0.7	0

Field #5 Marion County*

Date	2-spots/leaf	*N. fallacis*/leaf	Ratio	TSSM Eggs	Other
Aug. 21, 1997	0	0			
Sept. 4, 1997**	28	0			Syrphid fly larvae
Sept. 23, 1997	17	0.7	24:1		
March 18, 1998	0.35	0		e	
April 15, 1998 Thiodan appl.					
April 29, 1998	4	0.02	200:1	e	Aphids, lacewing eggs
May 29, 1998	4	0.08	50:1	e	Aphids, lacewing eggs

*This field is an older field (going into third production year) with root weevil problems. The field was sprayed 2X after harvest with Brigade, then propane burned.
e=eggs present, E=several eggs present

**Mite Counts within 3 weeks of *N fallacis* release:

Date	Flagged Release Sites		Non-Release Sites	
	2-spots	*N. fallacis*	2-spots	*N. fallacis*
Sept. 23, 1998	17 Ratio 25:1	0.7		

Management of Fungal Diseases in Onion and Garlic

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Summary

Allium crops in the western U.S. regularly are threatened by fungal diseases, especially those diseases which are tolerant of or are favored by aridity. Fungal diseases of very short season green bunching onions are well addressed with available control programs. For full-season bulb and seed onions, controls are available for fusarium basal plate rot (*F. oxysporum cepae*), pink root *(Pyrenochaeta terrestris*), downy mildew (*Peronospora destructor*), and purple blotch (*Alternaria porri*). When weather is highly conducive, better anticipation of the rapidly acting downy mildew and purple blotch epidemics would assist control. In areas in which both bulb and seed are produced, downy mildew tends to cycle from one crop to the other, and the industry would assist itself by eliminating close plantings. However, in some western regions, wild Alliums also may serve the same role. Botrytis neck rot (*B. allii*) and white rot (*Sclerotium cepivorum*) remain critical factors in onion bulbs and seed production. White rot may occur in cooler regions or wherever Allium crops are overwintered. Because white rot is a permanent soil infestation which rapidly increases to incite field-wide losses, this disease threatens individual growers, critical mass of regional production and product identity, and (in the case of dehydration) contracting companies.

For garlic, hot water clove treatment reduced seedling vigor, which led to penicillium (*P. hirustum)* decay if planting was delayed. The impact of penicillium seed decay, along with fungicide resistance in the penicillium fungus, has been reduced when alternatives to hot water seed treatment are implemented for bulb nematode. Losses in the field can be reduced with better timing of fungicide applications for purple blotch and botrytis (*B. porri, B. allii*) and better selection of seedstock for fusarium (garlic strains of *F. culmorum*). Previously rare, garlic rust (*Puccinia allii*) was devastating in 1998, in association with unusual climatic conditions; impact in 1999 appears to be low, and is being controlled with an emergency approval of Folicur fungicide. As all garlic is overwintered, white rot remains the largest obstacle to sustained garlic production for individual producers, regions, and contracting industries.

Future needs and IPM: For pink root of onion, better varietal resistance and less dependence on soil fumigants are desired. Varietal resistance is even more important in high organic soils where fumigants are ineffective.

Bulbs may be infected from airborne spores or more directly from leaf infections which progress to the neck prior to topping for botrytis neck rot in onion storage. Losses remain at 0.25 to 25 percent (rarely higher), primarily depending on spore loads at harvest and conditions influencing bulb maturity. Fungicides applied near or at harvest are ineffective. Field curing of necks prior to topping and heat curing in storage can reduce neck rot greatly. However, the market favors large bulbs (ergo, large necks), and high bulb prices sometimes require foregoing good neck curing. These factors beyond a grower's control chronically aggravate botrytis losses. This proportion might explain some neck rot incidence even when necks are well cured prior to topping. Even though seasonal systemic infection is not an accepted concept in the western U.S., perhaps this possibility should be revisited.

Once introduced into a field, white rot lingers at damaging soil populations for decades. There is no known source of breeding resistance, and traditional fungicide use has proven ineffective against high soil populations. Infections may occur shallow or deep in the soil. The fungus spreads plant-to-plant on root systems, and soil- and seed-applied fungicides near the bulb commonly do not last season long. Typically, infested fields are abandoned for Allium production. Recent research

indicates soil populations of *S. cepivorum* may be nearly eradicated with germination stimulants. Stimulants are applied in the absence of an Allium crop; sclerotia germinate, then die from lack of a living Allium food base. Integrating this approach together with fungicides applied at onion or garlic planting is a promising area of research. Because high sclerotial populations may rebound from just a very few infected plants, such integrated controls likely will need to be applied regularly on infested fields. For seed onions, the exceptionally long growing season may negate the effectiveness of pre-plant fungicides.

Because *S. cepivorum* is inhibited above about 75°F, production of spring planted, fall harvested onions may be sustained in infested soils in regions such as the Columbia Basin, Treasure Valley, and San Joaquin Valley. In these situations, root infections deeper in the soil profile do not penetrate the shallow, hot soil layer around bulb and stem plate. Reproduction in roots is very low. Such cropping naturally stimulates most sclerotia but reduces the population of *S. cepivorum*, lowering the white rot risk for subsequent overwintered Allium crops in the same field

Introduction

This overview is not intended to provide detailed differences among regions and crops with respect to all Allium diseases. In general, diseases such as downy mildew, purple blotch, fusarium plate rot, and pink root (of onion), and penicillium seed decay, botrytis neck rot, and fusarium bulb rot (of garlic) are controlled reasonably in many years using reasonably well-defined practices. When outbreaks of these occur, losses may be substantial. In general, control programs including weather prediction, fungicide applications, seed health, and selection are available and improving. This is especially true with the new wave of highly effective fungicides which have been introduced in recent years, and others which likely will appear in the next few years. Except to point to particularly difficult or pending problems, discussion of these diseases will be limited to the summary above. For additional information, refer to the APS Compendium of Onion and Garlic Diseases (APS Press, 1995).

The Pacific Northwestern and Western states (California, Oregon, Washington, Idaho, and Nevada) produce over 40 percent of the onions and nearly 100 percent of the garlic in the U.S. Much smaller production of leeks, shallots, chives, and other edible and non-edible Alliums also occurs. With respect to Allium production, there are many regional and sub-regional differences primarily characterized by climate, type of Allium crop grown, specific cropping season, and soil type. For some diseases, these differences have major influence.

Major types of Allium crops grown include:

- **Green bunching onions**. Primarily south central and southern California, coastal to desert climates.
- **Full-season bulb onions**. There are many types, ranging from short-season to long-season, mild through hot, even very hot for dehydrator types. For purposes of disease discussion, there can be distinct differences between:
    a. Spring sown, fall harvested. This is typical in the Columbia Basin of Washington and Oregon, the Treasure Valley of eastern Oregon and western Idaho, the Lake Labish region and other areas around Salem, Oregon, and the Tulelake/Klamath Basin of Northern California and south central Oregon. This category can be further subdivided between
        i. Hot summer production (Columbia Basin, Treasure Valley)
        ii. Warm to cool summer production (Lake Labish)
        iii. Cool to cold summer production (Tulelake/Klamath Basin)
    b. Fall sown, summer harvested. This is typical of the Walla Walla/Milton-Freewater region of northeast Oregon and southeast Washington.
    c. Winter sown, summer harvested. A variation which includes many acres of the dehydrator onions produced in the San Joaquin Valley and the California desert.
- **Onions for seed production**. These may be:
    a. Seed-to-seed, sown in mid-summer and harvested the following mid-summer (Central Oregon, Treasure Valley, Columbia Basin, northern and central California, etc.)
    b. Bulb-to-seed. In this variation, seed is sown and a bulb is produced. The bulb is stored over winter and planted into the same or another region for bolting.
- **Garlic**. All garlic is fall planted from cloves, and summer harvested. Even though

garlic is grown from Washington through the California desert, all regions are much alike with respect to fungal disease situations.

With respect to soil type, some diseases may act or respond differently to control efforts if the soil is very high in organic matter. In the western U.S., peat soils (nearly 100 percent organic matter) are found in the Lake Labish region and in the Sacramento Delta area, although few onions are produced in the Sacramento Delta in modern times. Relatively high organic soils (around 20 percent) are found in many fields in the Tulelake/Klamath region.

Downy Mildew of Onions

This disease is characterized by the extreme speed at which it can spread. It is promoted by cool temperatures, cloudy conditions, rainfall and/or sprinkler irrigation, and dew formation. In regions in which it occurs with some frequency, regular applications of fungicides are made to prevent epidemics from beginning. Once begun, the rate of spread and the ability to apply additional effective fungicides may depend on plant density, leafiness, canopy structure, etc. Any condition which encourages high humidity, free moisture on foliage, poor canopy penetration by fungicides, etc., seems to aggravate the situation.

With respect to integrated practices: Downy mildew can be especially destructive on seed onions because: (a) the fungus may carry over from one season to the next, (b) it can be difficult to provide good foliage coverage of effective fungicides once scapes (seedstalks) have elongated and canopies become relatively dense, (c) sprays may be curtailed during bee activity for pollination, and (d) the length of season allows much recycling of spores. If bulb onions are grown near seed onions, downy mildew activity in the seed crop, especially if carried over from the previous year, can cause an early epidemic spread in the bulb crops. In this situation, the regional level of control can be assisted by wide separation of seed and commercial crops, although such agreement and consensus may be hard to achieve. Working against such cooperation is the fact that in some regions, wild Alliums are present in nearby rangeland, and wild onion relatives may participate in downy mildew epidemics. Downy mildew seems to occur least where there is a clear, onion-free gap in the year, including the presence of wild Alliums closely related to domesticated onions.

Pink Root of Onions

Root infection by the soil-borne fungus *P. terrestris* results in reduced root systems and limited onion growth. This disease is worst where onions have been grown for many years, primarily because the fungus can grow on many other crops and plants and does not decline readily in soil. Crop rotation lowers inoculum levels only marginally. The fungus is active at moderate to high soil temperatures.

Good genetic resistance is available and is becoming more so, but the resistance is limited at higher soil temperatures (80°F). Resistant onions can be seeded such that high soil temperatures are avoided early in their development, so that root systems are well developed prior to substantial disease development; but this timing of seeding may not fit with the desired onion maturity period for all regions.

Fumigants have been used to control pink root in many regions, although these are ineffective in very high organic soils. Because the long-term future of all fumigant products remains uncertain, it is likely that additional research on pink root will be required if and when fumigants are no longer available.

Botrytis Neck Rot of Onion (and Scape and Umbel Blight of Seed Onions)

Neck rot typically occurs in storage, but the bulbs are infected by *B. allii* in the field. Where onions are marketed directly and consumed (e.g., Walla Walla Sweets) or processed without storage, neck rot is rarely a problem.

Spore sources are many, including rotting onions in cull piles or in the field, or sclerotia on soil. The common belief in the U.S. is that in nearly all years, all infection of commercial bulbs occurs at harvest when tops are cut, exposing damp neck tissues to infection. The fungus then grows down the neck into the bulb. (Similarly, on seed scapes and umbels, spores are believed to land, germinate, infect, and incite a local lesion, aided perhaps by any wounding present.) In general, this concept accounts for much of the disease seen in commercial onion crops, because when necks are well-cured prior to topping, a minimum of neck rot disease results. Artificial drying of bulbs may further reduce neck rot incidence, although if too much moisture is present during the drying operation, a secondary black mold (*Aspergillus niger*) can be created. For neck rot in onion storage, losses may range from 0.25 to 25 percent (sometimes higher), primarily depending on spore loads at harvest and conditions influencing bulb maturity. Fungicides applied near to or at harvest are ineffective. For many onion types, the market favors large bulbs (ergo large necks), and high bulb prices sometimes require foregoing good neck curing. These factors beyond a grower's control chronically aggravate botrytis losses. Careful balancing of onion variety and maturity, bulb size, and storage durations can allow some management of botrytis losses.

In a few years when cloudy, wet weather predominates, bulbs may be found infected at the soil line or basal plate in commercial fields, which elevates the damage in storage. In central Oregon seed onion fields, we commonly find infections at the basal plate in many fields in the spring or early summer. This does not seem to create a problem if the plants are vigorous, but in an already weak stand of onions, such botrytis basal infections may further weaken or even kill plants. Basal infections also serve as another source of spores for scape and umbel infections in seed crops, or for neck infections for commercial bulb crops. Currently, there is no attempt to manage such basal infections, although in central Oregon we did reduce plant losses in weakened stands by directing fungicide applications at the base of plants (data not shown).

Research in Great Britain indicated that *B. allii* spores infect green leaves all during the growing season, growing systemically downward from leaves into the neck (Maude & Presly, 1977a, b). If true, neck infection may result, even when tops are allowed to dry completely in the field, although good neck curing would reduce bulb infection. Similarly, if *B. allii* can grow asymptomatically in the plant, perhaps some scape or umbel blight might arise from infections which occur at some distance from the original infection and from much earlier infection. Fungicides applied directly to scapes and umbels have provided poor control of scape and umbel blight. For bulb crops, necks already infected from earlier leaf infections would not respond to such applications at or near harvest.

White Rot of Onions and Garlic (all Alliums)

Soil populations of *S. cepivorum* linger at damaging populations levels for decades; there is no known source of breeding resistance, and traditional fungicide use has proven ineffective against high soil populations. Infections may occur deep in the soil, the fungus spreads plant-to-plant on root systems, and soil- and seed-applied fungicides near the bulb commonly do not last season long. Typically, infested fields become abandoned for Allium production. Recent research indicates soil populations of *S. cepivorum* may be nearly eradicated with germination stimulants (Crowe, et al, 1990). Stimulants are applied in the absence of an Allium crop; sclerotia germinate, and then the fungus dies from lack of a living Allium food base. Integrating this approach together with fungicides applied at onion or garlic planting (especially long-lasting fungicides applied deeper than traditional to preclude plant-to-plant spread among root systems), is a promising area of research. Because high sclerotial populations may rebound from a very few infected plants, such integrated controls likely will need to be applied regularly on infested fields. For seed onions, the exceptionally long growing season may negate the effectiveness of pre-plant fungicides.

Because *S. cepivorum* is inhibited above about 75°F, production of spring planted, fall harvested onions may be sustained in infested soils in regions such as the Columbia Basin, Treasure Valley, and San Joaquin Valley. In these situations, root infections deeper in the soil profile do not penetrate the shallow, hot soil layer around bulb and stem plate. Reproduction in roots is very low. Such cropping naturally stimulates most sclerotia but reduces the population of *S. cepivorum*, lowering the white rot risk for subsequent overwintered Allium crops in the same field. Example: in 1990, white rot occurred in an onion seed field in the Treasure Valley, raising concerns that this disease was perhaps recently introduced and might spread throughout the main commercial bulb crop. However, because white rot was so widespread in the affected seed crop, this clearly was not the first incidence of white rot in that particular field, which had been planted occasionally with seed onions over several decades. Further, white rot was known to occur in many neighboring regions, with every likelihood that sclerotia of *S. cepivorum* had been introduced into the Treasure Valley many times over numerous years. Yet, white rot was heretofore unknown in the regions' main commercial onion bulb crops. Why was this so?

Soil temperature records for the Treasure Valley suggested that it might be too warm at the bulb level for white rot to occur. This is uncertain, however, because most temperature data shown to influence *S. cepivorum* was for constant temperatures in laboratory test systems, whereas diurnal field temperatures fluctuate widely near the soil surface. The Treasure Valley soil data indicated a fluctuation swing both above and below the established threshold temperature for mycelial growth. To test this hypothesis, onions were seeded in small plots in the infested field in April 1991. Half of the onions were harvested in October 1991, and no white rot was found on any harvested bulbs. The other half was left to overwinter and was harvested in July, 1992, at which point more than 95 percent of the onions were dead or dying from white rot infection on the bulb. During 1991, sclerotia were stimulated to germinate by onion roots, roots were infected below about 2 inches in the soil, but no infections penetrated the upper soil layers to reach the stem plates. Between April and October, 1991, more than 95 percent of the sclerotial population was eliminated by natural stimulated germination from onion roots. Of course, with cool fall and spring temperatures, active *S. cepivorum* infections were no longer inhibited, and surviving sclerotia in the upper soil layers (and the few reproduced on roots) germinated to incite high disease in 1992.

Based on this and other field experience, it appears that development of *S. cepivorum* stops totally when any daily temperatures fluctuate above the limit for mycelial growth. In the Treasure Valley, it seems likely that sclerotia have been introduced periodically. But any white rot sclerotia introduced into fields in which summer bulbs are grown most likely are eliminated; thus, the region sees only rare white rot occurrence in fields only planted to overwintered seed onions. (Since the 1990 seed onion occurrence, white rot occasionally has occurred on garlic in home gardens in the Treasure Valley.) Any switch in the Treasure Valley or Columbia Basin to widespread production of fall-planted, summer harvested onions or garlic would allow white rot to attack bulbs and reproduce abundantly, if *S. cepivorum* were present. For comparison, white rot is severe on overwintered garlic and winter-planted onions in the just-as-hot San Joaquin Valley.

Soil temperature also seems to play a major role in white rot incidence and fungicidal control in the Lake Labish region. In years with very warm summers, the disease is inhibited during the summer, only arising late in the season on the spring-seed onion crops. In those summers, white rot incidence may be a few percent in untreated fields, but nearly zero in fields in which preplant fungicides were used. In years with relatively cool summers, white rot incidence may reach 40 percent in untreated fields, and perhaps 20 percent in fields treated with pre-plant fungicides. In this region, even the coolest summers partially contain white rot activity, and this remains one of the few regions in the world in which onion production can be sustained in spite of the presence of regular white rot activity. It is also one of the few regions in which fungicides routinely have been beneficial.

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Integrated Management and Optimization of Fungicides to Control *Septoria* in Winter Wheat

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Diseases are important limitations on winter wheat yields in Western Oregon. One of the most costly spring diseases is Septoria, which has two species, *S. tritici* and *S. nodorum*. The disease is usually present, and the fungi can survive on wheat residue, volunteer plants, and some weeds. New plants can be infected in the fall. If wet conditions persist in the spring, with normal Willamette Valley temperatures, *S. tritici* will be found on the leaves and is the area's most common type of infection. If rains continue later into the spring and temperatures warm, this favors the development of the *S. nodorum* spores.

Genetic resistance to this disease would be the most effective, economical, and environmentally sound method of control, but at the present, none of the commonly grown varieties have resistance.

In 1990, the Bayer Corporation started work to develop a cereal disease diagnostic model that would enable growers to manage wheat diseases more effectively. This work was carried on in wheat production areas of the U.S. by company researchers, university plant pathologists, and other agricultural scientists.

From this work, the Bayer Fungicide Optimization System (BAYFOS) was developed. Using the proper fungicide at the proper time is an integral component of the diagnostic system. It recommends that a fungicide only be applied when the disease level triggers the diagnostic model for a "time to spray" decision. This can occur any time between Feekes 8.0 to 10.0.

The system allows for determination of the amount of infection on the lowest green leaf at a particular stage of growth, and as the wheat plant grows, the indicator leaf moves up. For Septoria, when 25 percent of the indicator leaf is infected, the system is triggered, and it then is time to apply a fungicide.

A grower should select a fungicide that allows flexible application timing, and one that can be used from early flag through heading. The BAYFOS system provides wheat growers with a cost-effective disease control program that maximizes the potential for a positive return-on-investment.

Alternative Strategies for *Septoria* Management in the Willamette Valley

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Background

Economic and Environmental Impact

Septoria tritici and *S. nodorum* are the major foliar diseases of winter wheat in western Oregon. Winter wheat was grown on 61,000 acres in the Willamette Valley in 1998 and accounted for 9 percent of state wheat production. Currently grown cultivars are susceptible or at best have moderate resistance; it is estimated that over 75 percent of acreage is sprayed annually with fungicide. At a minimum cost of $15 per acre for application and material, this disease represents a $685,000+ annual expense for growers plus the use of at least 3,000 pounds of fungicide active ingredient in western Oregon fields.

Causal Organisms

S. tritici, leaf blotch, is most common. It is an early season disease with wind-blown spores already present in the Valley in the fall prior to wheat planting in October. It destroys leaf tissue and can cause head infections. *S. nodorum*, glume blotch, has been less common historically but is increasing in prevalence. The introduction of *S. tritici* resistant varieties may be playing a role in the increase of *S. nodorum*, which is observed primarily as a later-season head blight, although it can cause leaf lesions as well. Both Septorias cause reductions in grain yield of 10 to 15 percent or more when not controlled. They both also cause reductions in grain quality through shrunken grain and resultant poor test weights. In 1997 and 1998, growers observed test weights as low as 52 lb/bu (a typical weight is 58 to 60), even in some sprayed fields. In more typical years, test weights of 55 to 56 lb/bu are not uncommon in severely infested fields. Hence, in addition to a yield reduction per se, crop value also may be reduced significantly by these diseases.

The incidence of Septoria appears to have increased through the 1980s to today's severe levels in some parts of the Valley. Possible reasons include growth of a very susceptible variety, Stephens, since the late-1970s loss of dinoseb herbicide (which was widely used on wheat and likely sanitized fields in mid-winter) and changes in weather patterns. Mild, wet winters and wet springs and early summers favor Septoria. Work by Mundt and Cowger also suggests that *S. tritici* goes through several cycles of sexual recombination in western Oregon each year. It previously was thought that Septoria only had one sexual cycle per year. With additional opportunities for recombination, selection for increased virulence is possible. A case in point is the variety Gene, which was released as a *S. tritici* resistant variety, but was overcome by disease in less than 3 years.

Control Strategies

Plant Resistance

As with many diseases, horizontal resistance would be the best control strategy. Several Pacific Northwest varieties—Yamhill, Hill81, Madsen, Foote—have some level of Septoria resistance, but all still are responsive to fungicide sprays. Sources of resistance are present in world germplasm (France, Germany, Eastern Europe) and are being incorporated into locally adapted material.

Fungicides

Fungicide control work was started in the early 1980s by OSU Extension and research faculty. Years of study showed that a single application of fungicide at flag leaf emergence was generally the most effective both biologically and economically, with some exceptions. This is still the standard practice to this day.

Benlate (DuPont) and Manzate (DuPont) were the first materials used and are still used today as second application sprays. Tilt (Novartis;

propicanozile) was introduced in the late 1980s and became the product of choice, due both to ease of use and biological effectiveness. The first new product to be labeled since that time is Quadris (Zeneca Ag Products; Azoxystrobin), which received a label in early 1999. DuPont, Novartis, and Bayer also have experimental materials at the field evaluation stage that contain active ingredients similar to that in Quadris. Additional registrations are anticipated in the next few years.

Threshold Determination Techniques

As both Septoria diseases are affected significantly by rainfall (moisture is needed for spore germination and rain splash speeds spore spread), spraying may not be necessary in all years. Over the past few years, south Valley fields have shown early, severe disease and have needed to be sprayed. But, many north Valley fields have shown less disease, and it may be possible to spray selectively; but reliable techniques for determining the need for a fungicide are not available. In 1998, we evaluated two spray threshold measurement techniques: the Bayer Disease Diagnosis System, which relies on an assessment of indicator leaves, and a Novartis On-site test kit, which is an immunoassay system.

Bayer Disease Diagnosis System©

Bayer Corporation has developed fungicide spray threshold procedures for several cereal diseases. In each, the goal is to protect upper plant leaves by assessing disease levels on lower leaves and applying fungicide when thresholds are reached. Thresholds for Septoria are a given number of lesions containing pycnidia (fruiting structures) on indicator leaves. Indicator leaves change as the plant matures. To test the Bayer system, replicated plots of Stephens winter wheat—a highly susceptible cultivar—were established at Hyslop Farm and sprayed with fungicide when system thresholds were reached. A data summary for this trial is given in Table 1.

Table 1. 1998 Hyslop Farm Bayer Decision Aid trial (variety: Stephens SWW).

Treatment	Yield (bu/a)	Test weight (lb/bu)	Protein (%)	1,000 K (g)	Height (cm)
Aid - 3 spray	115	59.3	8.8	48.9	113
Aid - 2 spray	93	57.5	9.5	43.4	119
Standard	86	56.3	9.8	39.9	115
Aid - 1 spray	74	53.4	10.9	37.2	115
Control	62	51.5	11.4	33.6	114
Average	86	55.8	10.0	40.6	115
PLSD (5%)	9	2.0	1.0	3.2	3
PLSD (10%)	7	1.7	0.8	2.6	2
CV	7	2	6	5	2
P-value	0.00	0.00	0.00	0.00	0.01

The 1998 growing season was conducive to Septoria, and threshold levels were reached on all assessment dates. Three fungicide applications were made and were economically viable. At $15 per application and current wheat prices of approximately $3 per bushel, yield increases of at least 5 bushels would be needed to recover spray costs (assuming there is no crop damage through use of aerial sprays or tramlines). The "standard" spray timing is at flag leaf emergence and was more effective than a single spray at the first threshold level, but less effective than a double or triple fungicide application (10 percent probability level) in this year. Typically, multiple fungicide applications have not been justified economically.

Threshold trials also were conducted in Yamhill County in cooperation with the Yamhill County crops agent and growers. Data from their trials are shown in Tables 2 and 3, respectively. A single "50 percent headed" application also was made in these trials. This type of application would be typical of a "salvage" spray if a grower missed earlier spray windows.

Table 2. 1998 Septoria trial in Yamhill County—Ellingson Site (Variety: MacVicar).

	Yield (bu/a)	TW (lb/bu)	Protein (%)	Height (cm)
Bayer 1 and 2	103	61.7	8.7	107
Flag/Bayer 1	91	61.2	8.7	106
50% head	79	60.1	8.8	105
Control	68	57.3	8.0	107
Average	85	60.1	8.6	106
PLSD (5%)	3	0.5	NS	NS
PLSD (10%)	3	0.4	NS	NS
CV	2	0	8	1
P-value	0.00	0.00	0.46	0.35

Table 3. 1998 Septoria trial in Yamhill County – Sweeney Site (Variety: Madsen).

	Yield (bu/a)	TW (lb/bu)	Protein (%)	Height (cm)
Bayer 1	97	61.0	9.7	106
Flag	95	59.9	9.7	106
Bayer 1 and 2	95	60.6	10.0	106
50% head	92	61.0	9.3	106
Control	74	56.9	10.5	106
Average	90	59.9	9.9	106
PLSD (5%)	5	1.5	NS	NS
PLSD (10%)	4	1.2	NS	NS
CV	3	1	7	2
P-value	0.00	0.00	0.42	0.99

In the Ellingson trial (Table 2), the standard flag leaf emergence and first Bayer threshold coincided. These sprays were significantly better than the unsprayed control or the 50 percent headed spray. The 50 percent headed spray was economically useful, but did not bring yield nor test weight levels to those of a properly timed spray. In this trial, as at Hyslop, a multiple application was both statistically and economically significant.

In the Sweeney trial, all fungicide treatments were similar in effect and significantly improved yield and test weight of harvested grain in comparison to the unsprayed control.

These tests indicate that the Bayer Disease Diagnosis System has promise. It has been used successfully in other parts of the country and has been effective in trial work done in Washington County. We will conduct additional tests with the Bayer system in 1999.

Novartis Crop Disease Diagnostics

Novartis Crop Protection has developed immunoassay disease diagnosis systems for several wheat diseases (Septoria, eyespot and fusarium) as well as for corn and banana. These are ELISA (enzyme linked immunosorbent assays) or PCR (polymerase chain reaction) technologies. Septoria On-Site© is a field-based diagnosis system that can be completed in less than 10 minutes once sample leaves are collected. Leaves are collected and macerated, and the expressed liquid is combined with assay solutions in a syringe. A color reaction indicates the presence of fungal tissue. Kits for both *S. tritici* and *S. nodorum* are available. Septoria Watch© is lab based system that can be used by a disease clinic or agrochemical dealer to test grower leaf samples for Septoria fungi.

We used a beta-test version of the Septoria On-Site kits in 1998, but found them to be more subjective than is desirable. Also, they were of little use in 1998 as obvious disease symptoms were present on leaves that were to be evaluated for incipient disease infection. We will evaluate new versions of the field kits in 1999. If effective, these kits could be very useful. Each year we have a large number of fields in the northern Willamette Valley that do not show disease symptoms at the late flag leaf growth stage when a fungicide application should be made to be most effective. Some of these fields later will develop severe disease infestations. These kits may allow us to test these fields for incipient infections and to make better fungicide application decisions.

Conclusion

Plant resistance ultimately will be the solution to the Septoria problem in western Oregon; but, until resistant, adapted varieties are available, disease threshold and diagnosis tools likely will be useful in making wiser fungicide application decisions.

Feeding on Transgenic Bt-Potato Plants by Phytophagous Heteropteran Predators

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Abstract

Transgenic potato plants have been developed to express the toxin gene of the bacterium *Bacillus thuringiensis tenebrionis* (Btt). Although these transgenic plants provide control of the pestiferous Colorado potato beetle (*Leptinotarsa decemlineata*), the toxin also is available to nontarget organisms feeding on the plant, including a group of facultatively phytophagous heteropteran predators. This study examines the effects on several predators of feeding on Btt-potato plants. We examined *Nabis* spp., *Geocoris* spp., *Orius tristicolor*, and *Lygus hesperus* feeding on leaf disks of Btt and non-Btt plants, and found no detrimental effects on the longevity of these predators. Thus, these findings suggest that direct plant-feeding by these predators should not reduce their capacity to provide biological control of Colorado potato beetle and other potato pest insects.

Key words: *Nabis* spp., *Geocoris* spp., *Orius tristicolor, Lygus hesperus*, facultative phytophagy, Bt nontarget effects

Introduction: *Bacillus thuringiensis tenebrionis* Toxin as a Plant-produced Insecticide

As insecticides become less frequently used due to pesticide resistance and toxicity concerns, alternative methods for controlling agricultural pests must be found to maintain adequately high crop yields. The bacterium *Bacillus thuringiensis* (Bt) produces a toxic protein that kills a wide range of insects by destroying the integrity of the gut lining, which alters the balance of electrolytes in the hemocoel (Martínez-Ramírez and Real, 1996). *B. thuringiensis* first was studied for biological control of lepidopteran pests in the 1920s and has been used with limited success as a spray-applied "biological pesticide" (van den Bosch et al., 1982; Gould, 1998). The bacteria and their toxins degrade rapidly in UV light, and application must be timed carefully for effectiveness (Ferro, 1994). In the past decade, researchers have isolated the toxin gene from different strains of *B. thuringiensis* and have successfully expressed the bacterial gene in the genome of several plants. Corn, cotton, tobacco, potatoes, and eggplant, as well as other crops, have been transformed to express the toxin to control caterpillar and beetle pests.

Potato plants have been transformed with the *Bacillus thuringiensis tenebrionis* (Btt) CryIIIA delta-endotoxin gene (Perlak et al., 1993) to control the primary pest of potatoes in the United States, the Colorado potato beetle (*Leptinotarsa decemlineata*). This insect costs U.S. potato growers approximately $100 million annually to control (Perlak et al., 1993) and has developed resistance to nearly all pesticides currently available (Ferro, 1994).

With the use of Bt-expressing transgenic potato plants, fewer pesticides will be used on potato crops, which will allow natural enemies to survive and provide additional control of pest insects. A wide range of natural enemies feed on the Colorado potato beetle and other pests of potatoes. Coccinellids, or lady beetles, carabids, lacewings, and several heteropterans are generalist predators that feed on aphids, beetle eggs, and young larvae on potatoes (Hazzard et al., 1991; Hilbeck and Kennedy, 1996; Hough-Goldstein et al., 1993). These predators frequently are killed by the application of pesticides (Hilbeck and Kennedy, 1996), and without spray applications of manufactured pesticides, these predators can control the pest arthropods remaining after Bt application. However, if the Bt toxin adversely affects predators, they cannot provide maximum control of pest insects remaining on the plants.

Bt Toxin Effects on Nontarget Organisms

The application of Bt toxin as a spray negatively affects many nontarget insects, including weed biological control agents (James et al., 1993) and honeybees (Flexner et al., 1986). Integration of the toxin in the crop plant genome reduces the nontarget species affected, but the toxin still can reach non-pest insects. Keller and Langenbruch (1993) provide a list of species found to be insensitive to the toxic effects of Btt. Most of the insect species listed are pests, with only one predator, *Chrysoperla carnea*, having been tested. Although insect members of seven orders were examined, no heteropterans were listed as species examined for nontarget effects.

Since Keller and Langenbruch's 1993 compilation, several researchers concerned with nontarget effects of the toxin have examined beneficial insects feeding both directly on the transgenic crops, and on prey fed on transgenic crops. Lady beetles were not affected by consuming aphids fed on transgenic potato plants (Dogan et al., 1996), but lacewing larvae showed a delayed development and increased mortality when fed lepidopteran prey reared on transgenic corn plants (Hilbeck et al., 1998). Some predators feed on pollen to supplement a prey diet, and so can ingest the toxin in pollen from transgenic plants. A recent study showed no negative effects of feeding on pollen from transgenic corn plants by predatory lady beetles, lacewings, and insidious flower bugs (Pilcher et al., 1997).

Some heteropteran predators actually have had higher populations in fields of Bt potatoes than in nontransgenic fields (Reed et al., 1993). However, this seems to be due to a lack of prey in the nontransgenic fields. The Colorado potato beetles decimated the potato plants in the control (nontransgenic) fields, had no more food, and so the beetle population fell to nearly zero and no food was available for predators (G. Reed, pers. com.). Therefore, the Bt toxin potentially could have detrimental effects on predator populations, but not as negative as a complete lack of prey.

A key group of predators, members of the Heteroptera, feed directly on plants for moisture and low levels of nutrients (Coll, 1998; Naranjo and Gibson, 1996). Several heteropteran predators have the ability to feed on the mesophyll of leaves (Cohen, 1990; Armer et al., 1998), where high levels of toxin are expressed (~0.1% of total leaf proteins, Perlak et al., 1993). Therefore, these predators would have access to high doses of toxin when feeding on plants. The study described below examines the effects of direct feeding on transgenic Bt potato plants on the longevity of plant-feeding predatory Heteroptera.

Testing Btt Effects on Predatory Heteroptera

Several species of heteropteran predators are common in potato cropping systems, including *Geocoris punctipes* and *G. pallens*, *Orius tristicolor*, *Nabis* spp., and *Lygus hesperus*. The first four feed on lepidopteran eggs and small caterpillars, aphids, and small Colorado potato beetle larvae. These predators are useful in reducing levels of the Colorado potato beetle as well as the disease-vectoring green peach aphid. *Lygus hesperus* feeds heavily on plants, and is considered a pest in some crops; this species was included as a positive control to indicate effects on heteroptera that feed extensively on plants.

Insects were provided fresh leaf disks daily, and were isolated without prey to force the predators to feed more extensively on the leaf than they might with prey; insects often go without prey for several days in the field, so this situation is not unrealistic. Field-collected predators were used within a day of collection. Half the insects received transgenic Bt leaf disks from greenhouse-grown Newleaf® (transgenic Russet Burbank variety) plants (see Armer et al., 2000 for more detailed description). The other insects received control disks cut from nontransgenic Russet Burbank leaves. Because immature insects often are more susceptible to toxins than are adults (for example, see Zehnder and Gelernter, 1989), we tested both adults and immature insects, as available.

No differences were found in longevity between insects feeding on transgenic Bt plants and nontransgenic plants (Figures 1-4), p=0.11 to 0.90 (Mann-Whitney U test). *Orius tristicolor* lived from 1-6 days, *Geocoris* spp. individuals lived 1-11 days, *Nabis* spp. lived 1-13 days, and *L. hesperus* lived 1-17 days on the leaf disks without prey. Although longevity cannot be directly compared between field-collected adults and immatures, nymphs did not seem to be more susceptible to the Bt toxin than adults (Figures 1-4).

We also examined transgenic plant-fed predators with an ELISA for the Bt toxin to see whether the insects ingested the toxin. None of the nymphal or adult insects examined ingested or retained significant amounts of the toxin. Additionally, experiments indicated that the predators did not defecate significant amounts of active toxin (CAA, unpublished data).

Safety of Bt-transgenic Plants for Heteropteran Predators

The field use of transgenic potato plants expressing the *Bacillus thuringiensis tenebrionis* delta-endotoxin should not reduce the longevity and control potential of the facultatively phytophagous heteropteran predators examined here. The predators might be unaffected by the toxin simply because the toxin does not bind to receptors in the midgut (Pietrantonio et al., 1993). Because intact toxin does not pass through the digestive system of these predators, they either break down the toxin to an inactive form that is not recognized by the ELISA antibodies, or they only ingest minute quantities of the toxin. The ELISA results support either of these two explanations, as do the studies on defecation of active toxins. The CryIIIA protein found in Bt *tenebrionis* bacteria seems to be a protoxin that must be cleaved with chymotrypsin to be activated to its toxic form (Martínez-Ramírez and Real, 1996). However, the active toxin is expressed in Newleaf potato plants (J. Feldman, Monsanto Co., pers. com.). The active toxin thus should be available to plant-feeding insects. The toxin protein does have an intestinal brush-border binding domain (Martínez-Ramírez and Real, 1996), binding only to appropriate receptor sites. The CryIIIA toxin seems to affect only selected chrysomelids, which might be due to either gut enzyme specificity or binding domain specificity. The toxin is highly host-specific, and some other chrysomelid pests, including flea beetles, are not affected by the toxin (R.E.B., pers. obs.). These other insects presumably do not have the appropriate toxin binding sites; however, the toxin might affect nontargets feeding on organisms that do have the appropriate binding sites. The toxin found in Bt corn, CryIAb, might affect nontarget insects once the protoxin has been digested to the active form (Hilbeck et al., 1998) by the target insect, suggesting the CryIAb toxin specificity might not be caused by binding domain specificity.

The *L. hesperus* individuals examined here showed a trend found in other facultatively phytophagous heteroptera (Coll, 1998), in which early instars can survive longer without prey than can older nymphs. This might allow younger instars, which are too small to feed on most prey items, to develop through the early stages before prey are necessary for survival. The *Nabis* spp. early instars studied here did not survive longer periods without prey; differences between *Nabis* spp. and *L. hesperus* patterns of phytophagy and survival in early instars might be due to evolutionary backgrounds of the two insects. *Nabis* spp. are cimicomorphs, and probably have been primarily predaceous far longer than *L. hesperus*, a pentatomomorph, has been a prey-feeder (Cohen, 1990). *Lygus hesperus* seems to be more adapted to feeding on plants, and so might be able to derive nutrients from the plant tissues that *Nabis* spp. cannot access. Differences in salivary and gut enzymes and plant feeding sites might affect what nutrients, as well as what toxins, an organism has access to. Thus, it is important to examine predators of different evolutionary lineages for responses to toxins in insect-resistant plants. *Geocoris* spp. are predators that belong to the pentatomomorph lineage of heteropterans (Cohen, 1990), and so they might access nutrients and toxins that other heteropteran predators, such as *Nabis* spp. and *Orius* spp., would not ingest. Immatures of *Geocoris* spp. were not available for experimentation at the time the above study was conducted. The possibility remains, although unlikely due to the reasons discussed above for lack of toxin effects on heteropterans, that *Geocoris* spp. early instars might be affected by Btt toxin when other heteropteran predators are not.

Future Research Goals for Biocontrol Agent-Bt-transgenic Plant Interactions

Several benefits arise from toxin expression in the plant (Rice and Pilcher, 1998). The plant is resistant to insect feeding at all times, not just after a bacterial spray application. Nontarget insects present in the fields, but not feeding on the transgenic plants, will not be affected by the toxin as would insects under a spray-application of the bacteria. However, the constant presence of an active toxin expressed throughout the plant potentially increases the rate at which target insects will develop resistance to the toxin, and Colorado potato beetle already has developed resistance to the toxin in laboratory colonies (Whalon et al., 1994). Additionally, the toxins might affect non-heteropteran nontarget insects that do feed on the plants or on prey feeding on the transgenic plants.

Studying the effects of pest control methods on beneficial insects clearly is important. As we lose the use of many insecticides, both biological and chemical, to pesticide resistance in pest insects, biological control agents will become more important in agriculture. Studies in the 1960s (Ridgway et al., 1967) indicated that beneficial heteropteran predator populations were reduced with the use of systemic pesticides; these predators clearly feed on plants, and so any toxin in or on the plant that is active against a pest also should be tested on these beneficial insects. Although our results indicate the toxin expressed by transgenic Bt potatoes is not toxic to the beneficial insects studied here, we must continue testing new pest control methods on beneficial predators and parasites. The toxin expressed by the Bt-transgenic plants apparently is specific to beetles, although other insect groups, such as the heteroptera, have not been tested extensively for susceptibility to the toxin. Future work should focus on predatory beetles feeding on Bt-fed hosts such as the

Colorado potato beetle. Dogan et al.'s (1996) study of coccinellids feeding on Bt-fed aphids was a positive step in this direction; however, aphids feed on the phloem, where little toxin is available. Other insects that consume the mesophyll of the plant, where toxin expression is highest, should be examined as prey for beetle predators. Hilbeck et al's (1998) work showed that mesophyll-feeding prey, such as lepidoptera, might be toxic to predators.

The use of Btt toxin-expressing transgenic plants for beetle control seems to be compatible with the use of heteropteran predators in IPM systems. The use of transgenic crops, when combined with methods to slow the development of pest resistance to the toxin (Whalon et al. 1994), should encourage the activity of biological control agents in cropping systems. Fewer insecticides will be applied to crops, so predator and parasite populations can increase to levels at which these beneficial organisms can provide additional control of insect pests. The use of various intercropping and weed management practices might increase the abundance of natural enemies. Thus, the use of transgenic crops, in combination with other practices to encourage beneficial organisms, will allow us to reduce pesticide usage while better controlling arthropod pests.

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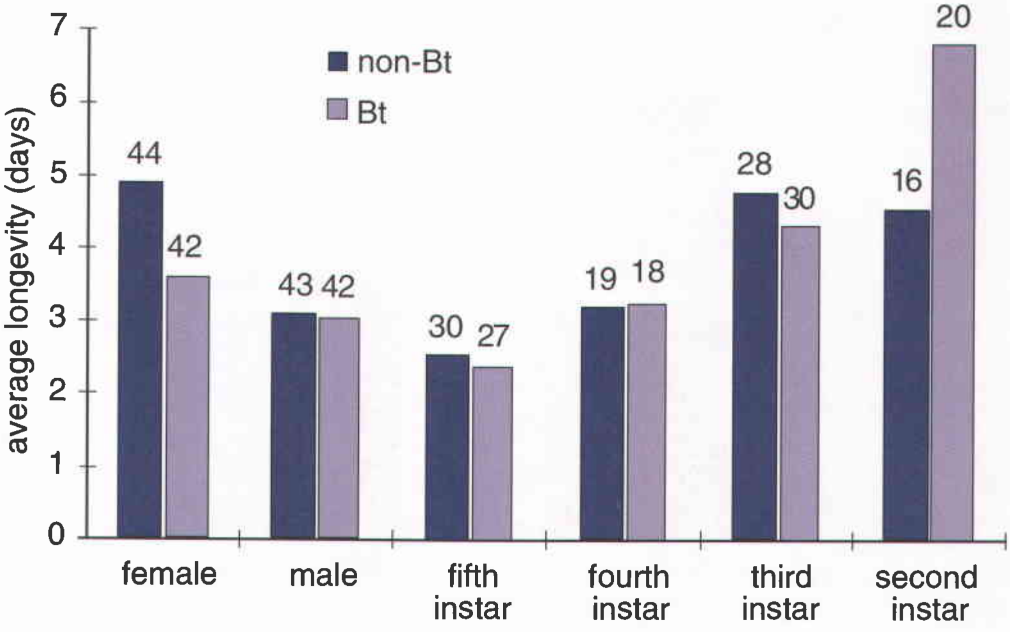

Figure 1. Average longevity of *Lygus hesperus* feeding on transgenic Btt leaf disks and control Russet Burbank leaf disks. Numbers over bars indicate sample size.

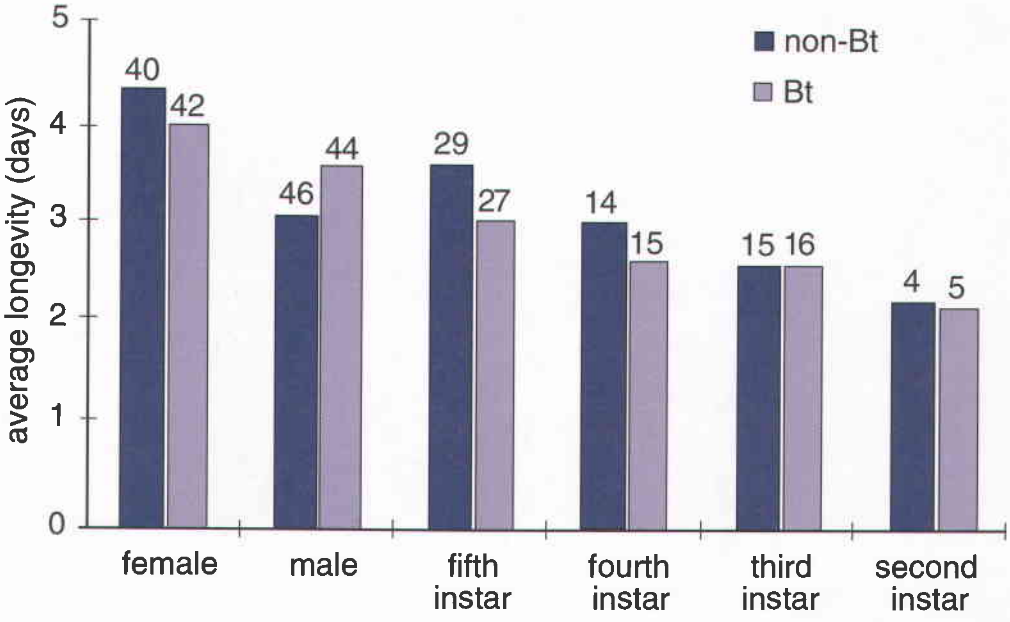

Figure 1. Average longevity of *Nabis* spp. feeding on transgenic Btt leaf disks and control Russet Burbank leaf disks. Numbers over bars indicate sample size.

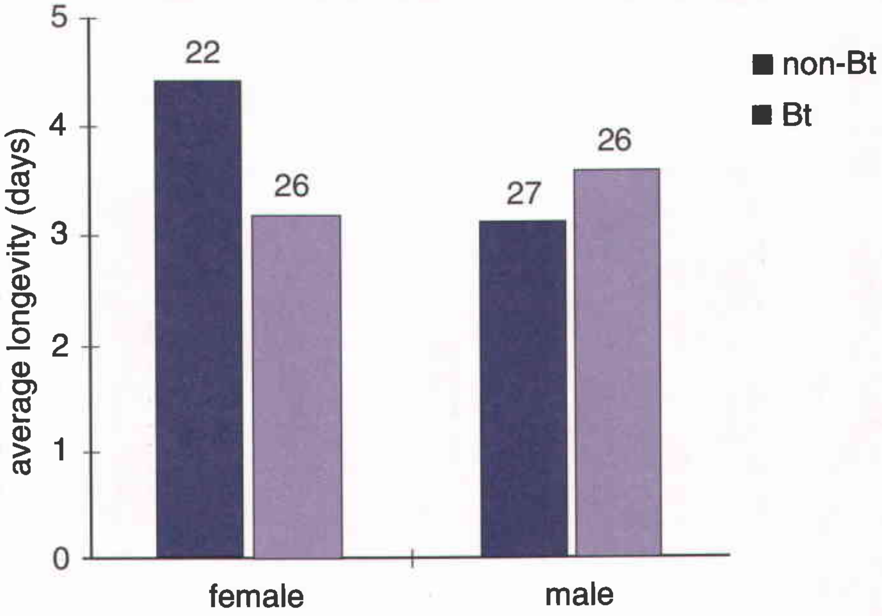

Figure 1. Average longevity of *Geocoris* spp. feeding on transgenic Btt leaf disks and control Russet Burbank leaf disks. Numbers over bars indicate sample size.

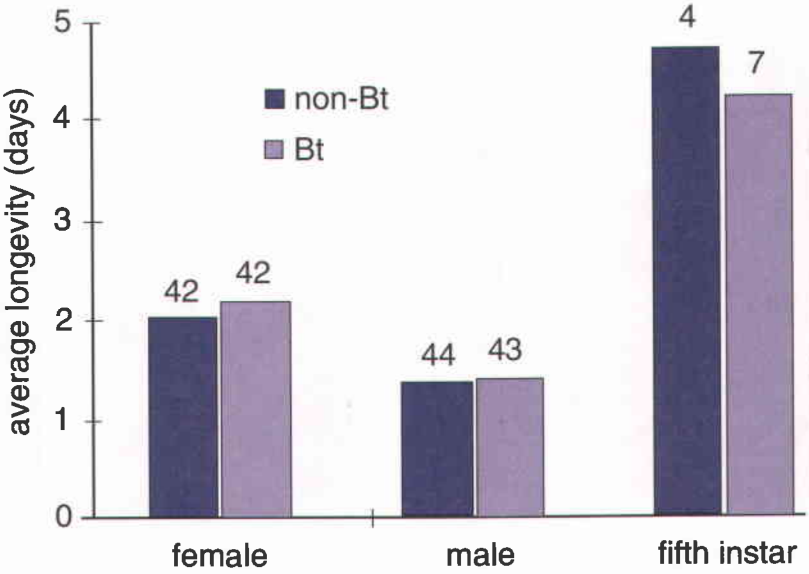

Figure 4. Average longevity of *Orius tristicolor* feeding on transgenic Btt leaf disks and Russet Burbank leaf disks. Numbers over bars indicate sample size.

Integrated Pest Management of Diseases of Grasses Grown for Seed in Oregon

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Abstract

The most important diseases affecting grass seed production in Oregon include rusts, choke, blind seed, ergot, leaf spots, and seed gall. Rust is the most serious disease, costing the industry over $7 million annually in fungicide costs alone. Recent progress in disease prediction and development of disease resistance will provide an effective means of reducing fungicide applications. An understanding of the biology and epidemiology of blind seed disease has led to effective cultural controls to manage the disease in the absence of field burning. Research on these and other diseases indicates that an integrated approach, including timing of fungicide applications, disease resistance, and simple cultural management practices (such as use of disease-free seed, planting seeds at least one-half inch deep, maintaining adequate fertilization, and harvest practices to reduce seed shatter and minimize seed left in the field) can provide effective and economically sound control of a diverse array of pathogens affecting production of grass seed.

Introduction

Grass seed for forage and turf in the Pacific Northwest is an important commodity for domestic and export markets. About 80 percent of the U.S. temperate forage and turf grass seed is produced in the Pacific Northwest. The bulk of the production is in Oregon, with over 400,000 acres planted to grass for seed (Sears, 1998). Grasses grown for seed in Oregon include bentgrass, fescues, ryegrasses, and orchardgrass. About 90 percent of U.S. ryegrass production occurs in the Willamette Valley of Oregon.

During the 1940s, blind seed disease, caused by the fungus *Gloeotinia temulenta*, threatened production of ryegrass seed in the Willamette Valley. By the mid 1940s, field burning was found to control the disease; and by the late 1940s, the practice was accepted. This marked the beginning of field burning as a management tool for control of blind seed disease. Field burning subsequently became the principal management tool not only for blind seed, but other diseases, weeds, insects, and for removal of straw residues (Hardison, 1980).

In 1991, the Oregon Legislature passed legislation to limit field burning to 40,000 acres annually after 1997. In response to concern about the reappearance of blind seed, surveys were conducted during the early 1990s to determine blind seed level in grass seed produced in the Willamette Valley. In 1997, several fields of tall fescue with a high level of blind seed (up to 25 percent infected seed) were found. Field burning was used to remove the high level of contamination, and information about cultural management practices to control the disease was distributed to growers.

The single greatest threat to production of perennial ryegrass and tall fescue is from a group of fungi commonly known as "rust fungi" (*Puccinia* sp.), because of rusty-colored lesions they produce on the grass stems and leaves. Rust is a potentially devastating disease, and several fungicide applications annually are essential for its control. More than $7 million a year is spent on fungicides to control rust in grass seed production. However, recent progress in disease modeling shows promise to predict optimal time for applications and to reduce the number of fungicide applications that normally would be applied. In addition, development of cultivars resistant to rust offer viable alternatives to costly fungicide applications.

Numerous other pathogens also can limit grass seed production, including fungi attacking the foliage, fungi that attack the seed, and nematodes that infect the roots or seed. Diseases such as Fusarium head blight (*Fusarium* sp.), choke (*Epichloë typhina*), and seed gall (*Anguina* sp.) have increased in importance in recent years. More than 600 diseases of grasses have been reported (Conners, 1967; Farr et al., 1989). Development of any of these diseases depends on a complex interaction of host, pathogen, and environment. Conditions favoring some pathogens may be highly unfavorable to others. Changes in production systems of grasses, including management of straw residue in the absence of field burning, may provide conditions favorable for some grass pathogens. Thus, new diseases and changes in dynamics of existing diseases are expected to coincide with changes in the production of grass seed and straw residue management. Control of diseases, as well as other pests, must be considered in development of grass seed production systems in the absence of field burning.

In this paper, diseases affecting grasses grown for seed in Oregon are described in terms of the causal agents, hosts infected, economic impact, general life cycle, and epidemiology, followed by a discussion of current integrated management practices for control of diseases of grasses grown for seed in the Willamette Valley.

Blind Seed Disease

Blind seed is a disease of grass seed caused by the fungus *Gloeotinia temulenta* (Prill. & Delacr.) (Wilson, Noble, and Gray, 1954). Principal hosts include tall fescue, perennial ryegrass, and annual ryegrass, although about 50 other species of grasses are susceptible (Hardison, 1962). Infected seeds are difficult to detect, but the disease's presence is manifest in reduced seed germination (Calvert & Muskett, 1945; Hyde, 1945; Wilson et al., 1945).

In Oregon, blind seed disease first was identified in 1943 (Hardison, 1949), although low germination was noticed in 1941 (Hardison, 1957). By 1944, blind seed was found in 85 percent of certified samples (Hardison, 1945) and about one quarter of the crop could not be certified (Hardison, 1948). Germination as low as 13 percent was reported (Hardison, 1945). By the late 1940s, field burning was recommended to control blind seed (Hardison, 1963). Post-harvest burning subsequently was adopted and provided an economical and effective means of blind seed control (Hardison, 1980). A legislative mandate to reduce field burning acreage during the 1990s renewed concern for the reappearance of blind seed. In 1995, a high level of blind seed was found in several fields of tall fescue in Oregon (Alderman, 1996). However, these appeared to be isolated cases, and recent surveys (Alderman 1991a, 1991b) have established a persistent but low level of blind seed in the Willamette Valley.

G. temulenta overwinters only in infected seed. In the spring, about the time grasses begin to flower, small, cup-shaped fruiting bodies emerge from the infected, overwintered seeds. Ascospores are ejected into the air and easily move around on air currents. Only spores which contact grass flowers can infect the ovary or developing seed; no other part of the plant is infected. Within about 7 to 10 days after infection, conidia are produced in large numbers and appear as a pinkish colored, sticky to waxy mass on the seed surface or emerging from the lemma and palea (Alderman, 1992; Wilson et al., 1945). Under rainy, windy conditions, the conidia can be dispersed to healthy flowers, rapidly increasing the level of infection. Cool, rainy conditions favor spore production and dissemination of spores; prolonging the flowering period under such conditions can increase the period of host susceptibility (Chestnut, 1958; DeTempe, 1966; Gorman, 1940).

Only seeds are infected by *G. temulenta,* and infected seeds are the only mechanisms for overwintering of the fungus. Thus, the greater the number of infected seeds remaining in the field after harvest, the greater the inoculum present the following spring.

Choke

Choke of orchardgrass is caused by the fungus *Epichloë typhina*. The fruiting body of this fungus appears prior to emergence of seed heads. A dense fungal growth within the tiller effectively blocks the emergence of the seed head, resulting in reduced seed yields. On the outside of the tiller, the fungus produces a fuzzy fungal mat that encircles the stem and extends 1 to 5 inches in length. At first white, it turns orange as it matures. This is the fruiting body in which large numbers of ascospores are produced and ejected into the air. Choke is a relatively new disease in Oregon (Alderman et al., 1997; Pfender and Alderman, 1998), and there still is much to learn about the mechanisms of infection and the timing of events in the infection process. A survey conducted in the Willamette Valley during 1998 determined that orchardgrass choke is now widespread in this crop; we found choke in all five counties where orchardgrass seed is produced, on virtually all cultivars we examined (Pfender and Alderman, 1999). Research from France indicates that the fungus gains entry through the cut stems at harvest. Research is currently under way to determine the dynamics of infection and to investigate cultural and chemical means of disease control. Post-harvest residue management may be an important aspect in reducing spread of this disease within a field.

Choke has been known in the fine fescues, but has not been a significant disease problem. The fungus that attacks orchardgrass differs from that infecting fine fescues.

Ergot

Ergot is caused by the fungus *Claviceps purpurea* (Fr.) Tul. *C. purpurea* infects about 200 species of grasses, including all of the grasses commercially grown for seed in Oregon (Bove, 1970; Brady, 1962). Ergot is distributed widely through temperate regions and has been known since ancient times as a malady of grasses (Barger, 1931; Bove, 1970).

The prominent feature of ergot is the elongated, hard, purple-black sclerotia which replace seed. The sclerotia generally extend beyond the glumes on infected plants. Sclerotia are the overwintering, or survival, mechanism for *C. purpurea*. A period of several weeks of near freezing temperatures are required to break the dormancy of sclerotia (Mitchell & Cooke, 1968). In the spring, small fruiting bodies grow from the sclerotia. Ascospores produced at the cap of the fruiting body are ejected into the air. Rainfall or high soil moisture is required for fruiting and spore production (Alderman, 1993). The ovary is the only organ of the plant susceptible to infection. Within a week after infection, conidia are produced on the surface of the ovary and mix with plant sap (Luttrell, 1980; Shaw and Mantle, 1980). The sugary mixture of plant sap and conidia commonly is called honeydew, not to be confused with the honeydew produced by aphids. In some cases, the honeydew is produced in such abundance that it can drip from the infected flowers. Insects, especially flies and moths, are attracted to the honeydew and may play a role in spread of the conidia to healthy flowers. Rain and wind also can disseminate the conidia and increase the spread of the disease (Barger, 1931; Bove, 1970).

Within about 2 weeks after infection, sclerotia begin to appear (Luttrell, 1980; Shaw and Mantle, 1980). Maturity of sclerotia coincides with maturity of the grass seed. As the grasses mature, sclerotia fall to the ground to survive the winter, completing the life cycle.

One interesting feature of ergot is that the ovary can develop resistance to infection after fertilization (Cunfer et al., 1975; Darlington and Mathre, 1976). This must occur prior to infection by *C. purpurea*. Thus, conditions that delay pollination can prolong the period of susceptibility. Grasses which have a long flowering period have a longer window of susceptibility. Other grasses, such as Kentucky bluegrass, which develop without the normal fertilization process, can be infected severely by *C. purpurea* (Alderman et al., 1998).

Leafspot Diseases

There are several leaf-spotting fungi that occur on grasses grown for seed in Oregon. These pathogens generally are active in the early spring. But most of them do not persist into the early summer, and therefore they are of little importance to seed yield or quality. The only leaf spot disease currently considered to require management is scald of orchardgrass, caused by the fungus *Rhynchosporium orthosporum* (Welty, 1991). Scald is controlled by one or two fungicide sprays in the spring. Another disease complex, which includes a leaf spot symptom, affects hard fescues in the Willamette Valley. The etiology of this disease is currently unknown, but a pycnidial fungus has been implicated in the leaf spot phase. Further research is required to assess the possible involvement of a root-invading organism in the complex and to develop appropriate disease management tactics.

Rust Diseases

Cool season grasses grown for seed are subject to a number of different rust diseases, caused by various species of the fungus genus Puccinia (Cummins, 1971). Stripe rust can cause economic losses in bluegrass seed production, and crown rust sometimes is damaging to orchardgrass. Stem rust, however, causes the most economic damage. It can reduce yields of unprotected perennial ryegrass or tall fescue by as much as 95 percent or 40 percent, respectively. It causes serious losses in the fine fescues, and is becoming increasingly common in annual ryegrass as well. We estimate that at least $7 million is spent by growers each year in the Willamette Valley for fungicide applications to control stem rust.

The stem rust pathogen (*Puccinia graminis* subsp. *graminicola)* survives over the winter as infections on susceptible grass species. In mild winters, the amount of disease may increase slowly between autumn and spring, but in extremely cold winters (temperatures below about 10°F) the overwintering rust population may be reduced significantly (Pfender and Vollmer, 1999). Spores (urediniospores) released from pustules are blown in the wind. When nighttime temperatures become warm enough in the spring for infection, the rust epidemic can begin to gather momentum by repeated cycles of urediniospores infection on the grass crop. The rate of cycling, and hence the severity of the epidemic, is affected by weather (temperature, humidity, leaf wetness) and by agronomic factors including grass species and cultivar.

Yield reduction in rusted plants is due to diversion of metabolites away from developing seeds and toward infected leaves and stems, water stress from disruption of the plant cuticle, and loss of photosynthetic area. The greater the plant area affected, the more the seed yield will be reduced. Currently, stem rust is controlled primarily through fungicide sprays. Well-timed applications of sterol-inhibiting fungicides (such as propiconazole or tebuconazole) can prevent serious yield loss (Welty and Azevedo, 1994). Recently, strobilurin type fungicides also have shown good activity against this pathogen (Pfender and Burr, 1998a; 1998b). Alternating or tank-mixing these two types of fungicide should reduce the chance that fungicide-insensitive strains of the stem rust pathogen will arise.

The ideal approach to control of stem rust is development of genetic host resistance. Efforts are underway to select and improve resistant host genotypes (Welty and Barker, 1992; Welty and Barker, 1993); however, it will be many years before adequate resistance in commercial cultivars is achieved. A prerequisite for efficient development of resistance is an understanding of the genetic variability in the pathogen population with respect to virulence/avirulence genes. The pathology program at the National Forage Seed Production Research Center (NFSPRC) is conducting research on pathogen variability, and the results will be used in a breeding program to develop germplasm for breeding cultivars with durable rust resistance.

The current major focus of the rust pathology program at NFSPRC is development of a warning system that can be used by grass seed growers as a decision aid for efficient and effective timing of fungicide applications. Because all years are not equally conducive to stem rust epidemic development, such a warning system could limit fungicide use to those times when it truly is needed. To this end, we have initiated a research program to assess predictability of stem rust epidemic increase as affected by weather, fungicide application, and agronomic factors. Such epidemiological studies will be combined with research on the relationship between disease severity and seed yield.

Preliminary results from 1 to 2 years of research are:

- In perennial ryegrass, yields decrease sharply as diseased leaf area between the time of flowering and harvest exceeds 5 percent; 20 percent disease during this time period results in 60 percent yield reduction.

- Severity of rust infection depends critically upon weather conditions during the night; leaf moisture of at least 2 hours duration is required, and infection increases exponentially with nighttime temperature above 36°F.

- Latent period (the amount of time elapsed between infection and development of a new generation of spores) is a critical determinant in the rate of epidemic development. Latent period duration depends upon temperature, and we are quantifying this relationship to enable us to gauge epidemic speed from temperature data.

- We are quantifying the effects of fungicides (propiconazole and strobilurin products) on infection and pustule development, including the effects of various delay times between infection and fungicide application.

We expect that additional epidemiological studies, including field plot research conducted over the next several years in Corvallis and Hermiston, and a Valley-wide survey for early rust occurrence west of the Cascades, will allow us to develop the basics of the disease warning system. The warning system then can be elaborated further through additional research comparing epidemiological effects of a range of cultivars under a variety of cultural conditions.

Seed Gall

Seed gall is a disease of grass seed caused by the nematode *Anguina agrostis*. The principle hosts for *A. agrostis* are species of Agrostis (bentgrass). The nematode attacks the developing seed and can reduce seed yield as much as 75 percent (Jensen, 1961). Symptoms are most pronounced when the panicles are fully emerged. Each infected seed is replaced by a slender, elongated, needle shaped black gall. Each gall replaces a single seed. The galls fall to the ground and overwinter. The nematodes molt while in the egg and emerge as second-stage juveniles. During midwinter to early spring, nematodes emerge, invade bentgrass plants, and feed near the growing point (Courtney and Howell, 1952; Pinkerton and Alderman, 1994; Southey, 1973). In the plant, the nematodes migrate to the inflorescence primordia. They feed on ovules and undergo three more molts to become adults. Each female can lay up to 1,000 eggs within a gall (Southey, 1973).

In galls stored dry, *A. agrostis* can survive decades (Southey, 1973). Under field conditions, the nematodes do not survive more than a year in the absence of a susceptible host (Jensen, 1961).

Anguina sp. in orchardgrass has been known since 1947 (Jensen, 1961), although incidence and severity appears to have increased in recent years. *Anguina* attacking orchardgrass is believed to be a different species than that attacking bentgrass (Southey et al., 1990). Nematode galls on orchardgrass are about the size of a seed, slightly shrivelled, and purplish in color (Southey, 1969). They are difficult to detect visually. However, infected seed heads often are distorted. A bacterium can be associated with *Anguina* in orchardgrass, causing a crusty yellowish coating on the galls.

Chewings fescue also can be attacked by *Anguina*. Chewings fescue screenings containing nematode galls are poisonous to livestock (Jensen, 1961). A laboratory test can be used to determine the presence of *Anguina* in grass seed.

Integrated Management of Diseases Affecting Grass Seed Production

Management of grass diseases is integrated into all phases of crop production, from site preparation and planting to post harvest management, including seed conditioning. In replacement of a grass field with another grass, one should consider the potential carryover of inoculum from one crop to another. Propagules or residue on the surface of the soil could provide an inoculum source if the crop is no-till seeded. This may be of less concern if one is establishing a grass field from a non-grass rotational crop.

An effective means of reducing surface contaminants is through deep plowing to bury the residues. Plowing is especially effective in management of blind seed and ergot since it buries many of the propagules. Plowing was an important means of blind seed control prior to the introduction of field burning.

Planting seed free of disease or disease propagules is recommended. Seed diseases, such as blind seed, ergot, and seed gall, can be introduced into a field through contaminated seed and provide a source of inoculum to establish disease within a field.

Seed treatments, such as fungicides, may provide a means of reducing seed-borne fungal contaminants. Fungicides are considered effective in reducing blind seed. In addition to fungicidal seed treatments, simply holding seed for 2 years is considered effective in reducing blind seed, since seed remain viable in storage longer than the blind seed fungus.

Whenever possible, disease resistant cultivars should be used. Disease resistance is the optimal choice for disease control. Kentucky bluegrass cultivars with resistance to ergot have far less ergot than susceptible cultivars. Disease resistance for rust control will be especially important in reducing our dependency on fungicides for disease control.

Planting seed at a depth greater than ° inch is recommended for control of diseases such as blind seed and ergot. Fruiting bodies cannot extend to the soil surface if planted sufficiently deep, thus preventing release of spores into the air.

Avoid moving propagules from clean to infested fields. Infected seeds can be moved through contaminated soil, on shoes or clothing, equipment, on animals, in irrigation water, or by wind blowing propagules from one field to another.

A healthy, vigorous crop provides greater resistance to infection by fungi such as blind seed. Nitrogen fertilization in particular has been shown to reduce the severity of blind seed disease (Hampton, 1987).

Management of weed grasses adjacent to fields can be important in reducing inoculum from areas surrounding the field. Preventing flowering in these grasses will reduce the contamination from ergot or other seed diseases. Herbicides have been used to eliminate hosts for grass seed nematodes. Scout for leafspot and rust diseases, and implement a rust management program (outlined above under rust diseases).

Harvesting to remove as many seeds as possible from the field is important in management of seed diseases such as blind seed, ergot, and seed gall. Delayed harvest can increase seed shatter and return of seed to the field. In addition, combines should be set to remove as many lightweight seeds as possible from the field. Infected seeds, such as blind seed, can be lighter weight, and returning these seeds to the field will increase inoculum levels.

Harvest methods may need to be considered for control of choke in orchardgrass. Since infections appear to occur at the time of harvest, management strategies such as chemical treatment or timing of reclipping may provide options for control. The best management options for choke control currently are being researched.

Seed conditioning can be an effective means of removing disease propagules such as light weight blind seeds, seed galls, and ergot sclerotia. Levels of blind seeds or disease propagules within a seed sample can be determined through laboratory testing.

Future Outlook

Management of grasses for seed production has changed significantly during the past decade, as the industry has moved away from open field burning as the primary management tool for controlling pests and diseases and for straw residue removal. Blind seed, which was an important disease during the 1940s, likely will not reappear as a major disease of grasses under current management practices. Other diseases, however, will continue to be problematic. Rust likely will continue as the greatest threat to grass seed production, and fungicides will be essential for disease control until rust resistant cultivars are developed and used though much of the acreage. Long term control of ergot also will be managed best through disease resistance. New diseases, such as choke in orchardgrass, will continue to challenge plant pathologists in developing effective, economically and environmentally sound disease management.

Future disease control strategies must consider options for management of grass seed production in the absence of burning, as well as management in terms of integrated control for diseases, weeds, rodents, insects, or other maladies. To this end, a comprehensive understanding of the biology, ecology, and epidemiology of grass pathogens relative to grass management, and interactions with other biotic and abiotic stresses affecting seed, will be essential to the integrated control of grass diseases and the profitable production of the highest quality of grass seed.

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Establishing a Grower Supported Weather Station Network

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Since 1993, Mid-Columbia growers have been establishing and implementing an Integrated Fruit Production (IFP) program for cherries. The process has included writing guidelines, conducting research on insect and disease pests, and developing educational material and other tools so that growers can make educated decisions about their IPM practices.

A key tool currently being developed in this process is a weather station network system. This network is a joint effort between the OSU Extension Service, Wasco County Fruit and Produce League, and Deschutes Digital, software developers.

There were several goals established for this project. Since the stations would be located in remote sites, they had to be solar powered. They also needed to present real time weather data, which is particularly important during frost season. In addition, growers and other users needed to be able to retrieve information easily and reliably. Most importantly, the information itself needed to be useful to growers for informed IPM decisions.

As the developmental stage progressed, it was recognized that there were several important weather station features that were critical for the operation and success of the system. Multiple cloudy days occur at certain times of the year, even in The Dalles. The stations, therefore, needed to be able to operate for extended periods of time on dark, mid-winter days without completely draining the battery. In addition, since most of the orchards are located in remote, hilly regions, the stations needed to be able to communicate with the base station via radio waves, and each station needed to be able to act as a repeater for other stations.

However, none of this is useful without easy access to understandable information by growers. Two methods of communication were chosen to accomplish this goal. The first and most comprehensive interface involves posting information on the web. Second, for growers who lack computer access or desire access from a remote site, such as a pickup or an orchard block, information is available via an automated phone system. Besides allowing remote access, the phone system acts as an advance warning system for frost. The system will call the orchard manager when the temperature/humidity index drops below a user-defined threshold.

As mentioned above, primary access is provided through a web interface at http://www.ifpnet.com. On the home page, growers will be able to view a table that gives them current data for each of the on-line weather stations in the district. Most growers have blocks in several different regions of the district, so this gives them a quick overview of climatological data and how it varies from region to region. Included here are temperature summaries, especially useful for frost control; wind speed, in case growers want to spray; and rainfall totals, etc.

The backbone of this system, however, is the IPM model summary. Incorporated into the system are pest models for cherry, apple, and pear. Cherry models include obliquebanded leafroller (OBLR), cherry fruit fly, western tentiform leafminer, and powdery mildew. The pest models for apples and pears include OBLR, codling moth, fireblight, and apple scab. Weather data from each station is automatically run through these models, and growers are able to see a summary of the next event to occur, such as egg hatch, pupation, etc. The number of degree-days until this event occurs and the estimated date that the event will occur is displayed also. In addition, alert indicators will tell growers at a glance if any action is required. These indicators will be adjusted according to the model and, in some cases, spray information that growers input.

Important news updates also are available at a glance. The Extension agent, scientist, or industry leader will be able to post timely information and announcements on the web in order to communicate rapidly with growers on important topics and issues. Where a newsletter might take several days, information posted at this location will be available in just a few minutes, and it can be updated just as quickly.

Finally, this page also displays the weather forecast for The Dalles from www.weather.com.

For those who want more information about weather trends, this information is displayed in several ways, including the following:

- Graphically compares historical data for a particular station.
- Graphically compares differences between microclimates of multiple stations.
- Compares high/low/average values from previous years.

More detailed information also is available on the various pest models.

- Graphically presents degree-day accumulation for the model, highlighting critical events and thresholds.
- Recommends potential courses of action or preventative measures.
- Tracks pesticide applications and changes the model accordingly.
- Models can be separately configured for each orchard block.

This last factor is important so that growers have the ability to input spray applications, thereby affecting the action step required.

This project is currently in the design and implementation stage. Eight weather stations have been installed throughout the district; however, building radios that will perform as specified has been challenging. Original equipment radios did not meet expectations. The software itself is approaching the test stage. We hope to have a limited but functioning system up and running by late spring. At that time, you will be able to view system progress and real time weather and pest management information by pointing your browser to http://www.ifpnet.com

Online Decision Support for IPM

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Introduction

The increasing presence of the Internet and World Wide Web is rapidly changing the way integrated pest management (IPM) information is exchanged among researchers, Extension agents, and end users. In fact, as we learn how to use online resources, the communication gaps and slow feedback mechanisms that we sometimes have observed in the past are giving way to near-instant satisfaction of information needs. The goal is to have more timely and better informed IPM decision making and improved production systems.

Let's review one definition of IPM:

"IPM is a **decision support system** for the selection and use of pest control tactics, singly or harmoniously coordinated into a management strategy, based on cost/benefit analyses that take into account the interests of and impacts on producers, society, and the environment." (Kogan, 1998).

A decision support system consists of the collected and integrated resources that provide a full spectrum of information needed in problem solving.

The Internet already has become an important source of information for pest identification and management, although the information mostly is scattered and poorly integrated. Note that the Internet is not a passing fad that will soon go away. In fact, the number of "hosts—that is, computers linked to the Internet at any one time—has grown from 15 million in January 1996 to 30 million in January 1998 to 45 million by January 1999. This is a growth rate unprecedented by any other new technology, past or present.

The purpose of this paper is to evaluate how online technologies are developing and how they can improve delivery and exchange of IPM information from the standpoint of decision support.

Online IPM should have several objectives:

1) To provide up-to-date, accurate information in areas including:
    a) Problem identification and diagnosis
    b) Control tactics and methodologies
    c) Decision support for determining if and when action should be taken
    d) Provide "real time" (or rapidly changing) data, such as pest outbreak alerts, weather-based products, pesticide regulatory information, etc.
2) To decrease the complexity of pest management; to make it simpler by hiding complexity, by integrating diverse resources, and by saving time
3) To shorten communication gaps between all parties involved

A summary of Internet-based technologies and how they continue to develop is presented in Table 1. The Web started around 1991, but was not noticed much until around 1994-5, and some forms of IPM information were posted at that time. These include conversions of many of the same extension publications traditionally produced in print form, such as management guidelines and pest fact sheets. One relatively early online example (since Jan. 1996) that is increasingly useful is Ted Radcliffe's IPM World Textbook (Radcliffe and Hutchinson, 1999) located at http://ipmworld.umn.edu/.

Static Information

Most forms of online IPM information were, and continue to be, static; that is, based on text and graphics only. Online static information may represent several rather obvious advantages over print versions, such as in saving paper and solving the problem of physical distribution of printed copies. As the Internet soon will be ubiquitous, people will expect information to be available and accessible at all times. Already the amount of information available on the Internet exceeds that of many libraries combined, and more than 1.5 million new Web pages are added daily. In the realm of IPM, according to the Database of IPM Resources, at http://www.ippc.orst.edu/cicp, there are over 5,000 unique IPM related links available worldwide.

Table 1. Developmental stages of online IPM decision support.

1st cases	Technology	Direction	User involvement & training
	Static	**1-way**	**click only**
pre95	Text		
1995	Graphics		
	Dynamic	**1-way**	**user input req.**
1996	Calculators		
1997	Models		
1996	Databases, general search engines		
	Interactive	**2-way**	**user initiated**
1990s	email, chat		
1999	mail lists		
1999	web conferences		
2000?	mail list archive, knowledge bases		
	Integrated	**multiway**	**user initiated**
2000+	multiple seamlessly integrated		

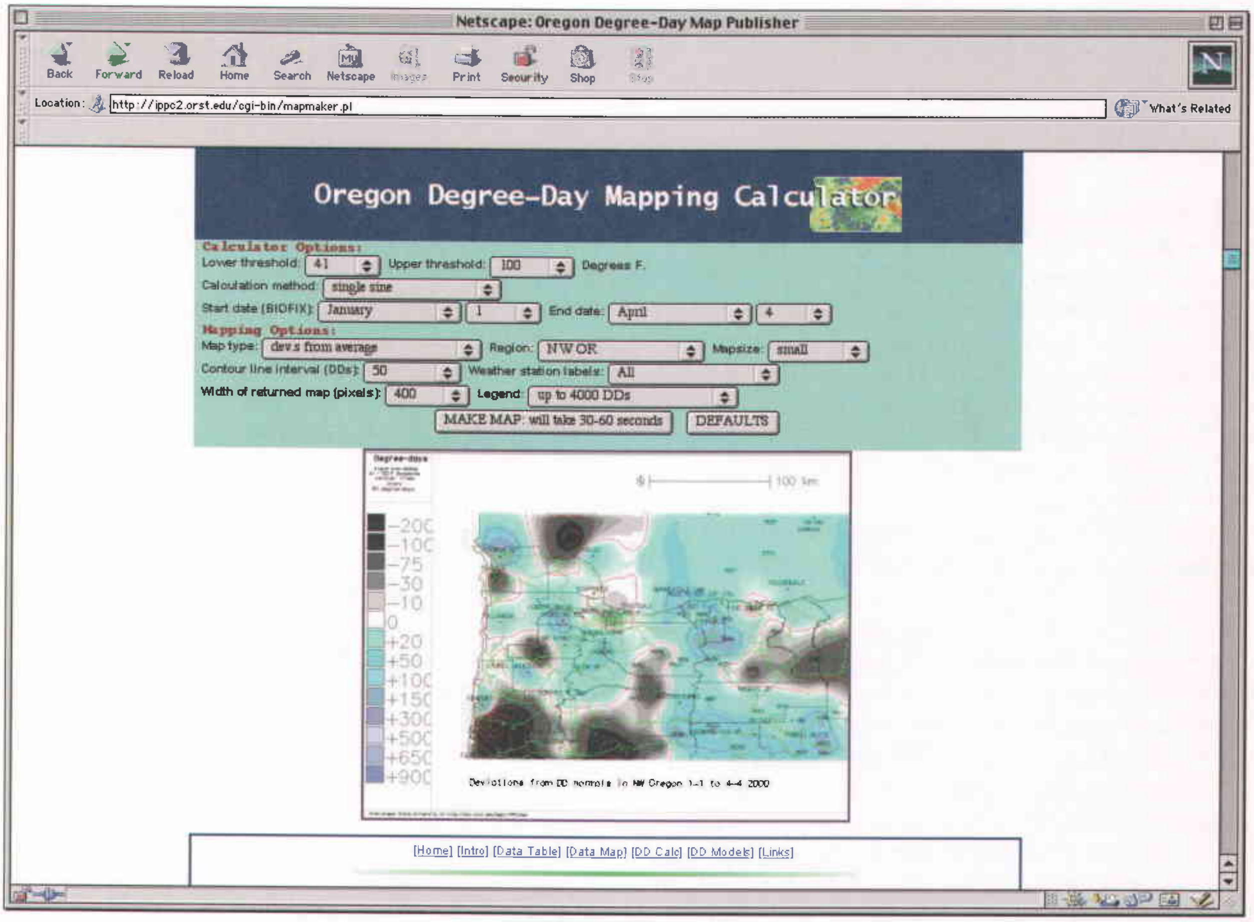
With primarily static information available, the direction of information flow on the Internet has been chiefly one-way, meaning that it is used almost like television, albeit with nearly infinite channels. This is odd, in that the Internet was designed to be used as a multi-way communications medium. In fact, after just over 5 years in existence, its multi-way capabilities remain underdeveloped (at least for IPM). Static online resources do have an advantage by offering a short learning curve; usually, all that is needed is general Web training, how to use a Web browser, how to use general search engines, and then a good IPM Website to start from. The main challenge is simply to find the right information, and much work remains in this realm—as anyone who now uses the Web knows too well.

Dynamic Tools

The next stage of development in online IPM decision support is the use of dynamic online computer applications such as calculators, models, and databases (Table 1). These are more than one-way, due to the need for user-selected inputs. Thus, users may need special knowledge and training to use dynamic tools correctly. On the part of the developer, these dynamic tools require much greater technological skill and training, which until now has not been expected of Extension information specialists. This is a factor that explains why dynamic tools are developing more slowly than static resources, even though they exploit more of the potential of the Internet.

There are several Integrated Plant Protection Center-developed, IPM-related examples of Web-based applications, such as an economic threshold and sequential sampling calculator for strawberry root weevil, at http://www.orst.edu/dept/entomology/ipm/eilcalc.html; a release calculator and guidelines for using the predator mite *Neoseiulus fallacis* to control twospotted spider mites in strawberry, at http://www.orst.edu/dept/entomology/ipm/mcalc.html; an online weather data and degree-day calculator at http://osu.orst.edu/dept/ippc/wea/weacalc.html; and the Database of IPM Resources, at http://www.ippc.orst.edu/cicp/. The latter two examples are truly dynamic because their information content changes on a daily basis, based on near-real time weather data, and from the changing IPM resources on the Web, respectively. Another concept associated with online dynamic tools is the "data warehouse," which lets the user access a set of database-driven analytical tools, which in the future will be instrumental in IPM decision support. A fairly modest example is a 1996 Survey of Oregon Pear IPM practices, conducted by IPPC, which links statistical summary tools to a database of the survey results, located at: http://ippc.orst.edu/IPMsurvey/cfgph/pearsurvey.cfm.

Among the main reasons that many growers have started using computers and the Internet is the availability of weather data and forecasts for IPM pest phenology models, frost control, irrigation, and other needs. Value-added weather data products are critical for growers who must make informed management decisions. Two central resources for IPM decision making in the Pacific Northwest are the IPPC "IPM Weather Data and Degree-Days" Website, http://osu.orst.edu/Dept/IPPC/wea; and PAWS (Public Agricultural Weather System), http://index.prosser.wsu.edu/. For example, the IPPC Website has a variety of tools to aid in tracking and forecasting heat-driven events related to IPM. This site brings together 43 Agrimet, 41 National Weather Service, 18 Hydromet, and more than 100 National Forest Service and other Federal lands management weather stations, with more than 19 models of insect pests, disease pests, crop development, and (soon) weed development, and other heat unit-driven event models. There is documentation for the models, and features such as the ability of users to upload their own weather data to the models, and ability to graph degree-day accumulations. Development models are stored and retrieved from an online database, which allows new species to be added very easily through a Web form interface. A product recently was added that can compute degree-day maps for any region within Oregon—the "Oregon Degree-Day Mapping Calculator," at http://ippc2.orst.edu/cgi_bin/mapmaker.pl. This product can compute and interpolate elevation-corrected degree-days for the region of choice using all the same options available for the standard degree-day calculators, plus mapping options such as the contour line interval, output legend, labels, and map size. The calculator and example map is shown for deviations from average degree-days in Northwest Oregon from January 1 to April 4, 1999 (Figure 1).



Location: http://ippc2.orst.edu/cgi-bin/mapmaker.pl

Calculator Options:
Lower threshold: 41 Upper threshold: 100 Degrees F.
Calculation method: single sine
Start date (BIOFIX): January 1 End date: April 4

Mapping Options:
Map type: dev.s from average Region: NW OR Mapsize: small
Contour line interval (DDs): 50 Weather station labels: All
Width of returned map (pixels): 400 Legend: up to 4000 DDs

Deviations from DD normals in NW Oregon 1-1 to 4-4 2000

Figure 1. Screen shot of online degree-day mapping calculator showing deviations from normal DDs, shown for northwest Oregon, January 1 through April 4, 1999, using a 41°F lower threshold.

This degree-day mapping tool uses Oregon Climate Service-developed PRISM maps (Daly et al., 1994, Website at http://ocs.orst.edu/prism/prism_new.html); a geographic information system (GRASS version 4.2, USACERL 1993); a degree-day calculator; up-to-date daily temperature data from all available stations (up to 160 total); and historical average temperature data from up to 200 stations. Maps are delivered directly over the Web 30 to 60 seconds after the "Make Map" button is selected.

The above examples demonstrate that dynamic online resources are now available, either in the case of general use tools (such as degree-day calculators) or for a small number of specific pest situations. However, much work is needed before we can claim to have good decision support tools for all major pests. In addition, dynamic tools at this time are not tightly integrated with other online resources. As mentioned earlier, there is also a greater need to introduce and train end-users in how to use dynamic tools such as models and calculators.

Integrated Tools

The availability of some static and some dynamic tools calls up the need for centralized, integrated decision support systems that can provide end-users with a starting point and a direction to take as they begin to solve pest problems. These may be derived from pest control guides, and may have evolved from PC-software based systems, such as the WISDOM potato decision program (Stevenson et al., 1989); and IPMP for peppermint IPM (Berry et al., 1995), which soon will be fully revised for online use. There are presently few good online examples that serve the Pacific Northwest. The Online Guide to Plant Disease Control (Pscheidt and Ocamb, 1999), at http://pnwhandbooks.orst.edu/guide1998/index.htm, provides an example of the integration of disease management information with pictures of symptoms. The online PNW Insect Control Handbook (DeAngelis et al., 1999) is under development, and has a prototype showing how text and links to other resources may be integrated, at http://ippc2.orst.edu/cgi_bin/pnw2.pl. Advantages that will become inherent for integrated online decision tools include: (1) The opportunity to be multi-regional, with contributors from many states and disciplines; (2) The ability to update content at the proper temporal scale. For example, weather data may be updated in real-time, pesticide registration status can change suddenly but infrequently, whereas identification photos rarely change; (3) Tightly integrated feedback and discussion abilities, which virtually will eliminate the currently "vertical" communication structure among research, Extension, and end-user communities (detailed next).

Interactive Tools

The final development in online decision support includes much higher levels of interaction, where end-users may respond to and share information online. Currently, e-mail, e-mail list servers, newgroups (USENET), chat groups (internet relay chat or IRC), and Web-based conferencing systems all are used to add interactivity to Websites. A few very general local IPM-related online conferencing groups currently exist, including several mail lists related to issues in small fruit production, at http://osu.orst.edu/dept/infonet/mail.htm. As we have seen with mail lists in other areas, it can be a challenge to develop and sustain effective online group discussions. For IPM discussions, it may require recruitment of certain list moderators to generate information and examples of IPM questions and answers to model effectively this form of communication. Another form of online discussion is the Web-based conference, which most primitively takes the form of a guest-book. These are Web pages that allow threaded (topic-driven) discussions to occur. Newer versions integrate with e-mail, so that subscribers may receive new postings via e-mail, and anyone including non-subscribers simply can go to the Website and access recent postings or search archives. We have yet to see chat groups integrated with Websites for IPM, which could provide a nice conversational medium at certain designated times during the week. With these technologies, a database of common problems and solutions can be accumulated, providing yet another technology to support IPM decision making.

Also, the regular posting of pest sample data, model forecasts, and pest alerts may encourage adoption of such mail lists and Web-based conferences. In other words, for interactive tools to work effectively, they should be integrated with other online resources. The relationship will be symbiotic: the support provided through interactive tools will hasten training and adoption of the static and dynamic information resources. As we develop early examples, this chicken or egg situation may result in slow initial acceptance, and it may be the support personnel (applied research and Extension) that show greatest reluctance to move in this direction. This is understandable, as we know the effect that shrinking resources and increasing workloads can have on learning and adopting new technologies. This is where the technologically enabled can step in and provide training and support and, most importantly, hide the complexity that computer technologies initially exhibit.

In summary, as we plan for the future of IPM decision support, we see that technology, particularly the Internet and Web, will become absolutely essential tools that will change the way nearly all parties do their work. This will, in turn, bring the users group closer together as a community, with the common goal of speeding the adoption rate and refining the goals of IPM. One element of the Web that has been observed: it turns all users into researchers. We log on, ask a question, search for an answer, make judgments about the results, and look for verification from independent sources. Hopefully, we become wiser for it, and make better decisions in crop and pest management. This is the potential offered by these new technologies; and, ultimately, the use of non-selective pesticides will continue to decline, the environment will benefit, and the safety of our food and fibre will increase. IPM is information intensive, and a seamlessly integrated, interactive approach that fully exploits the opportunities offered by the internet will one day be taken for granted, when we perhaps will have trouble visualizing how it was done during bygone eras.

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The Delay Between Development and the Adoption of IPM Practices in Oregon Agriculture

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The integrated management of insect and mite pests in agriculture is based on correct identification of potential pests, an understanding of their life histories, and which key agricultural and ecological factors regulate their populations and influence their "pesthood." Quantifying potential and actual in-field or orchard populations requires cost- and **time**-effective methods that can be related realistically to expected crop injury and dollar loss. Satisfactory and fairly simple control options must be available; consequences of their uses (non-control of other pests or potential creation of other problems) must be known.

An entomological background, such as formal coursework or concerted effort learning from or working with an entomologist, is essential to insect pest management. Distinguishing pests and beneficials, differentiating pest from non-pest populations, and recognizing and anticipating those factors that will create or diminish pest populations in fields or orchards is no easy matter. Often, on-farm factors unaccounted for by initial research to estimate populations of pests or "action thresholds" influence the utility of sampling methods and "action levels" for various insect and mite pests.

When dealing with farming practices and/or systems, the transition from agricultural research to use has been accomplished traditionally and most successfully through the land grant University system of Extension delivery and implementation programs. Extension agents and specialists facilitate this technology transfer. In Oregon, Extension FTE commitment by administration for on farm IPM demonstration and implementation is practically non-existent. Agricultural Extension agents left in the system now must cover multiple counties, often become involved in issues and policies, and have little time to devote to IPM implementation.

On-farm personal contact and pest control information most often is conveyed to the farmer by processor or agricultural chemical field personnel, a few private consultants, and fewer Extension people. To date, the most reliable, inexpensive, and consistent pest control, production of blemish-free produce, and top yields in Oregon have been realized with insecticides and miticides. For most crops, alternatives have yet to be demonstrated as being suitably cost effective with a consistency of pest control on par with pesticides to many full time farmers and their most pervasive and constant advisors—field representatives for agricultural chemical suppliers or wholesale buyers.

Database Management System for Internet IPM Information

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Abstract

The Database of IPM Resources (DIR) is a continually updated and expanding information management and retrieval system for worldwide IPM information resources accessible through the Internet. This system is presently a compendium of about 2,000 documents, i.e., unique URLs developed specifically for DIR. DIR has four main components, including directories of Internet IPM resources, search engines, informational databases, and knowledge-bases. Currently, DIR contains eight bibliographic databases, five knowledge-bases, and a database with more than 5,000 documented Internet resources and their hyperlinks searchable through its search engines. DIR is a database of "metadata" that functions as an information system, linking IPM researchers and practitioners through a central network, which can be used by anyone seeking crop protection information. The basic goals of this system are: (a) to assist in IPM information dissemination, (b) to raise public awareness about new and emerging techniques for agricultural, forest, livestock, and medically-important pests, and (c) to provide support for decision-making in IPM.

Introduction

The Internet, a global network of computers, has developed over the past few years into a powerful medium for fast, worldwide dissemination of up-to-date information. Its instant nature and global domain provides a quick access to vast amounts of information (Stinner, 1998a). In fact, access to information is the essence of the Internet (net). The net is not just a transmitter of information, it is also a means for exchange of information and can be used for storing, sorting, and analyzing information. Internet access is becoming ubiquitous, and as bandwidth improves, increasingly sophisticated graphics, audio, video, and animation elements can be included in the Internet-based information systems. The net is expanding at a remarkable rate (Figure 1). In January, 1999, there were about 44 million computers connected to the Internet (Network Wizards, 1999) serving an estimated 163 million individuals worldwide (Global Reach, 1999), compared with about 1.5 million computers serving an estimated 15 million individuals in 1993 (Miller, 1993).

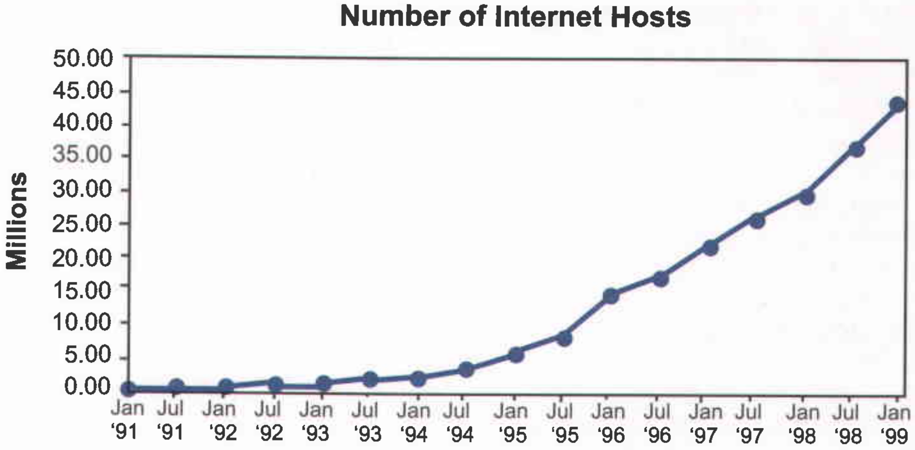


Figure 1. Number of computers connected to Internet from 1991 to 1999 (Network Wizards, 1999).

Knowledge and information play a key role in pest management decisions. Integrated pest management (IPM), a system for decision making in pest management, is information-intensive, depends heavily on accurate and timely information, and demands quick transmission of information from scientists to their clientele. On the other hand, researchers and Extension specialists need the most updated information to design new projects and set future research goals and directions. Fortunately, there is a large volume of useful IPM information available on the Internet, scattered all across the globe. These resources range from topics such as IPM definitions and basic concepts to modeling and systems analysis. As awareness of the Internet increases worldwide, more people are participating, not only as users of the information but also as creators of new information; as a consequence, the number of both IPM Internet servers and clients is increasing exponentially.

Unfortunately, finding information on a particular topic is time-consuming and often frustrating, particularly when searching by one of the several general search engines (e.g., Yahoo, HotBot, Alta Vista, Excite, Northern Light, etc.). Even the best engines retrieve only 16 to 20 percent of the relevant information on any given topic. These search engines normally turn up thousands of links, only a few (or none) of which may fit the user's needs. Moreover, these search engine sites, at times of peak traffic, may be overloaded, and attempts to connect may be refused. There are several other ways of locating information on the Web. For example, many attempts have been made to compile Internet resources into listings which can be used as a reference point for information retrieval on a given subject. Although these resources are useful, they generally focus on local/regional needs and lack complete coverage of the subject matter, global perspective, or important features such as searching utilities with proper indexing and cataloging of keywords. There is, therefore, a dire need for a user-friendly retrieval and referral system to organize current IPM knowledge/information available through the Internet for easy and swift access.

To fill this increasingly wide gap between the accumulated information and its accessibility to users, we developed a "Database of IPM Resources" (DIR) as a key component of IPMnet, a cooperative project of the Consortium for International Crop Protection (CICP), the Integrated Plant Protection Center (IPPC) of Oregon State University, and the National Science Foundation Center for Integrated Pest Management (CIPM). DIR is a continuously updated and expanding information management, exchange, retrieval, and referral system for global IPM information resources accessible through the Internet. The basic goals of this system are: (a) to assist in IPM information dissemination, (b) to raise public awareness about new and emerging techniques for agricultural, forest, livestock, and medically-important pests, and (c) to provide support for decision-making in IPM. The first section of this paper mainly focuses on the use of the Internet as an information delivery tool. The second part discusses the architecture and modeling of the DIR database management system and its information retrieval and referral capabilities.

Internet based-Information Delivery Systems

Internet Services and Recent Trends in Information Delivery

The most popular Internet tools, namely Telnet, File Transfer Protocol (FTP), Gopher, and the World Wide Web (WWW or Web), operate as client/server systems. All these are basically interactive. In an interactive program, a user interacts with a client program (e.g., browser), which manages the details of how data is presented to the user. The client program interacts with one or more servers (e.g., Web server). The server receives a request, processes it, and sends a result back to the client. The advantage of the client/server model lies in distributing the work so that each tool can focus on a specialized task: the server serves information to many clients while the client software for each user handles the individual user's interface and other details of the requests and results.

The fastest-growing part of Internet is the WWW. The Web is easier to use (point and click) than other Internet services (Stinner, 1998b). It is a true global information system that provides a user-friendly interface to accessing online information (Green, 1995). The WWW uses the HyperText Transfer Protocol (HTTP) to distribute hypermedia (a combination of hypertext and interactive multimedia) information across the Internet. It can incorporate animation, graphics, sound, and video to provide a media-intensive vehicle for publishing information (Peet, 1998). It is a network system that ties computers together using existing phonelines, Ethernet, and Fiber Optic networks.

The Web permits a flexible organization of information including hierarchical menus, tables, and linked hypertext documents. Generally, search engines are used to locate information in Web pages and databases that are accessible over the Web.

An example of information delivery on the Internet is electronic text (etext)—comprehensive up-to-date information available via the Web in the form of text, images, movies, and sound files (Gordh,1998). These resources can be accessed directly through a Web browser. This service may be used as an alternative to the purchase of expensive and rapidly outdated textbooks (Gordh,1998). Some information delivery systems are based on so-called "Hybrid Technology," which combines WWW access with a CD-ROM. In this technology, images and an executable program (analytical processing) are stored on the CD-ROM and text is server-based. There are several advantages to this scheme; the most practical is minimizing the amount of time spent downloading information. Thousands of still images, or about 75 minutes of video, can be stored on a CD ROM.

The Web provides excellent interfaces for all kinds of interactive network databases. This feature allows the Web to be used as a network "front-end" for many kinds of analyses and data processing. Web-based models and Decision Support Systems (DSS) are becoming popular because little or no client software is required, thus reducing software management and distribution costs (Power and Kaparthi,1998). Several Internet-based DSSs have been developed for industry, medicine, business, meteorology, and agriculture, including pest management. For example, various weather-based disease and insect pest models are available online for local forecasting of pest situations based on real time, near-real time, and/or historical weather data. For example, the phenology model database of University of California Statewide IPM Project (UCIPM, 1998) contains information about, and models of, more than 100 plants, pests, and beneficial organisms (predators and parasitoids). The Integrated Plant Protection Center (IPPC) of Oregon State University developed several online interactive resources including real-time daily weather data, various degree-days products (calculators, models, maps, and map calculator), and phenology models for pest management decision making in the Pacific Northwest (Oregon, Washington, and Idaho) (IPPC, 1996). The potential for using the Web to integrate all types of static and interactive (dynamic) information is unprecedented. No other medium offers such ability as simultaneous real-time weather information, multimedia, analytical processing, and multi-way discussion and feedback.

Internet as an Information Delivery/ Exchange Tool

Using the Internet as an information delivery tool makes information accessible globally to any person at any time (Jensen et al., 1996a). The only requisite is an Internet connection. The Web provides a cost-effective (Channin and Chang, 1997) means of delivering and exchanging quantitative and qualitative information via its user-friendly interactive interface. The Web is advancing quickly toward mass-media status in the world. It has sustained double- and triple-digit annual growth in the U.S. and throughout the world (Figure 1). Having started with a small number of users (less than 1 percent of the U.S. population and less than 0.1 percent of the world population) in 1990 (Gardner, 1999), the WWW currently has approximately 163 million users around the world (NUA Surveys, 1999). In the U.S., 28.3 percent of the population used the Internet in January, 1999, and the number is expected to grow to 48.6 percent in 2000 and 72.1 percent in 2005 (Gardner, 1999). The current share of different regions is as follows: North America, 55.5 percent; western Europe, 23.3 percent; Asia Pacific, 15.5 percent; eastern Europe/Russia, 2 percent; Latin America, 1.8 percent; and Middle East/Africa, 1.9 percent (Gardner, 1999). The Internet is projected to be four times bigger by 2005, with a total of 716 million users: 32.1 percent in North America, 28.2 percent in western Europe, 23.8 percent in Asia/Pacific, 6.1 percent in Russia, 6.1 percent in Latin America, and 3.7 percent in the Middle East/Africa (Gardner, 1999).

Internet is impacting cooperative research on a global scale (Green, 1995; King et al.,1998). Several international, public-domain databases are now online and are available free of charge. Among these are several molecular biology and bibliographic databases such as Genbank and Agricola. GenBank is the U.S. National Institute of Health (NIH) genetic sequence database, an annotated collection of all publicly available DNA sequences (Benson et al., 1999). GenBank is part of the International Nucleotide Sequence Database Collaboration, which is comprised of the DNA DataBank of Japan (DDBJ), the European Molecular Biology Laboratory (EMBL), and U.S. National Center for Biotechnology Information (NCBI). These three organizations exchange data on a daily basis (Benson et al., 1999). The GenBank database and related resources are freely accessible at: http://www.ncbi.nlm.nih.gov. AGRICOLA (AGRICultural OnLine Access) is a database of bibliographic records created by the U.S. National Agricultural Library and its cooperators. This database covers materials dating from the 16th century to the present. The records describe publications and resources encompassing all aspects of agriculture and allied disciplines. AGRICOLA can be searched via the Web at http://www.nal.usda.gov/ag98/.

At present, most information accessible via the Internet is static, electronic versions of informational brochures, fact sheets, Extension guides and papers, etc. Many sites, however, are designed as interactive systems that permit users to interact with a Web-based database through "form interface" comprising buttons, pull-down menus, and text-boxes. To submit a request, a user fills out a form and submits it to a Web server. The server forwards relevant portions to a CGI (Common Gateway Interface) application, an interface between the server and the database. This program then generates an output to be sent back to the user as a new document. It is up to the application to format the data it sends back for viewing as a hypertext document. The information is processed for database searches, abd the requested document is created "on the fly" and sent back without ever being stored. In effect, users see a custom-made, "virtual" document that was created specifically for them by an application program. This facility permits a far richer information system than would be possible with static document retrieval. (Green, 1998).

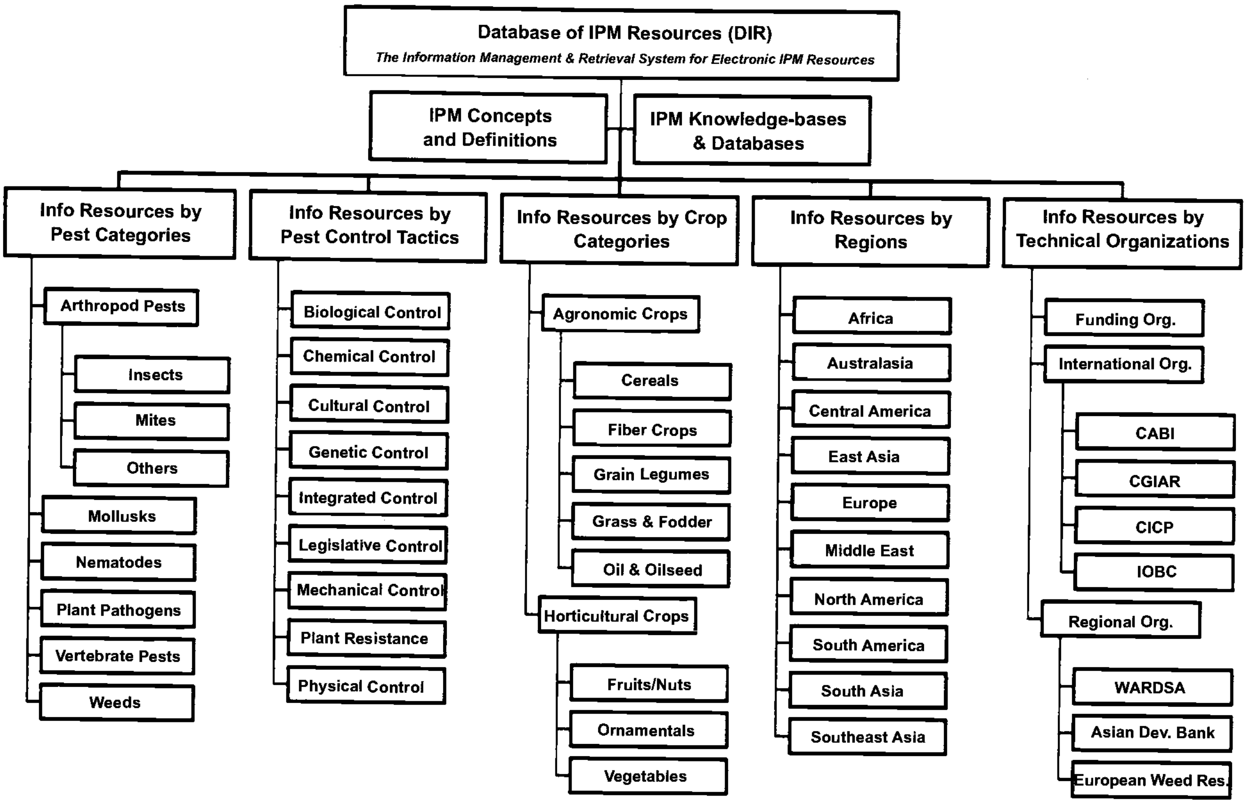
The Internet is being used increasingly for multiway information exchange (including feedback). Electronic mail or e-mail typically is used to send short textual messages between computer users. Clientele can access designated specialists/experts via e-mail. Internet News Groups permit users to read and post messages to various discussion groups organized by topic. The most popular public news group is called USENET. Educational topics range from agriculture to zoology, but news groups exist on almost every topic. News group postings (traffic) are very much like e-mail messages, but are grouped by topic for a given subject (thread). Internet's Bulletin Board Systems (BBS) offer a wide range of services such as e-mail, file downloads, and discussion groups. They are, however, smaller in scale and scope than news groups. Internet Chat is a real-time, text-based communication program that allows groups of users to talk to one another. Unlike News Groups and BBS, Chat does not create a record or log of what is discussed. Chat is used best to get immediate feedback from many users. FTP, another Internet-based tool, allows users to transfer or "FTP" files over the Internet from one computer to another. A user must gain access to another computer containing the desired files using an FTP client or application. Many systems allow users to log in anonymously by simply providing an e-mail address. A user can log in with a secure name and password for more secure access to files. Most current Web browsers can access anonymous FTP sites by using the ftp:// and the server name in place of the URL.

The Internet also is becoming a preferred means of providing data and analytical processing for decision making via Online Analytical Processing (OLAP) applications. Now it is possible to run multi-source information integrated, multimedia, multi-threaded, site-specific automatic decision support systems on the Internet (Power and Kaparthi, 1998). Such systems facilitate a user's access to the decision making process (Eastwood, 1998). Dynamic sites that include interactive models, GIS based decision systems, real-time weather, and market information are being developed rapidly and made available on the Internet.

Internet-based IPM Information Resources

IPM is an information-intensive system for the control of pest populations whenever they impinge on human activity and well-being (or welfare). Its research and implementation depend on the reliable supply of timely information. IPM researchers, like other scientists, must rely on access to data from extant studies (Jensen et al., 1996b). They are more interested in setting up improved channels of communication and methodology for finding information, rather than creating new databases (King et al., 1998). For example, many scientists in the field of weed research, an important part of IPM, believe that a researcher network and information system designed to enable them to exchange data and access other research more easily is quite beneficial to their research (King et al., 1998). The Internet (particularly the Web) has opened a vast array of data resources for IPM research, Extension, teaching, and learning that was not readily available before. The Web is fast becoming a critical component of IPM information exchange. There are now thousands of IPM sites online from all over the world. The future of IPM delivery systems through the Internet is bright; Internet-based information exchange quickly is becoming an absolute requirement for local, regional/areawide, and international implementation of IPM systems.

Currently, DIR provides a user-friendly interface to more than 5,000 Internet IPM resources. It presents Internet IPM resources in a logical, structured, and searchable way that greatly increases the speed and success rate over the use of general search engines on the Web. DIR provides access to relevant information on all aspects of IPM and supporting sciences, including crops, pests, control tactics, organizations, technical/scientific societies, educational and research institutions, and related topics in a format that is searchable and highly customized (Figure 2).



With DIR directories and search engines, one can focus quickly on the desired information, as distilled from thousands of IPM Internet information resources. All DIR databases and knowledgebases are updated regularly and revised. Infomine (a scholarly resource guide for biological, agricultural, and medical sciences) of the University of California designates DIR as a well organized, annotated Web virtual library of IPM information. Infomine is available at: http://infomine.ucr.edu/search/bioagsearch.phtml. DIR has been named an "Outstanding Education-Related Site" on the Web by The Education Index library of IPM information. Infomine is available at: http://infomine.ucr.edu/search/bioagsearch.phtml. DIR has been named an "Outstanding Education-Related Site" on the Web by The Education Index (http://www.educationindex.com/index.html), an annotated directory of the best education-related Web sites. DIR was awarded "Majon's Web Select Award," a seal of excellence as described by Wall Street Journal, for demonstrated creativity, quality design, and usefulness in purpose (http://www.majon.com/). DIR also has been named as an "Extraordinary Website" by the Plant Pathology Internet Guide Book (PPIGB), a subject oriented Internet resource guide compiled and maintained by Dr. Thorsten Kraska, Institut für Pflanzenkrankheiten (Institute for Plant Diseases), University of Bonn, Germany (http://www.ifgb.uni-hannover.de/extern/ppigb/ppigb.htm).

DIR, a Model Database for Internet IPM Resources

Server Architecture

The DIR system is a precise (97.33 ± 0.24 percent successful hits since January 1, 1997), fast [Agrisurf (www.agrisurf.com/], stable, and secure system. The system is hosted on an Intel Pentium-based machine with 128 Mb memory and a 3 GB of SCSI hard drive, including a UPS power management system. The software component of the system includes Windows NT 4.0 (operating system), MS-Access 7.0 (database management software), Netscape Enterprise 3.0 (server software), and Cold Fusion Application Server. The local network is connected through a firewall to the Internet and uses the standard TCP-IP protocol.

To guarantee data security, guidelines given by Wjst and Immervoll (1998) are adopted and implemented. The software is updated regularly with the latest patches and versions, and audit trails are enabled for file accesses and system functions. Any user profiles, however, have been avoided to ensure privacy of information retrieval. For data safety, backups are run weekly after checking for computer viruses and consistency of the database tables. There are always mirror copies of the actual database that are not available to the public.

Database Design, Modeling, and Web Connectivity

Databases provide invisible, but essential, core functionality of data storage and manipulation (Date, 1995). The process of getting a full-fledged database on the Web requires three essential components: a relational database, a Web server, and an application server to glue everything together. SQL (Structured Query Language) provides a common syntax for query building. The Open Database Connectivity (ODBC), a standard protocol for SQL databases, provides an abstraction layer between the application interface and the database. Common Gateway Interface (CGI), an interface between a Web and the other resources of the server's host computer, is a mechanism that allows Web clients to execute programs on a Web server and to receive their output. CGI programs often are used to produce HTML pages on the fly; they also are used to process the input from an HTML form. In general, CGI allows the Web to be used as a network "front-end" for many kinds of analytical and data processing (Green, 1998). It can handle complicated client requests such as database access (through an ODBC), computation, and dynamic Web page generation. It can be used to solicit and interpret user-supplied data, retrieve requested information, or process content which has been customized for a particular user.

DIR provides an interactive environment to its users. The core to this system is several relational databases connected to the Internet via server-side CGI programs and/or a middleware, Cold Fusion. Both CGI programs and Cold Fusion communicate with the databases through ODBC. Cold Fusion works similarly to the CG program for database querying, computation, and HTML page generation. DIR's database interface is coded in CFML (Cold Fusion Markup Language)- SQL. CFML-SQL is a procedural language extension to SQL. With a full range of data types, conditional statements, and exception handling capabilities, CFML-SQL provides the program logic not available in declarative SQL language. CFML-SQL can bundle related data-types and subprograms to promote reuse of common local variables and subprograms.

DIR's design and schema permit information retrieval on a particular subject with minimum efforts in as little time as possible. The main database relies on a relational structure. Custom data type, primary and foreign keys, index field, and relations all were planned to avoid redundant data structure and repeated entries and to anticipate further growth (Wjst & Immervoll, 1998). Its entity-relationship diagram (E-R diagram) is given in Figure 3. This diagram illustrates classes in the DIR database model, along with their attributes and relationships. In the diagram, an entity class is denoted by a rectangle and its attribute by an ellipse. The relationships are denoted by diamonds.

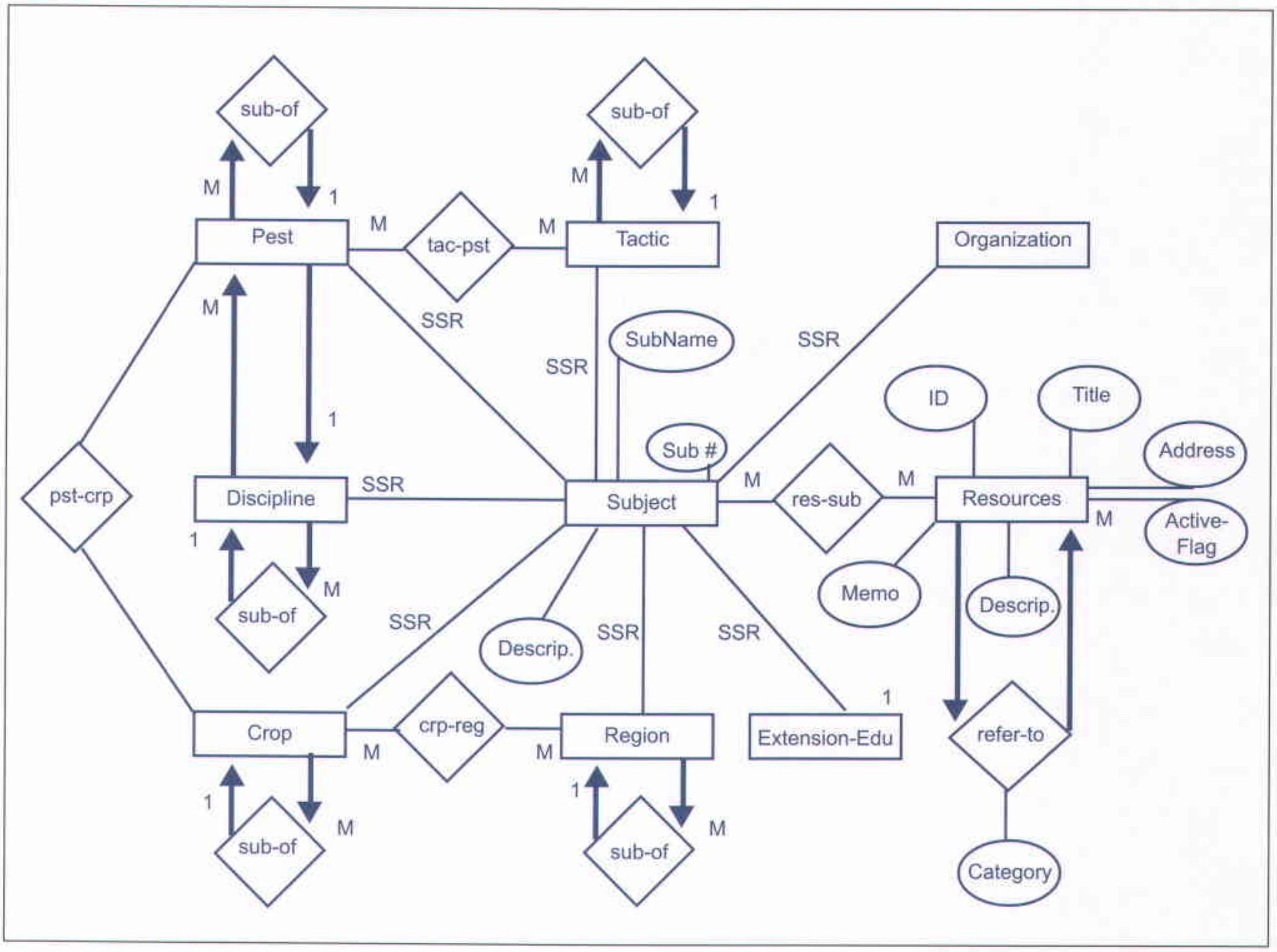


Figure 3. Entity-relationship (E-R) model for Database of IPM Resources (DIR).

An entity class is denoted by a rectangle and its attribute by an ellipse, and the relationships by diamonds. *SSR*: supertype-subtype relationship; M-M: many-to-many relationship; 1 – M: one-to-many relationship; *sub-of*: hierarchical structures for entities of entity types crop, pest, tactic, disciplines and region; and *refer-to*: one resource entity refers to another resource entity. res-sub: relationship between a subject entity and a resource entity—this relationship makes an IPM resource (a *Resource* entity) searchable with keywords stored in the *Subject* entity. A relationship of type tac-pst denotes which (control) *Tactic* is used against what kind of pests; crp-reg what crops are grown in which regions; and pst-crp, which pests damage what type of crops.

Access Information
DIR is available at http://ippc.orst.edu/dir/ and http://www.ipmnet.org/dir/. DIR is being accessed by 553 ± 26 users (users are defined as different IP numbers in the Web access log) per day (Figure 4).

Since its inception in 1996, DIR's clientele and usage has increased exponentially (Figure 5).

During the 12-month period of June, 1998 to June, 1999, the number of hits (page views) to all pages was 144,860. During this period, there was an increase of 158 percent in DIR clientele and 30 percent in the page views. A comparison of DIR clientele and its usage in those 3 years is given in Figure 5.

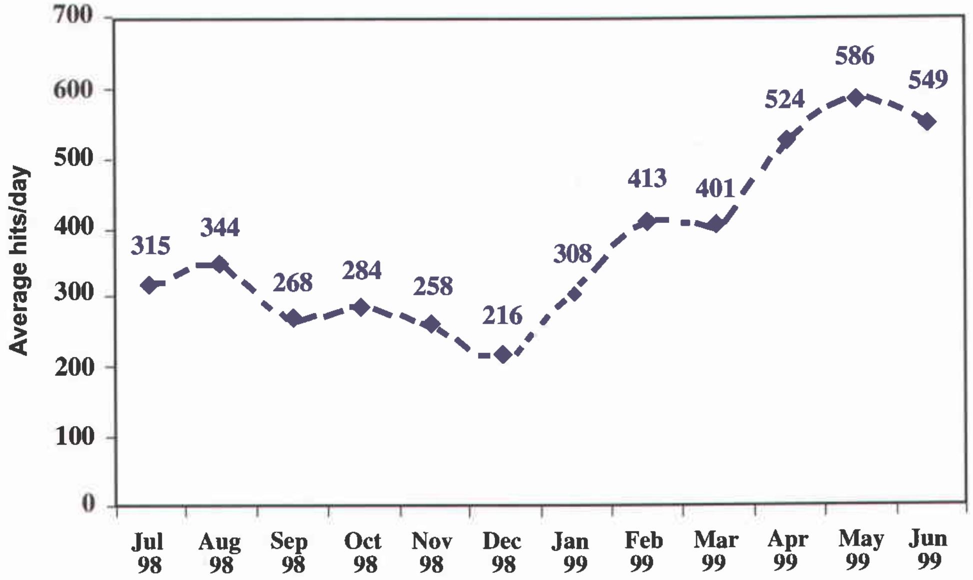


Figure 4. DIR usage in 12 months between July 1998 and June 1999.

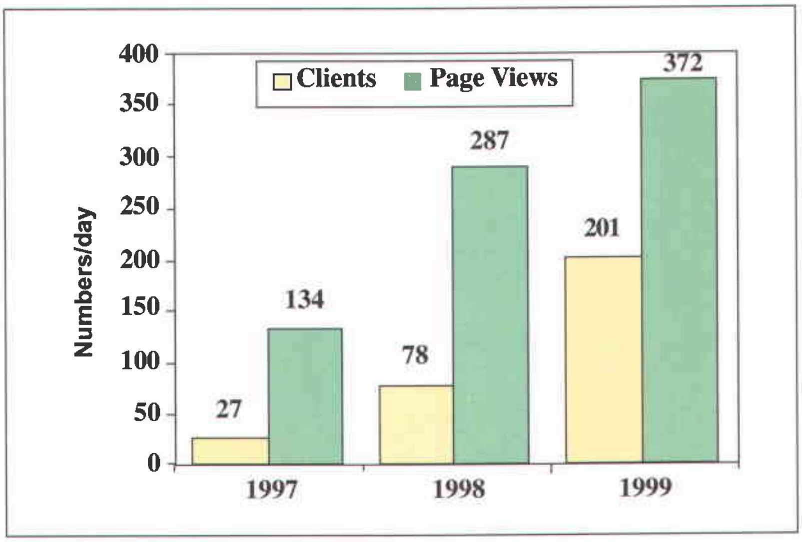


Figure 5. DIR clientele and usage over 3 years (June 1996 to June 1999)

Resources and Components
Currently, DIR contains 8 databases, 5 knowledge-bases, and a database with more than 5,500 documented Internet resources and their hyperlinks searchable through its search engines (Table 1). The databases and knowledge-bases include: Compendium of IPM Definitions (67 definitions and literature citations), a knowledge-base on Indigenous Methods of Pest Control in East Africa, Database of Natural and Traditional Pest Control (East Africa), Codling Moth Information Support System (CMISS), Database of IPM Textbooks, Database of IPM Literature (IPMlit), IPM Informatics (an interactive site on the use of computers and information technology in IPM), Model Systems for Insect Phenology and Population Dynamics, and Internet-based Interactive Information Systems and several Specialty Bibliographic Databases.

As shown in Figures 6 and 7, the major contributors to the resources of DIR are, by region, North America (3,397); by country, U.S. (2,832); and by pest type, insects (1,582). Europe and Australasia are represented by 555 and 317 records, respectively.

Table 1. Current Resources of Database of IPM Resources.

Resource Type	Current Status
1. Directories of Internet IPM Resources	Highly Customized 750 Directories
2. Searchable Database of Internet IPM Resource	Simple & Advanced Search Engines- 5,000 documented Internet Resources
3. Informational Databases & Knowledge-bases	Eight Databases & Five Knowledge-bases

Contributions by other regions, such as Africa (195), Asia (378), and South America (87), are confined mainly to a few countries. These countries include South Africa (41), Malaysia (33), Kenya (23), China (23), Japan (50), Argentina (11), and Brazil (45). Resources from international organizations are 52 (Figure 6). Resources by pest types follow a pattern that reflects diversity (species richness) as pests of agricultural crops (insects, 1,582; plant diseases, 951; weeds, 412; mites, 239; nematodes, 213; vertebrate pests, 201; and mollusks, 46) (Figure 7).

How to Find Information with DIR?

DIR uses two main indexing approaches: search engines and a main index of DIR directories (based on various IPM topics).

Search Engines
Currently, DIR has three types of search engines: a keyword search engine, a simple search engine, and an advanced search engine. The keyword search engine can be used for single keyword searches and is available from several DIR pages. The simple search engine can be used for simple keyword and phrase searches with or without the word combination operator "AND." The advanced search engine (ASE—pronounced *Ace*) is a customized and efficient tool for narrowing (with word combination operators AND and NOT) or expanding (with word combination operator OR) search parameters. This search engine is useful for retrieving information by region, country, language, organization, crop, pest type, and keyword with or without use of the word combination operators AND, OR, or NOT for all search fields. All these searching utilities ensure retrieval of the desired information precisely and efficiently. To commence a search, the user submits one or more key words to the search engine which then returns a list of documents containing those key words in their titles or text.

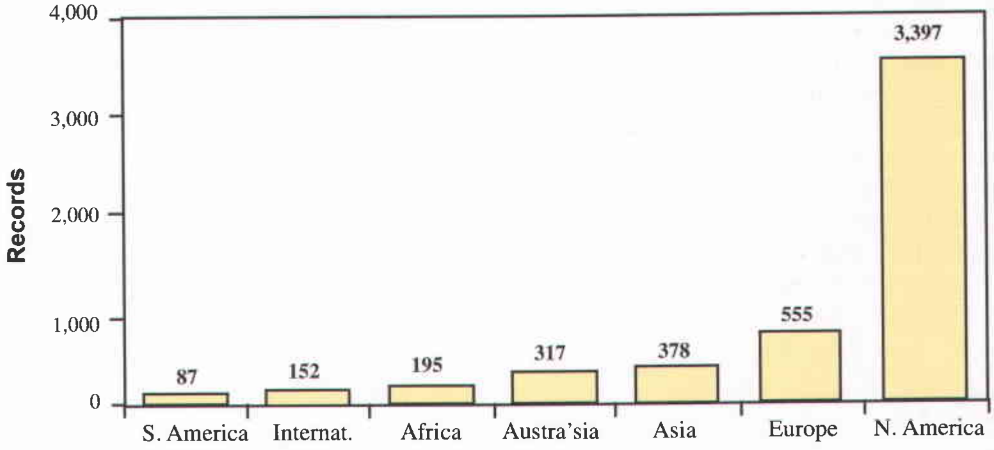


Figure 6. DIR resources by regions (Internat.: International and Austra'sia: Australasia).

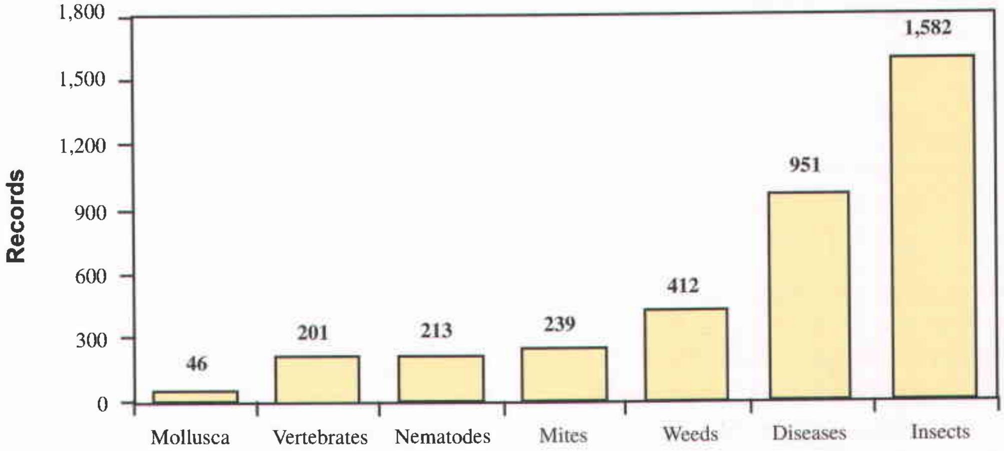


Figure 7. DIR resources by pest type.

Customized Subject Directories

If the user has difficulty with the search engines finding a specific topic, DIR offers a customized, 750-component directory to browse (Figure 2). In each directory, a general topic leads to a specific site. These directories usually lead to relevant information to the user and are available through the Main Index, Select a Crop, and Website Gateway. In these directories, a few mouse clicks take a DIR user to the exact pages on any number of sites where the desired information is found.

Conclusion

The volume and variety of on-line IPM information is growing at an exponential rate. The Internet enables collaboration and information sharing on an unprecedented scale. It is becoming a prime medium for research and Extension communication. The World Wide Web—the Internet's hypertext, multimedia publishing protocol—makes it possible to combine information from many different sites in a completely seamless fashion. However, the existing online IPM research and Extension information is poorly organized, at present. DIR offers a central, Web-based, interactive (searchable, etc.), unbiased source of IPM information. It provides a complete information environment that quickly directs IPM practitioners to relevant resources. Its overall goal is to promote global IPM development and adoption through rapid access to information across the Internet with the least possible cost to the end-user. Few other services or systems on the Internet parallel the goals, objectives, and capabilities of DIR. This database is designed to become a focal point on the Web for IPM researchers, Extension specialists, pest management practitioners, students, teachers, crop consultants, and policy makers.

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An Interactive, Knowledge-based System for Integrated Codling Moth Management

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Abstract

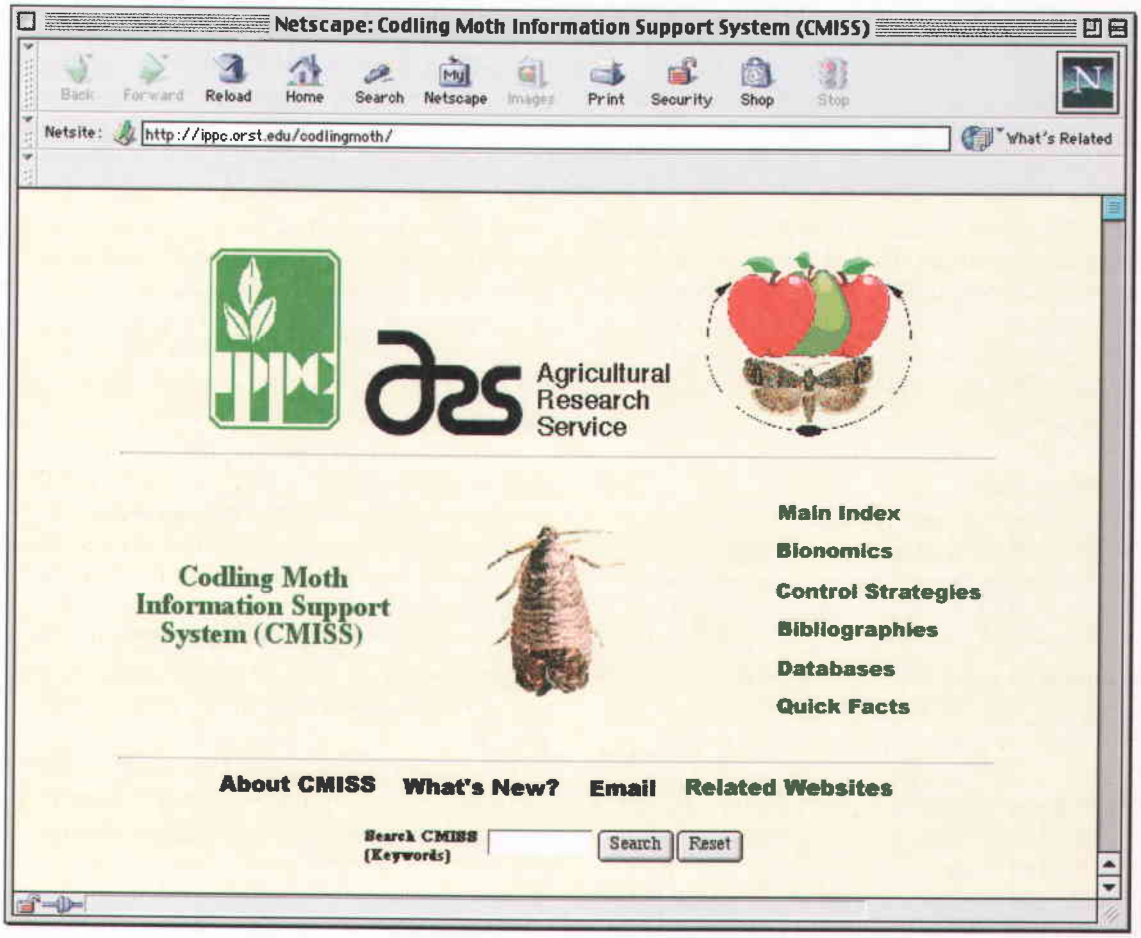
Successful management of Codling Moth (CM), *Cydia pomonella* L., depends heavily on accurate and timely information and demands a quick transmission of information from scientists to clientele. The Internet has proved its potential as an effective information delivery/exchange system. In addition to the wide geographic availability of material, the Internet offers the advantage of very quick delivery, and the material itself is usually as current as possible. An Internet-based information and support system, Codling Moth Information Support System (CMISS), recently has been developed. CMISS is a comprehensive source of biological and management information on codling moth. This site uses both static (text, graphics, and tabular) information and dynamic (database-driven and server-side programs) information, and represents the state-of-the-art for Web applications and decision support systems. CMISS currently hosts various databases and knowledge-bases on different aspects of codling moth biology, ecology, and integrated management. It also provides information distillation on various aspects of codling moth phenology and population dynamics, including modeling parameters, etc. Its generalized degree-day calculator can be used from anywhere in the world for forecasting codling moth phenology under local conditions. This calculator requires a local weather data file uploaded to the server from the client computer. CMISS is available at http://ippc.orst.edu/codlingmoth/.

Introduction

The Codling Moth (CM), *Cydia pomonella* L., is a cosmopolitan insect pest of deciduous fruits (Reed et al., 1985). Successful management of this insect depends heavily on accurate and timely information and demands quick transmission of information from scientists to clientele. On the other hand, researchers and Extension specialists need the latest reviewed information to design new projects and set their future research goals/directions. As such, like other IPM programs, codling moth management requires development of improved methods of accessing and disseminating information.

Currently, different methods are being used for accessing and disseminating information, such as printed material in the form of paper hard copies, and electronic publishing like archiving material on CD-ROM, Websites on the Internet, etc. Printed material, though a standard method of providing information, is bulky, making transmission to remote locations expensive (MacRae, 1996). Electronic publishing provides the ability to search and index text, quick access to reference materials, and interactive multimedia capabilities. Information on CD-ROM has the advantage of being randomly accessed and is easy to store and ship, but it is inherently static and unchanging. CD contents rapidly become outdated. Internet, a powerful new information delivery and exchange tool, provides a significant improvement over other information systems (Bajwa and Kogan, 1999). The Internet carries several kinds of communication services including e-mail, file transfer protocol, and Usenet newsgroups. The fastest-growing part of the Internet is the World Wide Web, a graphical, user-friendly (point and click) approach to accessing information. The Web is easier to use than other Internet services. Information published on the Internet has a number of advantages over publication of paper hardcopies or archiving information on CD-ROM. Information on the Internet is available immediately from all across the globe (Stinner, 1998). In addition to the wide geographic availability of material, the Internet offers the advantage of very quick, inexpensive delivery, and the material itself usually is very current. Also, Internet can provide a contact point for scientists/researchers working on similar problems (MacRae, 1996). The number of computers connected to the Internet has grown exponentially in the past few years—thus the scope, contents, and influence of online publishing. The potential now exists to reach more people electronically than through hardcopy (MacRae, 1996).

There are Internet resources on codling moth scattered all across the globe. While these resources are useful, they generally focus on site-specific information on pest control and lack coverage of some important aspects like biology, ecology, phenology, modeling, etc. A sound knowledge of these areas is the basis for successful integrated management of this pest. To fill this gap, an Internet-based interactive knowledge-based system, the *Codling Moth Information Support System* (*CMISS*) has been developed. This unique resource can be browsed at: http://ippc.orst.edu/codlingmoth/ (Figure 1).



Netsite: http://ippc.orst.edu/codlingmoth/

Figure 1. Home page of CMISS.

Objectives and Scope

CMISS is a continuously updated and expanded information retrieval, exchange, and decision support system for codling moth. CMISS provides information on biological and management information on codling moth. This site uses both static (text, graphics, and tabular) information and dynamic (database-driven and server-side programs) information, and represents the state-of-the-art for Web applications and decision support systems. An electronic information system like CMISS provides efficient information management: development, updating, storage, retrieval, referral, and delivery.

CMISS currently hosts various databases and knowledge-bases on different aspects of codling moth biology, ecology, and integrated management. Among the databases, the Codling Moth Index (CMI), a general bibliographic database of worldwide codling moth literature, contains approximately 6,500 references. This database provides nearly complete coverage of codling moth literature from the years 1700 through 1999. CMISS also presents some specialty bibliographic databases, which cover topics like Biological Control, Chemical Control, Sex Pheromones of Codling Moth, and Systems Analysis and Modeling of Codling Moth Phenology and Population Dynamics. The database on Systems Analysis and Modeling of Codling Moth Phenology and Population Dynamics contains up-to-date information and a bibliography on modeling parameters extracted from worldwide codling moth literature. CMISS knowledge-bases like Bionomics, Control, Sex Pheromones, Historical Events, Frequently Asked Questions (FAQ), and Quick Facts are based on archival and current information and provide an up-to-date review of the subject matter.

The overall goal of CMISS is to provide information support for research and Extension programs related to codling moth. This site is designed to become the focal point on the Web for research and Extension specialists, pest management practitioners, students, teachers, crop consultants, and policy makers.

CMISS Resources

All CMISS databases are built on a "state-of-the-art" relational structure. They are updated and improved regularly. In these databases, custom data types, primary and foreign keys, index fields, and relations all are planned to avoid redundant data structure and repeated entries and to anticipate further growth (Wjst and Immervoll, 1998).

FAQ (frequently asked questions)—Questions about historical aspects, biology, and integrated management of codling moth.

Quick Facts—Knowledge-base on Quick Facts provides swift access to biological and ecological parameters required for codling moth modeling, forecasting and risk assessment, zoogeography, bibliographic information, phenology modeling information, etc. The information in this knowledge-base is extracted from worldwide codling moth literature and presented in tabular and graphic format with appropriate bibliographic citations.

Guide to Historical Codling Moth Events—Various discoveries and events pertaining to codling moth biology, ecology, toxicology, and pest management.

Bionomics of Codling Moth—A knowledge-base on codling moth biology, ecology (including ecological adaptation), phylogenic, zoogeography, and taxonomy.

Integrated Codling Moth Management—This knowledge-base provides a detailed account of basic and applied aspects of integrated codling moth management. It covers a wide array of topics including biological, chemical, cultural, microbial, and semiochemical controls. It also provides information on application of geographical information system (GIS) and the areawide pest management concept to integrated management of codling moth.

Codling Moth Index (CMI) – A searchable database of worldwide codling moth literature from the years 1700 to 1999 (almost 6,500 references). This bibliographic database contains references from journal/review articles, book chapters, conference papers, and technical reports, and generally includes abstracts when available. This database is designed to allow convenient searches by author, year of publication, title, publication (journal/book title), and keywords with and without use of logical (Boolean) operators "AND," "OR," and "NOT."

Specialty Databases – These searchable databases have a similar format as that of CMI.

Chemical Control of Codling Moth – A chronologically arranged bibliographic database with more than 1,000 references from the years 1700 to 1998.

Biological Control of Codling Moth – A chronologically arranged bibliographic database with over 600 references from the years 1700 to 1998.

Systems Analysis and Modeling of Codling Moth Phenology and Population Dynamics – A knowledge-base and searchable bibliographic databases of worldwide literature on the subject matter.

Generalized Phenology Model/Degree-day Calculators – This calculator can be used from anywhere in the world for forecasting the codling moth phenology under local conditions. The program works by allowing the client computer to upload a local weather data file to the server.

Population Dynamic Model – An online population dynamics model allows users to determine the combined effects of multiple control measures such as mating disruption and reduced rate of chemical insecticides.

Information Distillation on various aspects of codling moth phenology and population dynamics including modeling parameters, etc. The modeling parameters are extracted from worldwide archival and current codling moth literature.

Codling Moth Pherobase – A knowledge-base on basic and applied aspects of integrated codling moth management by sex pheromones. The section on basic aspects covers topics like pheromone chemistry, endocrinology, olfaction (including perception and mechanisms of pheromonal communication), effect of pheromone on sexual behavior, synergists and antagonist (antipheromones, inhibitors, masking agents, etc.), disruption of pheromonal communication, effects of environmental cues (temperature, light, etc.) on female calling and male response, etc. The section on applied aspects encompasses aspects such as codling moth monitoring and pheromonal control.

Searchable Database of Internet Codling Moth Resources—This database provides links to more than 250 online codling moth resources from all over the world.

Worldwide Codling Moth Distribution—An Example from CMISS. A few paragraphs from CMISS on worldwide distribution of codling moth are given below to show the type of information available through CMISS.

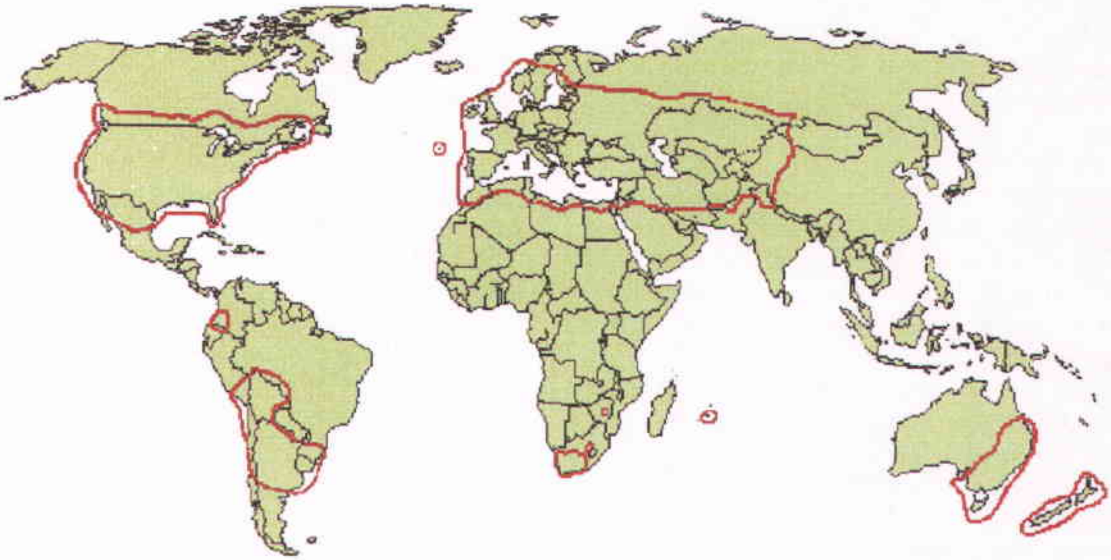


Figure 2. Codling Moth Distribution Map from CMISS.

"The native home of the codling moth is considered to be southeastern Europe, from which it spread to various parts of the world (Figure 2). Theophrastus mentioned this insect in his writings in 371 B.C. Cato, the great orator of ancient Rome, speaks of "wormy apples" in his treatise on agriculture written nearly 200 years before the Christian era. In the first century A.D., both Columella and Pliny doubtless referred to this insect in their writing. The codling moth is now a cosmopolitan insect occurring in almost every country where the apple is grown. It is evident that present distribution of codling moth is related to climatic factors as well as to food conditions. In view of the nature of the life history of the codling moth, the most common mode of its spread from one place to another is through the transport of infested fruit and packing material. The boundaries of present day ranges are largely determined by temperature conditions. In most localities, the northern boundary is defined by the amount of heat in the summer, a sum of effective temperature above 10°C of the order 600 degree-days. Owing to the considerable cold resistance of the diapausing caterpillars and their overwintering beneath the snow, winter minimums restrict the range of the species only in the most continental regions, e.g. eastern Siberia and Canada. In the tropical regions, the limits of the range are mainly determined by the overwintering conditions and by absence of winter cooling that is essential to reactivation of the diapausing larvae; these limits coincide closely with the +10°C isotherm of the coldest months.

"In Europe, northern limits of the codling moth extend through Scotland and Scandinavia, where it reaches latitude 640°N, and on through Southern Karelia, Kirov and Perm, which correspond closely to the limits of apple cultivation. There has been far more distribution of this insect in Asia, mainly within the Commonwealth of Independent States (CIS). The codling moth has even followed the apple into Siberia, and does serious damage in most localities. In the East, however, outside the CIS, the codling moth is found only in Chekiang and Sinkiang Uighur (China). It is absent elsewhere in China, and is an object of both internal and external quarantine. The southern distribution limit of the codling moth extends through the mountainous area of North Africa (including Tunisia, Morocco, and North), across Israel, Syria, Iraq, and Iran, ending towards 300°N. In Pakistan, this pest came through Afghanistan, where it spread from Iran and the Central Asian states. It has also been observed in the mountains of northern India (in the state of Himachal Pradesh). In South Asia (Indo-Pakistan subcontinent), the infestation is confined to areas between 4,500 and 9,000 feet above sea level and the pest thrives best between 5,000 and 7,000 feet.

"In the USA, codling moth was probably introduced from Europe in packages containing infested apples and pears. It was first observed in New England in 1750, in Iowa in 1860, and in Washington (state) in 1880. It is now found in almost every state where apple/pear are grown. In Canada, it inhabits southern regions from New Brunswick to Vancouver Island, approximately to latitude 50°N. In Mexico, this insect is distributed only in the north-central areas. The codling moth has also become firmly acclimatized in the southern hemisphere. It has spread in Australia and is destructive in the southeast of the continent, in Tasmania and in New Zealand. It once occurred in western Australia, but was eradicated in 1958. In Africa, it is confined to South Africa as far as Pretoria and Orange River. In South America, it occurs in Argentina, Uruguay, Brazil, Columbia, Chile, and Peru."

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