Research Article

Received: 16 July 2009 Revised: 3 September 2009 Accepted: 17 November 2009 Published online in Wiley Interscience:

(www.interscience.wiley.com) DOI 10.1002/ps.1913

# A web-based decision support system to enhance IPM programs in Washington tree fruit

**Vincent P Jones,[a*] Jay F Brunner,[a] Gary G Grove,[b] Brad Petit,[a] Gerald V Tangren[a] and Wendy E Jones[a]**

## Abstract

**BACKGROUND: Integrated pest management (IPM) decision-making has become more information intensive in Washington State tree crops in response to changes in pesticide availability, the development of new control tactics (such as mating disruption) and the development of new information on pest and natural enemy biology. The time-sensitive nature of the information means that growers must have constant access to a single source of verified information to guide management decisions.**

**RESULTS: The authors developed a decision support system for Washington tree fruit growers that integrates environmental data [140 Washington State University (WSU) stations plus weather forecasts from NOAA], model predictions (ten insects, four diseases and a horticultural model), management recommendations triggered by model status and a pesticide database that provides information on non-target impacts on other pests and natural enemies. A user survey in 2008 found that the user base was providing recommendations for most of the orchards and acreage in the state, and that users estimated the value at $16 million per year.**

**CONCLUSIONS: The design of the system facilitates education on a range of time-sensitive topics and will make it possible easily to incorporate other models, new management recommendations or information from new sensors as they are developed.**


**Keywords:** decision support system; Washington tree fruit; crop risk management; pest and disease management; modeling

## 1 INTRODUCTION

Integrated pest management (IPM) programs can be thought of as a method of pest control that substitutes information-based complexity to reduce damage in place of simple control tactics that are applied on a repetitive basis regardless of pest pressure or timing. Under IPM, the cost savings from eliminating repetitive spraying and undesired environmental and worker safety problems frequently offset the cost of obtaining the information needed to guide the pest management program. However, the biggest impediment to implementing sound IPM programs is the breadth of information required and the fact that the information is generally highly time sensitive. To be successful, managers must be able to obtain information from a wide range of sources quickly and efficiently, integrate this with management actions for the full range of pest problems on the crop, as well as deal with the normal (non-pest-related) problems of growing and producing a marketable commodity.[1]

In the tree fruit industry in Washington State there has been a marked increase in the complexity of the IPM programs in the past 10–15 years.[2] Reasons for this include: (1) legislatively mandated or influenced changes in pesticide availability; (2) development of new control tactics such as mating disruption; (3) increased knowledge of the biology of pests, diseases and their natural enemies; (4) introduction of or increase in new or previously minor pests and diseases. Concurrent with these factors, there has been a relatively long-term reduction in extension funding and an inability to provide anything more than basic outreach programs.

The best-known legislative mandate is the 1996 Food Quality Protection Act (FQPA), which has eliminated or restricted the use of several formerly available and critical pesticides for tree fruit pests and diseases.[3,4] However, at the same time, the FQPA indirectly stimulated the registration of new pesticides to replace those being lost. These new pesticides typically have lower efficacy and reduced residual activity compared with older pesticides that have been outlawed or severely restricted. In addition, they may have a different way in which the target pest acquires the toxic dose (e.g. ingestion versus contact) and a different spectrum of activity on non-target pests and beneficial natural enemies.[2] The new insecticides may have good activity against the pest, but changes in efficacy, residual activity, mode of acquisition

* Correspondence to: Vincent P Jones, Tree Fruit Research and Extension Center, 1100 N. Western Ave., Wenatchee, WA 98801, USA. E-mail: vpjones@wsu.edu

a Washington State University, Tree Fruit Research and Extension Center, Wenatchee, WA, USA

b Washington State University, Irrigated Agriculture Research and Extension Center, Prosser, WA, USA

 

and non-target effects mean that errors in timing or incorrect choice of product can result in poor control or instability in the management programs. Fortunately, the drawbacks of the new pesticides are offset to some degree by increased knowledge of pest and natural enemy biology. This new information makes it possible to schedule scouting and control activities better, so that new pest management programs can be optimized.

To facilitate solutions to the problems mentioned above, the authors have for the past 4 years been developing and improving an IPM decision support system for Washington tree fruit growers and IPM practitioners.[5–7] This paper will focus on the historic background behind decision support systems, the design, structure and implementation of the Washington system and the changes in knowledge transfer engendered by the system. Finally, user survey data will be presented that evaluate the system and provide clues as to the directions that need to be taken in the future.

### 1.1 Historic background on decision support systems

Modeling systems to help extension began to appear in the mid-1970s, using mainframe computers. Michigan State University was a leader in several systems including PMEX (Pest Management Executive System),[8] the PETE (Predictive Extension Timing Estimator) program[9] and finally BIOSCHED (Pest Biological Scheduling System).[10] PETE is probably the best-known system and was initially a mainframe FORTRAN program that evolved over time to mini- and finally desktop computers. Decision support systems in agriculture began appearing in the late 1980s and early 1990s, when desktop computers became more readily available and affordable. These programs culminated in 'expert systems' that attempted to distil expert opinions into a series of 'rules' or a decision tree that allowed users to input their data (e.g. weather data, trap counts, sprays applied and timings) and determine the best management program. For tree fruit, perhaps the most notable system was Penn State University's Apple Orchard Consultant (PSAOC).[11–13]

It appears that most expert systems, including PSAOC, were discontinued partly because of three problems: (1) the time required to input data and to retrieve useful information back from the system; (2) the difficulty in supporting maintenance such as updates in tactics and changing recommendations; (3) lack of infrastructure needed for constant updating of the products being offered.[1] However, it is important to recognize that technical and cultural aspects made the desktop-computer-based system difficult to implement at the time that PSAOC was being developed. For example, in the early 1990s, computer-savvy IPM consultants were rare. The user base was therefore small, program updates had to be copied onto floppy disks and mailed and weather data often needed to be entered by hand.[1] The latter part was even more problematical for disease predictions, which are typically driven by more independent variables (e.g. relative humidity, rainfall) than insect phenology models. While truly a revolutionary piece of work, the timing, the mode of delivery, the time commitment needed from users and the complexity of the program required extensive training that was ultimately unsustainable.[1] Many of the problems associated with expert systems in the early 1990s have been greatly reduced by the more widespread availability of personal computers. The Internet and web-based programs remove many of the other limitations.

One of the longest-running decision support systems in tree fruits is a program called SOPRA. This program has been used in Switzerland and southern Germany to forecast development of multiple pests in apple orchards for the last 8 years.[14–17] This program is a Windows-based application that now has a web-based interface (www.sopra.info). SOPRA predicts development of eight different pests using extensive biophysical modeling based on solar radiation, air temperature and soil temperature (as appropriate to each pest). The system went online in 2007 for six of the most important tree fruit pests, and two more models were added in 2008. In addition to the phenology information, a decision support system is integrated into the output to help users decide on proper management techniques. The success of SOPRA is indicative of the critical role that decision support systems can play in IPM implementation.

## 2 EVOLUTION OF THE WASHINGTON STATE UNIVERSITY (WSU) DECISION AID SYSTEM (DAS)

In Washington State, the WSU-PAWS (Public Access Weather System) was the first attempt to provide users with direct access to models in the early 1990s.[18] The system had the codling moth, western cherry fruit fly, apple scab and fireblight models online, with a simple tabular output in the format of date, degree-days, percentage emergence or percentage egg hatch and (in the case of diseases) infection risk. However, no attempt was made to interpret the models from a pest management context. The next step was the development of pesticide spray recommendations based on the WSU pesticide recommendations,[19] which were implemented as a thinkDB® database program for Palm PDAs and a Microsoft Access and Filemaker Pro version of the same files.[20] In 2005, Jones and Brunner[21] developed a Microsoft Excel-based spreadsheet (called 'phenosheets') with custom-written Visual Basic routines that provided users with management recommendations and phenology information for five different locations and five different insect pests after users entered their weather data. This program was partially the result of understanding that the complexity of the IPM programs demanded a dynamic representation of the various actions required for good IPM. Experience with the phenosheet program and user response convinced the authors that there was a need for a more expansive program that automated several of the aspects of the system and included pesticide recommendation databases similar to those implemented on PDAs by Jones and Grove.[20] The new system is known as the WSU decision aid system (DAS; das.wsu.edu).

A key factor that made the DAS possible occurred in 2005–2006, when the Washington State legislature provided funding that supported the development and expansion of WSU-PAWS from 56 stations into AgWeatherNet (AWN, weather.wsu.edu) with 132 stations and a budget to sustain long-term maintenance of the system. This investment made it clear that AWN weather data would be the main raw data source for the system, and it broadened the scope of the decision support system. AWN is a near-real-time environmental data acquisition system where data from each station are transmitted back to a central server primarily using wireless cell modems. These data are stored in a central mySQL database and dispensed in various forms by AWN. The DAS has direct access to all the data, including historic environmental data for some stations back to the early 1990s. The relationship between AWN and the DAS is symbiotic; AWN is the underlying infrastructure for the DAS, while the DAS adds significant value to raw weather data.

In 2005, models and management information from the phenosheets were transferred into a web-based program that would access a limited subset of automated environmental monitoring stations from WSU-AWN.[7] In 2006, access was expanded to all AWN stations, and the system was opened to a small beta user group. The system was opened to general use in 2007.[5]

### 2.1 Structure of the WSU decision aid system

The goal of the DAS is to provide a clear framework for pest management programs that will help pest managers obtain information needed to optimize management decisions in a timely fashion. At its heart, the DAS is a mySQL database application that imports weather data, uses the data to drive insect and disease models and then integrates that information with physiological time-based pest status and management messages. For example, between 101 and 160 degree-days, the message for a given model may indicate what percentage of the population is in a particular stage and give an indication that adult flight may start by a certain time. The model subroutine then fills in the percentage in that stage, based on the current degree-day accumulation. The management recommendations for that timeframe may provide information on timing of sampling, pesticide applications, times to restrict pesticide application to preserve natural enemies or risks associated with a delay of management tactics. Because it is a simple database table, it was possible to add organic recommendations in another database field; users can switch back and forth between organic and conventional recommendations from any screen. These warnings are relatively easy to change, and they provide far more information than the typical model output found in older systems such as WSU-PAWS. The current design separates the interface from the model subroutines, so that the interface can be changed without having to be concerned that the models might be inadvertently changed when the HTML code that draws the actual screen image is rewritten. This sort of design simplifies the maintenance of the program and opens the door to easy change of the language by simply translating the database tables; this design is enabling a Spanish version to be put online this coming year with only minor changes to the overall system.

Integral to the entire process is a beta user group (currently 14 users) who assist in troubleshooting problems, suggesting new features, and who work with a particular part of the system for an entire season before it is released to the public. The beta test group is composed of growers, fieldmen or consultants from several of the major tree-fruit-growing regions in the state. The beta group has dramatically improved the quality and adoption of the system; they catch problems early, so that the general release is relatively error free, and they serve as enthusiastic supporters among their peers.

As mentioned above, the DAS is only as good as the underlying environmental data, which are currently available from two possible sources. The most common source is AWN, but a second source is user-entered data from user-maintained environmental monitoring stations. These data are typically more restricted (either by sensors or time interval recordings), and quality control of the data is entirely the responsibility of the user. The disease models are not active when user-entered data are used because of the complexity of the environmental data (multiple sensors, each with their own calibration issues) required for most disease models. Recording intervals are also issues with the disease models that may negatively impact upon model reliability. The authors have devised a simple interface for allowing users to cut-and-paste data from spreadsheets or text files, or directly to import weather data from text files.

A key feature of the DAS is the ability to project pest and disease conditions into the near future (1–10 days) to provide time for managers to plan and implement management tactics. To this end, xml feeds from NOAA are used to obtain site-specific ($5 \times 5$ km grids) weather forecasts that make it possible to project pest and disease conditions into the near future.[22] Although longer-term forecasts of pest phenology would be possible using historical weather data, this feature has not yet been implemented, in part because AWN has added a large number of stations at new monitoring sites within the past year, so that historical weather data are not available. The NOAA weather data also provide the raw forecasting data that will eventually make it possible to provide comprehensive weather forecasts (including wind speed, probability and amount of precipitation, weather radar, etc.) as needed to help interpret and plan management activities.

In terms of models, the DAS currently has ten insect models, four diseases and a model for storage scald of apple (Table 1). Several new models are also being worked upon, which it is hoped will be implemented within 2 years. All models in Table 1 have been either developed in Washington or validated using Washington data. In terms of output, users have graphical output of pest phenology, as well as a short text message indicating pest population trends, such as timing for emergence, percentage of the population in different stages or whether populations are increasing or decreasing (Fig. 1). If the management recommendations indicate that a control tactic is needed, the user can access the pesticide recommendation database built into the DAS. This database automatically displays (in a new window) the materials that would be appropriate for the pest and time of year. Users can further filter the materials on the basis of the type of program (no-OP, conventional and organic) or by pest pressure. The window also details other pests controlled by a particular material and the effects on natural enemies. The pesticide database is based on WSU Extension Bulletin EB-0419 'Crop protection guide for tree fruits in Washington',[19] which is currently moving to an online pesticide database (jenny.tfrec.wsu.edu/eb0419/).

To use the system, each user must register and set up a profile that specifies which models to run for which environmental data stations. A Google® Maps station locator (google.com) has been implemented, which allows the users to specify a location by city, zip code, address or latitude/longitude pairs. The station locator allows the users to pinpoint their orchard location and then determine the difference in distance and elevation from each station. The station markers are also color coded, so that the user can tell which stations they have set up, and the type of station (user defined or AWN). The Google Maps interface greatly simplifies the location of stations, which in AWN are often named rather randomly (e.g. Fishook, K2H, BMF, Station 2, Station 4). When users have selected the appropriate station, they simply choose which crops and models they wish to use, and whether that station by default displays conventional or organic management recommendations. Once the user profile is complete, the users merely log on with their username and password and receive (on the next page) model output and recommendations for all the sites and models. Users can sort the output by model (e.g. codling moth at each site) or by site (e.g. all models for site 1), or can set up groups of stations that they want to access at the same time (e.g. all the sites they would typically visit on the same day of the week). The Google Maps interface also simplifies the configuration of user-defined weather stations and provides location information needed to access the NOAA site-specific weather forecasts used

  

**Table 1.** Models available on the WSU-DAS and the source of models

| Common name | Species | Source of model |
|---|---|---|
| **Insects** | | |
| Apple maggot | *Rhagoletis pomonella* Walsh | Jones *et al.*[28,29] |
| *Campylomma* bug | *Campylomma verbasci* (Meyer) | Reding[30] |
| Codling moth | *Cydia pomonella* (L.) | Riedl *et al.*,[31] Welch *et al.*,[9] Jones *et al.*[32] |
| *Lacanobia* fruit worm | *Lacanobia subjuncta* (Grote & Robinson) | Doerr *et al.*[33] |
| *Pandemis* leafroller | *Pandemis pyrusana* Kearfott | Jones *et al.*[34] |
| Peach twig borer | *Anarsia lineatella* Zeller | Brunner and Rice[35] |
| Obliquebanded leafroller | *Choristoneura rosaceana* (Harris) | Jones *et al.*[34] |
| Oriental fruit moth | *Grapholita molesta* (Busck) | Croft *et al.*[36] Degree-day calculation only for quarantine requirements |
| San Jose scale | *Quadraspidiotus perniciosus* (Comstock) | Jorgensen *et al.*[37] |
| Western cherry fruit fly | *Rhagoletis indifferens* Curran | Jones *et al.*[38] |
| **Diseases** | | |
| Apple scab | *Venturia inaequalis* (Cooke) | Mills and LaPlante,[39] MacHardy and Gadoury,[40] MacHardy[41] |
| Cherry powdery mildew | *Podosphaera oxyacanthae* (Wallr.: Fr.) Lev | Grove *et al.*[42–46] |
| Fireblight | *Erwinia amylovora* (Burrill) | Smith[47] |
| Shot hole of stone fruits | *Wilsonomyces carpophilus* (Lev.) Adaskaveg, Ogawa & Butler | Grove[48] |
| ***Horticultural model*** | | |
| Apple storage scald | | Fidler,[49] Merritt *et al.*[50] |

for projecting pest and management recommendations into the near future.

For customer support, the authors are implementing short (<2 min) narrated video screen capture tutorials for various tasks (e.g. setting up a profile, setting up a user-defined weather station), and they already have a frequently asked questions database that is maintained to help users with problems. An email account is also provided that is checked regularly to deal with user problems.

## 3 IMPLEMENTATION ISSUES

The biggest technical problems to date have been related to different web browsers. Most of the open source browsers have few problems, but Microsoft Internet Explorer 7.0 and 8.0 implement HTML differently from the industry standard, which results in significant alterations in appearance and functionality. The authors therefore routinely test web pages against ten Macintosh and Windows browser combinations to ensure compatibility and similar functionality. Along with the display irregularities, Explorer 7 and 8 also have several settings that need to be changed to ensure compatibility with the DAS. In order to remedy or circumvent the settings issue, it has been necessary to implement routines that prompts clients to change their browser settings as needed.

Another problem that surfaced in the implementation of WSU-DAS was that, while predictions for insect phenology are done on a degree-day (physiological time) basis, consultants and managers tend to think in terms of calendar time. This difference necessitated several changes in the output to accommodate the users. First, all graphs have a drop-down menu that provides users with a choice of graphical output based on degree-days or calendar days. For most graphs, views of either the cumulative percentages that have passed through a stage (e.g. cumulative % adult emergence) or the relative number of the different stages present are provided. In addition, whenever a predicted event is forthcoming, the time of predicted occurrence according to the models is provided on a degree-day basis, and this is then converted into days using the projected weather forecast. The graph options are currently being expanded and color-coded to allow users quickly to see patterns (e.g. green means that treatments will not disrupt natural enemies) that will simplify interpretation of management timing.

Perhaps the challenge to full-scale adoption of the DAS is not technical but educationally/culturally based. Regardless of the interface, there still appears to be a significant fraction of users who are intimidated by a computer or who are afraid that they are going to break things unintentionally. Some of this will be overcome by familiarity over time, but it will probably require significant educational efforts to engage this user group. While some efforts will be web based (screen capture videos as described above), it is likely that one-on-one or small class interactions will be necessary for certain groups and/or users of computers who are afraid to change user settings for fear of either breaking something or opening their computer to virus invasion.

### 3.1 Advantages of web-based systems

The web-based decision support systems have many advantages over the desktop-based expert systems of the early 1990s. First, household computer usage increased from 22.8% in 1993 to 61.8% in 2003 (the last year for which census data are available).[23] In addition, broadband Internet access is becoming more common, and wireless Internet access via cell technology allows access for users in remote areas. Increasingly common smartphones also provide Internet access without the expense or weight of a laptop; users can either directly access the website or have predictions emailed to their phone.

Another factor favoring web-based systems is the ability to access and integrate data from widely separated locations in a manner transparent to the user. For example, the DAS routinely accesses the AWN weather server at WSU in Pullman, the NOAA

  

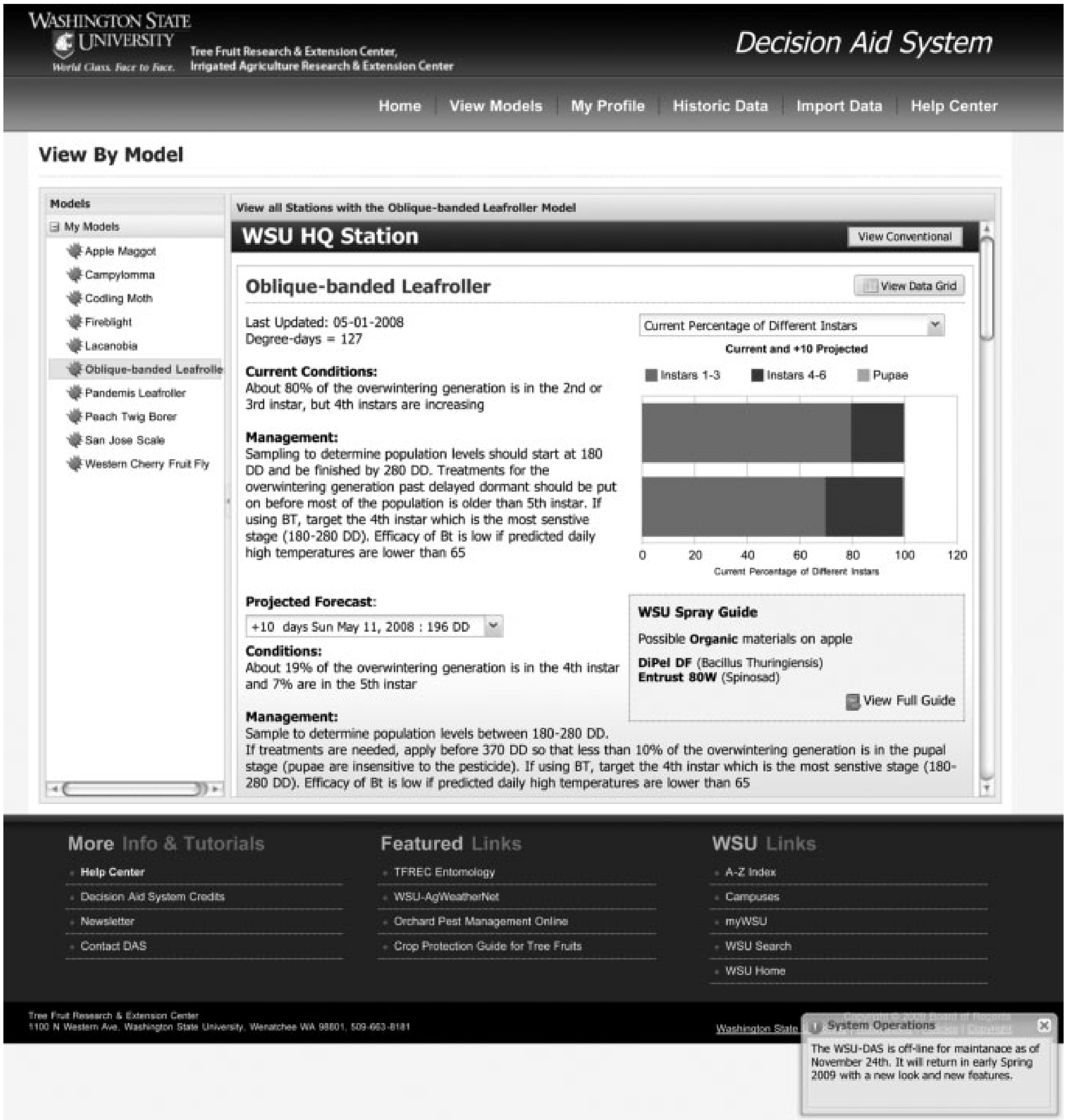


**Figure 1.** Screen capture of WSU-DAS, showing the output for the obliquebanded leafroller and the various options. The graph is color coded so that users can see at a glance the stage of the populations and whether treatments would be a reasonable management option at this time. If the bar is mostly green, larvae are small and would have caused minimal damage, and pesticides would be appropriate; if the bar is mostly red, damage has already occurred and a treatment would disrupt natural enemies; if the bar is mostly orange, they would be in the pupal stage and not affected by pesticide treatment.

server, databases housed at WSU Tree Fruit Research Center in Wenatchee, WA, and web pages for diseases at the WSU Irrigated Agriculture Research and Extension Center in Prosser, WA. The web-based program allows a modular design; there is no need to worry about how to integrate the interface with AWN or NOAA, or to worry extensively about a monolithic program, which has many competing design constraints. Instead, it is merely necessary to know how to access the data and focus on how to design the functions and interface elements required to satisfy user needs.

A major advantage of web-based systems is that the automation of the various complex tasks frees outreach personnel from answering routine questions on things that can be easily predicted and displayed. From the research perspective, the information can be presented dynamically to give the user a clearer understanding of complex phenomena than would be possible using printed matter alone. In addition, web-based systems provide users with continuous access to predictions and recommendations without having to filter the information through various levels of the extension hierarchy that may introduce errors in the intended meaning or be subject to the availability of the extension personnel.

Perhaps the greatest advantage of web-based systems over desktop-based software programs is that changes in the decision support system at the server are instantly propagated to all users at the next login, so errors can be quickly corrected without having to send out notices that users need to update their system. The current DAS system is a 'pull' system, where the user requests data each time. However, there is the capability of easily adding a 'push' system, where user-requested information can be directly emailed to users depending on their stated preferences. Proper implementation of the push system will probably require some of the messages to be rewritten to fit the display limitations of smartphones. However, up to 20% of users have already accessed the current DAS unmodified on their smartphones.

Finally, because the system requires login and passwords, it is possible to require all users to take part in a simple survey designed to determine problem areas, desired features and which demographics are needed to help access the system. In addition, because all the user data are stored on the authors' server, it is possible to determine the relative importance of the different models, stations and frequency of access – all factors that will help to improve the service to clients.

## 4 ESTIMATION OF USER BASE AND USER SURVEY RESULTS

The user base for the DAS was initially determined by simply counting the number of registered users in the database. By this measure, to begin with there were only the original 13 beta users in April 2007, by the end of the year there were 510 registered users and by fall of 2008 there were 1199 users. However, a close review of the database showed that there were 121 duplicate accounts, and 62 affiliated with WSU, for a total of 1016 unique non-WSU users. The database also tracks how many times a user logged on, and 527 users never logged on after registering, 151 logged on once, 76 logged on twice and 51 logged on 3 times. To improve the estimate of the user base, it was considered that a user would have had to log on a minimum of 10 times, which gave an estimate of 259 users, which was very close to the value (247) obtained from the mandatory survey (see below) that was conducted in 2008. The numbers of people that registered but never used the system are a question mark suggesting that they had trouble setting up a profile, that they obtained the data in another fashion (e.g. someone else downloading it for them) or that they were unsure when registering what services they could expect from DAS.

In 2008, all users were required to complete a web-based survey before they could access the model predictions (each user did the survey only once). The survey consisted of two parts: the first part of the survey was focused on user demographics, and all users were required to take it when they initially logged in. The second part of the survey was focused on use patterns and the value of the system to their operation, and was implemented only after the users had been registered more than 3 months. Unfortunately, an error in the second part of the survey required that part of the survey to be shut down after a short period because some users were prevented from accessing WSU-DAS. A total of 247 users completed the first section, and 127 the second section. Full access to all the information can be found at entomology.tfrec.wsu.edu/VPJ_Lab/DAS; only the key parts of the survey are discussed below.

Initially, the authors were concerned that there would be fewer older users because of potential problems with computer familiarity. However, the user age profiles showed increasing use with age, to the point where 47.7% of the users were 50+ years of age (Fig. 2). Perhaps even more surprising was that 66.7% of the users had BSci degrees or better, which is more than twice the state (30.3%) or national averages (27.5%)[24] (Fig. 3). An additional 13.2% indicated that they had Associate or technical degrees, and 13.4% indicated that they had some college. The user base was predominately male (87.8%).

The users generally considered themselves 'average' computer users (78.5%), with roughly equal numbers considering themselves 'expert' (10.9%) or 'novice' users (10.5%). Most users used both a

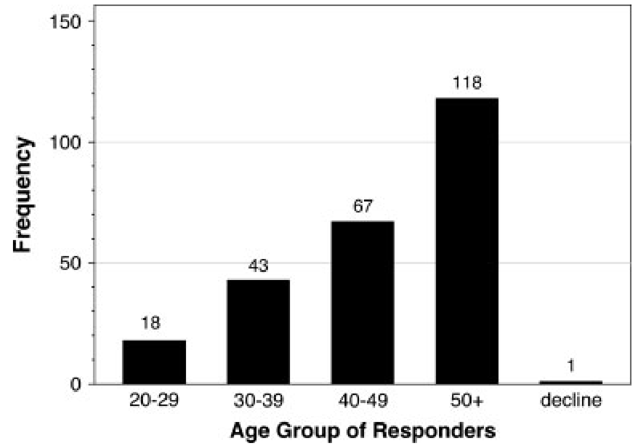


**Figure 2.** Age class distribution of WSU-DAS users in summer 2008.

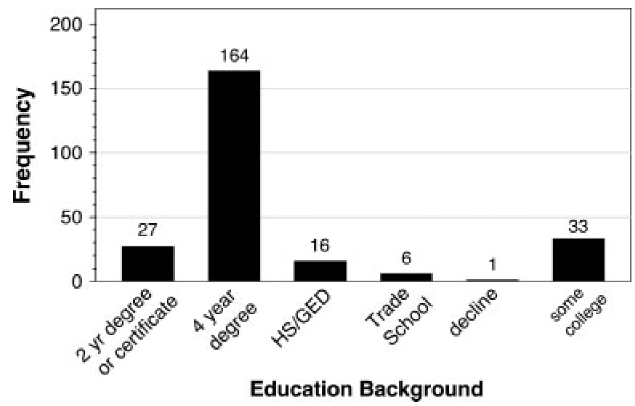


**Figure 3.** Educational background of WSU-DAS users in summer 2008. HS/GED = high school diploma or passed the general education development test (high school diploma equivalent).

laptop and a desktop computer to access the DAS, with about 20% also using a smartphone to access the system in conjunction with either a laptop or desktop machine. In terms of ease of registering for the first time, 96% thought it was easy to neutral (on a five-point scale, with easy being 1, neutral being 3 and hard being 5), with 97% indicating that setting up a profile was easy to neutral.

The largest number of users found out about the DAS at industry meetings (55%) or from a friend/employer/supervisor or colleague (25.6%). Search engines were responsible for about 9% of the users finding the system, but articles in grower magazines were only responsible for about 5% of the total users.

Perhaps the most surprising numbers out of the survey related to the market penetration that was achieved in just 2 years. The users indicated that they provided pest control decisions on 2888 orchards and 250 094 acres, where the industry size estimates are ≈3000 orchards and 215 427 bearing acres.[25] The market penetration estimates are high because it was not possible to control for multiple people who might give recommendations on a single orchard. Nevertheless, it is clear that a large portion of the industry is using the system to help guide IPM decisions.

The cropping systems represented by models on the DAS are apple, cherry, pear and stone fruits such as peaches and nectarines. As apple is the largest commodity in the state, with the most models, 98.4% of the users grew apples, 80.3% grew cherries, 58.3% grew pear and 34.6% grew stone fruits (peach, nectarine,

  

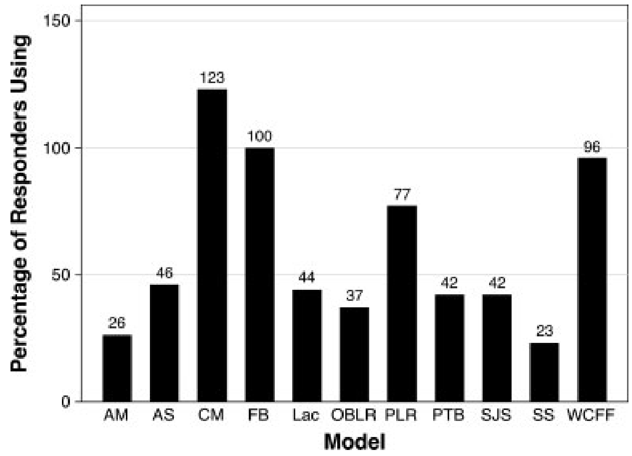


**Figure 4.** Model usage by WSU-DAS users in summer 2008. AM = apple maggot, AS = apple scab, CM = codling moth, FB = fireblight, Lac = *Lacanobia* fruit worm, OBLR = obliquebanded leafroller, PLR = *Pandemis* leafroller, PTB = peach twig borer, SJS = San Jose scale, SS = apple storage scald, WCFF = western cherry fruit fly.

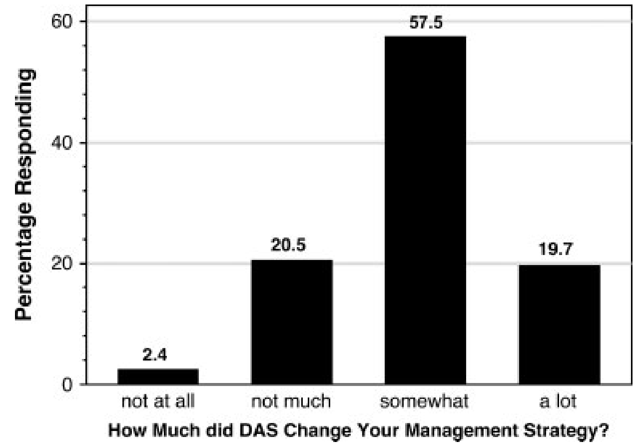


**Figure 5.** User response to the question as to how much WSU-DAS had changed their management strategies.

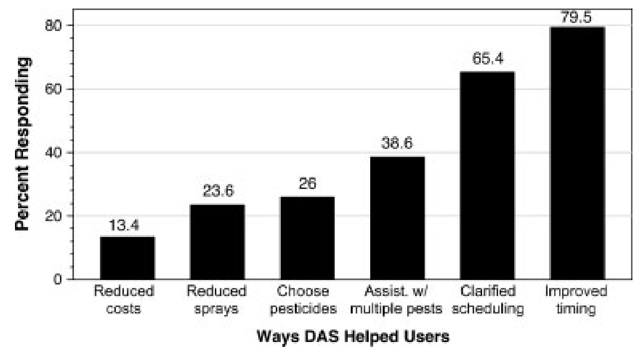


**Figure 6.** User response to the question as to the different ways in which WSU-DAS had helped improve user IPM programs.

apricot, prune). Model popularity did not exactly follow the same trends, with the codling moth being the most widely used model (96.8%), fireblight being the next most used (78.7%) and Western cherry fruit fly being the third most used (75.6%) (Fig. 4). The popularity of the *Pandemis* leafroller model compared with the obliquebanded leafroller model points to a potential problem in recognition between the different species, as obliquebanded leafroller has been displacing *Pandemis* leafroller in much of the fruit-producing areas in Washington State.

Two different approaches were taken to evaluate the value of the DAS. The first was simply to ask users how much the system had affected user practices and the different ways it helped the user, while the second was to ask directly the value of the system on a per acre basis and how it should be supported financially. In terms of how much the DAS changed management strategies, 57.5% indicated that the system changed management 'somewhat' and 19.7% indicated a very large impact, 20.5% felt the changes were 'not much', while only 2.4% indicated 'not at all' (Fig. 5). Taken together, the top two categories showed that the DAS had a significant effect on 77.2% of the users. The main way the DAS affected management programs was in altering timing of management tactics (79.5%), clarifying scheduling (65.3%) and helping with multiple pest species (38.6%), with other categories receiving less than 25% of the votes (Fig. 6).

The estimated monetary value of the DAS on a per acre basis was highly variable and many of the users did not fill in values or put in wildly unrealistic values (e.g. \$1500 acre$^{-1}$). The data were evaluated in two ways to estimate the value: (1) the wildly unrealistic values (\$0, or >\$300 acre$^{-1}$) were eliminated, and (2) all the data were used. In both cases the mean values per acre were similar: in condition 1 the estimate was \$75.77 acre$^{-1}$ (SD = 66.8, $N$ = 53), and in condition 2 it was \$73.75 acre$^{-1}$ (SD = 177.9, $N$ = 87). These two estimates suggest that the 215 427 bearing acres in Washington State give the DAS a value of \$15.8–16.3 million.

In terms of who should financially support the DAS after the development grants have expired, 53.2% indicated WSU-Extension, 32.5% felt the industry as a whole should support it and 14.3% felt user fees should be used. The survey also asked what sort of fees the users felt would be appropriate, with fairly broad ranges of values supplied. If fees were required, 80.9% felt that \$50–100 (per user per year) would be appropriate, 13.5% went for \$100–200, 2.4% for \$200–300 and 3.2% for \$300+.

## 5 DISCUSSION

Affecting change in pest and disease management programs is complicated by the need to integrate changes into the current management system in a simple and logical fashion. The problems are greatly magnified when multiple new tactics are involved, the pest complex is large and the information is time sensitive. The current transition from OP materials to non-OP insecticides in tree fruit and the wide range of new insecticides with different modes of action, different effects on natural enemies and potentially different application timings are exceedingly complex. The DAS is greatly simplifying this transition because it clearly outlines and displays differences in timing, allows the user to see the effects of pesticides on different natural enemies (when they are known) and helps preserve natural enemies when their phenology is known. The educational component of the DAS will be expanded considerably in 2009 because changes in the system design make it possible to highlight seasonally appropriate problems and to provide active learning on a range of topics without being obtrusive.

Another key point is that some of the pesticide recommendations can be simplified because, even though it is legal for a given pesticide to be used during a particular time, it might not be the best choice for efficacy. For example, the efficacy of *Bacillus thuringensis* (*Bt*) for leafroller control in the spring can be reduced unless temperatures are above 65 °F and dry weather is forecast.[26] Because the weather forecast is routinely used to provide predicted population status and management in the DAS, a simple 'grid view' has been developed that allows the users to see the forecast for the 10 days to help them decide if *Bt* is a good management choice.

Overall, while the DAS is a major educational supplement for management programs, for it to be most useful, the overall educational system for users needs to change. The DAS effortlessly integrates so many different factors into the management recommendations that educational efforts focused on timing and pesticide choice are counterproductive. Instead, users need a background that clarifies limitations and assumptions on which the DAS and the IPM programs in general are based, the logic behind the overall management program and specific management issues that the DAS does not cover. As the DAS becomes more complex in the future and begins to integrate new sensors and models, it is critical that the educational system address these changes so that users are better able to implement IPM programs.

The user survey provided an important snapshot of the client base and their views on the decision support system. First, their high educational background compared with farm workers in general (66.7% with a Bachelor's degree or better versus 5% with education past high school[27]) suggests that pest control is one of the more difficult tasks that managers have, and help is needed to cope with the complexity. Secondly, the way users discovered the system was primarily through meetings and word of mouth; articles and Internet search engines were of relatively minor importance, which suggests that a redistribution of effort may be warranted. Third, users felt that the system was easy to use and a great way to get a large amount of information with a minimal time investment. Fourth, the recommendations had a relatively large impact on growers and helped them clarify timing and scheduling of the key pest management decisions. Ultimately, the user survey makes it possible to focus some educational and design efforts on areas that might otherwise have been ignored or missed.

The discrepancy between the perceived value of the DAS and the price users were willing to pay was noteworthy. A close review of written comments also showed that some of the questions were not precise enough. For example, many users felt that the legislatively mandated pesticide changes were costing them money, and that the increased efficiency provided by the DAS was simply offsetting their losses, but they did not consider that in their estimate of the value of the system. The reaction against legislatively mandated pesticide changes was probably a factor in the user survey where the majority of respondents (85.7%) wanted either WSU-Extension or the industry to pay for system maintenance and upgrades. If a user fee is eventually required, and the user base remains at roughly 260 users, fees of nearly $600 would be needed reasonably to support a programmer, required upgrades and a manager/educator to oversee the system and provide the constant educational component needed for continued use and increased adoption. For this level of support to be feasible, it is likely that other models and options (e.g. models for predicting sunburn of apples, thinning models) would need to be added before users would pay that price. However, even at $600 per year, in terms of the number of pests, pest status, management options, predictions using weather forecasts and pesticide recommendation database, the DAS still provides considerably more value than commercially available decision support solutions.

The number of users recorded using the survey and querying the database is probably best thought of as an absolute lower estimate of the user base. First, an important point is that the DAS has only been out for 2 years, and the user base will probably continue to grow, albeit more slowly than it did in the first 2 years. Second, although both methods agreed that the number was around 260 users, a different set of queries shows that there are some users who were accessing all the models for 15–25 stations. These 'super users' are for the most part office employees for large organizations that log on, copy the model output, print it out and then distribute it to the various people responsible for IPM in their company. The authors have confirmation of this practice from several of the large commercial pest control companies. In addition, several private consultants have said that they regularly receive calls from colleagues in the industry to ask for the latest projections for various pests, rather than logging in themselves. This means that the actual number of people relying on the DAS is much greater than can be directly estimated from either the survey or from database queries alone. The importance of this will be magnified if user fees have to be adopted, because actual paying users will have to be charged more to offset the revenue lost by users passing out the information to non-paying individuals. Different mechanisms to fund the long-term viability of DAS are currently being investigated, because it is clear that research grants cannot continue to fund the program. Extension is unwilling to fund its operation, in spite of the impact on the tree fruit industry and the reduction in workload for its specialists and county agents.

Finally, the trends of increasing complexity of tree fruit IPM programs and decreased faculty, staff and funding for outreach efforts will require a major change in how information flows between researchers and consumers of that research. Decision support systems can act as a counter to the above trends, but, to be successful, they will still require involvement of outreach faculty and industry personnel to ensure that the systems evolve over time to meet user needs. Extension should also reconsider its support for decision support systems, because they offer a cost-effective way of reaching a large proportion of users at a relatively low cost and at the same time relieve overburdened extension personnel from doing mind-numbingly repetitive tasks.

## ACKNOWLEDGEMENTS

This work was supported by grants to VPJ and JFB from the Washington Tree Fruit Research Commission and Washington State Commission on Pesticide Registration. The authors thank Jessica Goldberger (Washington State University) for reviewing the user survey questions.

## REFERENCES

1 Magarey RD, Travis JW, Russo JM, Seem RC and Magarey PA, Decision support systems: quenching the thirst. *Plant Disease* **86**:4–14 (2002).
2 Brunner JF, Dunley JD, Beers EH and Jones VP. Building a multi-tactic biologically intensive pest management system for Washington orchards, in *Certified Organic and Biologically Derived Pesticides: Environmental, Health and Efficacy Assessment*, ed. by Felsot A and Racke K. American Chemical Society, New Orleans, LA (2005).
3 Brunner JF, Welter SC, Calkins CO, Hilton R, Beers EH, Dunley JE, *et al*, Mating disruption of codling moth: a perspective from the western United States. *IOBC WPRS Bull* **5**:207–225 (2001).

  

4 Whalon ME, Jacobson BJ, Rawlins D, Ricks D and Swinton M, Agricultural impact of the sudden elimination of key pesticides under the Food Quality Protection Act. Council for Agricultural Science and Technology Issues, Paper No. 11, pp. 1–14 (1999).
5 Jones VP, Grove GG, Brunner JF, Tangren GV and Jones WE, Making the complex simpler: IPM decision aid system now and in the future. *Proc Wash State Hortic Assoc* **103**:139–142 (2008).
6 Jones VP, Grove GG, Brunner JF, Tangren GV, Beers EH and Smith TJ, Advances in decision support technology. *Proc Wash State Hortic Assoc* **102**:185–187 (2007).
7 Jones VP, Brunner JF, Eastburn CC and Wilburn TD, Pest supermodels – new ways to improve our pest management programs. *Proc Wash State Hortic Assoc* **100**:113–119 (2005).
8 Haynes DL, Brandenburg RK and Fisher PD, Environmental monitoring network for pest management systems. *Environ Entomol* **2**:889–899 (1973).
9 Welch SM, Croft BA, Brunner JF and Michels MF, PETE: an extension phenology modeling system for management of multi-species pest complex. *Environ Entomol* **7**:487–494 (1978).
10 Gage SH, Whalon ME and Miller DJ, Pest event scheduling system for biological monitoring and pest management. *Environ Entomol* **11**:1127–1133 (1982).
11 Travis JW, Rajotte E, Bankert R, Hickey KD, Hull LA, Eby V, *et al*, A working description of the Penn State apple orchard consultant, an expert system. *Plant Disease* **76**:545–554 (1992).
12 Rajotte E, Bowser T, Travis JW, Crassweller RM, Musser W, Laughland D, *et al*, Implementation and adoption of an agricultural expert system: the Penn State apple orchard consultant. *Acta Horticulturae* **313**:227–231 (1992).
13 Travis JW and Latin RX, Development, implementation and adoption of expert systems in plant pathology. *Ann Rev Phytopathol* **29**:343–360 (1991).
14 Samietz J, Graf B, Hohn H, Schaub L and Hopli HU, Phenology modelling of major insects in fruit orchards from biological basics to decision support: the forecasting tool SOPRA. *Bull OEPP/EPPO* **37**:255–260 (2007).
15 Graf B, Hopli H and Hohn H, Optimising insect pest management in apple orchards with SOPRA. *IOBC WPRS Bull* **26**:43–50 (2003).
16 Graf B, Hopli HU, Hohn H and Blaise P, SOPRA: a forecasting tool for insect pests in apple orchards. *Acta Hort* **584**:207–214 (2002).
17 Graf B, Hopli H and Hohn H, Improving the prediction of adult codling moth (*Cydia pomonella* L.) emergence in a natural environment. *Bull OILB/SROP* **24**:127–132 (2001).
18 Ley TW, Willett MJ, Boyer J, Wright MA, Muzzy A and Graves CB, Implementing a real-time weather data acquisition and information delivery system for enhanced crop production in Washigton State, in *Computers in Agricultural Extension Programs*. American Society of Agricultural Engineers, Orlando, FL, pp. 129–134 (1992).
19 Bush M, Dunley JD, Beers EH, Brunner JF, Grove GG, Xiao C, *et al*, Crop protection guide for tree fruits in Washington. Bulletin EB0419, Coll. Ag. and Human and Nat. Res., Washington State University, Pullman, WA (2009).
20 Jones VP and Grove GG, *Palm and Desktop Database Version of Crop Protection Guide for Tree Fruits in Washington*. [Online]. Available: http://www.tfrec.wsu.edu/protectdb/index.html [8 January 2010].
21 Jones VP and Brunner J, *Phenology and Management Spreadsheets*. [Online]. Available: http://entomology.tfrec.wsu.edu/VPJ_Lab/VPJ_Pages/Decision_Aids.html [20 November 2009].
22 *National Digital Forecast Database (NDFD) Simple Object Access Protocol (SOAP) Web Service*. [Online]. NOAA. Available: http://www.nws.noaa.gov/forecasts/xml/[8 January 2010].
23 Cheeseman-Day J, Janus A and Davis J, Computer use and internet use in the United States: 2003, in *Special Studies*. US Census Bureau, Washington, DC (2005).
24 *United States and States: R1502 Percent of People 25 Years and Older Who Have Completed a Bachelor's Degree*. [Online]. Available: http://factfinder.census.gov [8 January 2010].
25 Noncitrus fruits and nuts 2008 summary, January 2009. NASS (2009).
26 Brunner JF, Doerr M and Smith L, *Bacillus thuringiensis* products and leafroller control in Washington apple orchards. *Proc Wash St Hort Assoc* **90**:102–108 (1994).
27 Carroll DP, Samardick RM, Bernard S, Gabbard S and Hernandez T, A demographic and employment profile of United States farm workers, in *Findings from the National Agricultural Workers Survey (NAWS) 2001–2002*. United States Department of Labor, pp. 1–80 (2005).
28 Jones VP, Davis DW, Smith SL and Allred DB, Phenology of apple maggot associated with cherry and hawthorn in Utah. *J Econ Entomol* **82**:788–792 (1989).
29 Jones VP, Smith SL and Davis DW, Comparing apple maggot adult phenology in eastern and western North America, in *Apple Maggot in the West: History, Biology and Control*, ed. by Dowell RV, Wilson LT and Jones VP. University of California Press, Oakland, CA (1990).
30 Reding ME, Biology, monitoring, and management of *Campylomma verbasci* (Meyer) (Hemiptera: Miridae) in Washington apple orchards. *PhD Thesis*, Washington State University, Pullman, WA (2000).
31 Riedl H, Croft BA and Howitt AJ, Forecasting codling moth phenology based on pheromone trap catches and physiological-time models. *Can Entomol* **108**:449–460 (1976).
32 Jones VP, Doerr MD and Brunner JF, Is biofix necessary for predicting codling moth emergence in Washington State apple orchards? *J Econ Entomol* **101**:1651–1657 (2008).
33 Doerr M, Brunner JF and Jones VP, Phenology of *Lacanobia subjuncta* (Lepidoptera: Noctuidae) in Washington and Oregon apple orchards. *J Econ Entomol* **98**:2100–2106 (2005).
34 Jones VP, Eastburn CC, Wilburn TD and Brunner JF, Instar-specific phenology of *Pandemis pyrusana* and *Choristoneura rosaceana* (Lepidoptera: Tortricidae) in Washington apple orchards. *J Econ Entomol* **98**:875–883 (2005).
35 Brunner JF and Rice RE, Peach twig borer, *Anarsia lineatella* Zeller (Lepidoptera: Gelechiidae), development in Washington and California. *Environ Entomol* **13**:607–610 (1984).
36 Croft BA, Michels MF and Rice RE, Validation of a PETE timing model for the oriental fruit moth in Michigan and central California. *Great Lakes Entomol* **13**:211–217 (1980).
37 Jorgensen CD, Rice RE, Hoyt SC and Westigard PH, Phenology of the San Jose scale. *Can Ent* **113**:149–159 (1981).
38 Jones VP, Alston D, Brunner JF, Davis DW and Shelton MD, Phenology of western cherry fruit fly (Diptera: Tephritidae) in Utah and Washington. *Ann Entomol Soc Am* **84**:488–492 (1991).
39 Mills WD and LaPlante AA, Diseases and insects in the orchard. *Cornell Univ Ext Bull* **711**:1–5 (1951).
40 MacHardy WE and Gadoury DM, A revision of Mills criteria for predicting apple scab infestion periods. *Phytopathology* **79**:304–310 (1989).
41 MacHardy WE, *Apple Scab: Biology, Epidemiology, and Management*. APS Press, St Paul, MN (1996).
42 Grove GG and Boal RJ, Overwinter survival of *Podosphaera clandestina* in eastern Washington. *Phytopathology* **81**:385–391 (1991).
43 Grove GG and Boal RJ, Powdery mildew of sweet cherry: influence of temperature and wetness duration on release and germination of ascospores of *Podosphaera clandestina*. *Phytopathology* **81**:1271–1275 (1991).
44 Grove GG and Boal RJ, Factors affecting germination of *Podosphaera clandestina* conidia on leaves and fruit of sweet cherry. *Phytopathology* **81**:1513–1518 (1991).
45 Grove GG, Meteorological factors affecting airborne conidia concentrations and the latent period of powdery mildew of sweet cherry. *Plant Disease* **82**:741–746 (1998).
46 Grove GG, Boal RJ and Bennett LH, Managing powdery mildew of cherry in Washington orchards and nurseries with spray oils. *Plant Health Progress* DOI:10.1094/PHP-2000-0728-01-RS (2000).
47 Smith TJ, Report on the development and use of cougarblight 98C – a situation-specific fireblight risk assessment model for apple and pear. *Acta Horticulturae* **489**:429–436 (1999).
48 Grove GG, Influence of temperature and wetness period on infection of cherry and peach foliage by *Wilsonomyces carpophilus*. *Can J Plant Pathol* **24**:40–45 (2002).
49 Fidler JC, Scald and weather. *Food Sci Abstracts* **28**:545–554 (1956).
50 Merritt RH, Stiles WC, Havens AV and Mitterling LA, Effects of preharvest air temperatures on storage scald of Stayman apples. *Proc Am Soc Hort Sci* **78**:24–34 (1961).


  