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A Working Description of the Penn State Apple Orchard Consultant, an Expert System

Agricultural production has evolved into a complex business. It requires the accumulation and integration of knowledge and information from many diverse sources, including marketing; horticulture; insect, mite, disease, and weed management; accounting; and tax laws. Emerging sustainable practices require even more information (to substitute for purchased inputs) for implementation. Farm managers seldom have at their disposal all information available in a usable form when major management decisions must be made. Increasingly, modern growers must become experts in the acquisition of information for decision making in order to remain competitive. However, because integrating and interpreting information from many sources may be beyond the means of individual growers, they use the expertise of agricultural specialists. Unfortunately, the assistance of these specialists is becoming relatively scarce even as the complexity of agriculture is increasing. To alleviate this problem, current information must be structured and organized into an accessible system for growers and agricultural specialists. Because no organized structure is available for information storage and retrieval, technical information is often lost or unavailable to potential users. The use of electronic decision support systems is one way to make this information readily available.

Historically, growers and consultants have effectively controlled diseases and insects of apple (*Malus domestica* Borkh.) by protective pesticides applied at regular intervals. There was very little day-to-day decision making and very little pest damage in orchards. During the past two decades, however, circumstances surrounding pest management have changed. Growers find that many previously effective pesticides no longer are available, are available for restricted use only, or have lost effectiveness. Sterol demethylation inhibitor (DMI) fungicides are very effective in controlling apple diseases but are difficult to use properly. Because DMI fungicides are growth regulators, growers must change the management strategy from protecting leaves and fruit from infection to eradicating the pathogen after infection has occurred, with very little margin for error. The use of DMI fungicides as postinfection materials requires that growers monitor weather, record infection periods, and spray at short notice if infections have occurred. Satisfactory control often requires two applications of the fungicide after an infection period. As growers struggle with the new "rules" of disease management, they are faced with a still greater problem. The public wants reduced pesticide residues but high-quality fruit. The rapid change in pest control is multiplied by new labor, marketing, and social concerns that threaten to exceed the capacity of what growers can manage.

University extension and research personnel are concerned that traditional methods of information delivery (i.e., newsletters, production meetings with growers, and production guides) seem inadequate for the delivery of complex dynamic information. In the 160-page *Pennsylvania Tree Fruit Production Guide* (14), the traditional means of published production information for growers since the mid-1940s, recommendations are made on a statewide basis. Ranges for pesticide application rates and timing are suggested, but rates and timing for specific locations depend on local circumstances. This form of information delivery inhibits implementation of new, site-specific integrated pest management (IPM) strategies by growers. Pesticide labels and information are revised weekly or monthly, but the production guide can be updated only annually. A more effective decision support tool should include the capability of incorporating constant change into complex management strategies to provide interpretive, integrated, timely, site-specific recommendations.

Expert Systems

To improve delivery of IPM programs and provide more precise and effective pesticide recommendations, an expert system has been developed for use in IPM decision making (13). An expert system is a computer program designed to simulate problem-solving mechanisms that imitate those used by experts in a narrow domain or discipline. An expert system is normally composed of a knowledge base (information, heuristics, etc.), an inference engine that analyzes the knowledge base, and an end user interface that accepts inputs and generates outputs. The path that leads to the development of expert systems differs from that leading to conventional programming techniques. Concepts for expert system development come from the subject domain of artificial intelligence and require a departure from conventional computing practices and programming techniques. A conventional program consists of an algorithmic process to reach a specific result. An

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artificial intelligence program consists of a knowledge base and a procedure to infer an answer.

Because the inference engine is separate from the knowledge base, expert systems can be improved by simply adding new knowledge (i.e., rules, frames) into the system. In contrast, a conventional program with integrated knowledge base and inference procedures requires a major time commitment to make changes in the program logic. Expert systems can deliver quantitative information, much of which has been developed through research and includes economic thresholds, crop development models, and pest population models. Rule-of-thumb heuristics are used to interpret qualitative values, which may be used in lieu of quantitative information. Expert systems can address imprecise and incomplete data through the assignment of confidence values to inputs and conclusions (5,6,15).

A powerful attribute of expert systems is the ability to explain reasoning. Because the system remembers its logical chain of reasoning, a user may ask for an explanation of a recommendation. The system then displays the factors it considered for a particular recommendation, which enhances user confidence in the recommendation and acceptance of the expert system.

Development of an electronic decision support system requires combined efforts of specialists from many fields of agriculture and cooperation of growers who consult them. Specialists tend to be trained in narrow domains and are best at solving problems within their domains, but complex problems faced by growers go beyond the abilities of individual specialists. Interdisciplinary teams of specialists who work in unison can be effective when agriculture is viewed as a system of interacting parts in which the perturbation of one part affects many others. In agriculture, expert systems are capable of integrating the perspectives of individual disciplines (e.g., plant pathology, entomology, horticulture, agricultural meteorology) into a framework that best addresses the type of integrated decision making required of modern farmers. Expert systems can be one of the most useful tools for providing growers with the day-to-day integrated support needed for crop production.

The Penn State Apple Orchard Consultant

The Penn State Apple Orchard Consultant (PSAOC) was developed on a Macintosh computer and employs a frame-based expert system tool, Pennshell, that was written in the C programming language. Although parts of PSAOC were built directly from the C language, Pennshell is designed as a "toolbox" of often-used functions so that little direct coding is necessary. Each frame in PSAOC stores knowledge about a particular object (e.g., development stage of the apple trees). The status (or value) of the frame (e.g., pink stage) helps to determine the final recommendation. Frames can be either independent or dependent. A dependent frame must make use of other frames or specifically built functions to determine its status. An independent frame's state (i.e., its value) remains fixed, does not depend on other frames, and is determined by querying the user. Development stage, cultivar, disease status, last spray date, and last pesticides sprayed are examples of independent frames. The states of the independent frames and other functions built into the C language are used to determine the states of dependent frames (i.e., disease potential, cultivar susceptibility, and infection).

Each frame contains five cells. An action is performed when any cell is called directly or indirectly by the user of the system. The ABOUT cell is a description of the object for which the frame was built. The EXPLANATION cell contains reasons, based on the frame's status, for a certain recommendation provided by the expert system. The RESPONSE cell performs an action based on the state of the frame. The HELP cell can be used to help the user understand a particular question asked by the system. The GETVALUE cell contains the information used to determine the state of the frame. Only the GETVALUE cell of any particular frame must have something built into it for the frame to become activated.

Different components (modules) of the expert system are called by a menu interface. The menu items for the IPM portion of PSAOC include orchard profile, scouting, weather, diseases, insects, and IPM. Horticultural modules (leaf analysis for nutrients, tree spacing, irrigation scheduling, and weed control) are also available. The user can choose one insect or disease, all diseases, or all insects or receive an integrated insect and disease control recommendation by selecting IPM. Once the menu item is selected, the program executes the GETVALUE cell of the particular frame called. This frame (e.g., disease potential) is dependent and is assigned a value based on the status of other frames (independent or dependent), whose values are obtained from profile information or user interaction. In the RESPONSE cell, another dependent frame (e.g., chemical selection) is called to determine its state and response. More dependent frames or custom-built functions are called until all information needed to offer a recommendation has been obtained.

Some information used by PSAOC during an interactive session may originate from sources other than the user. A profile of permanent (e.g., cultivar, expected harvest date) and temporary (e.g., plant development stage, last spray date) independent information can be created. By accessing the information in a profile the system already has about a particular orchard site, the user may obtain a recommendation without interacting with the system and without the system repeating questions each time it is consulted.

Pennshell allows the programmer to make use of the resource capabilities of the Macintosh. Within the resource file used by the expert system are graphic and text capabilities as well as icons and cursors. The resource file then is combined with the source code to build the final application. The Pennshell-Macintosh interface can also be used in DOS-based (IBM) machines. Macintosh- and DOS-compatible versions of the expert system are for sale to fruit growers through the Pennsylvania Cooperative Extension Service.

System Design

Because the information needed to assemble a meaningful expert system is derived from many areas, a team approach is used to develop the knowledge base. The team includes experts from plant pathology, entomology, horticulture, agricultural engineering, agricultural meteorology, agricultural economics, and rural sociology. Expert systems are best conceived as a whole, then divided into smaller units for the actual development. For example, PSAOC covers the range of problems encountered by a fruit grower but is built as a series of modules (pest management, leaf analysis, tree spacing, etc.). Each module may be subdivided several more times to arrive at a point of simplification where the information is manageable. For instance, the pest management module of PSAOC includes lower level modules encompassing potentials for apple scab, powdery mildew, and cedar apple rust and for insect thresholds, chemicals, chemical rates, and spray intervals. Modules below these predict infection periods, chemical residue levels, etc. These modules, which are built separately, interact to derive an integrated disease and insect recommendation. The relationship and number of modules in an area are determined by the experts designing the system. To efficiently utilize information put into the system by the user, the system stores the orchard description supplied by the user for use by all modules.

System Description

The pest management portion of PSAOC comprises three parts: 1) the orchard profile, which is composed of the variables that describe the orchard; 2) the pest rating modules, which deter-

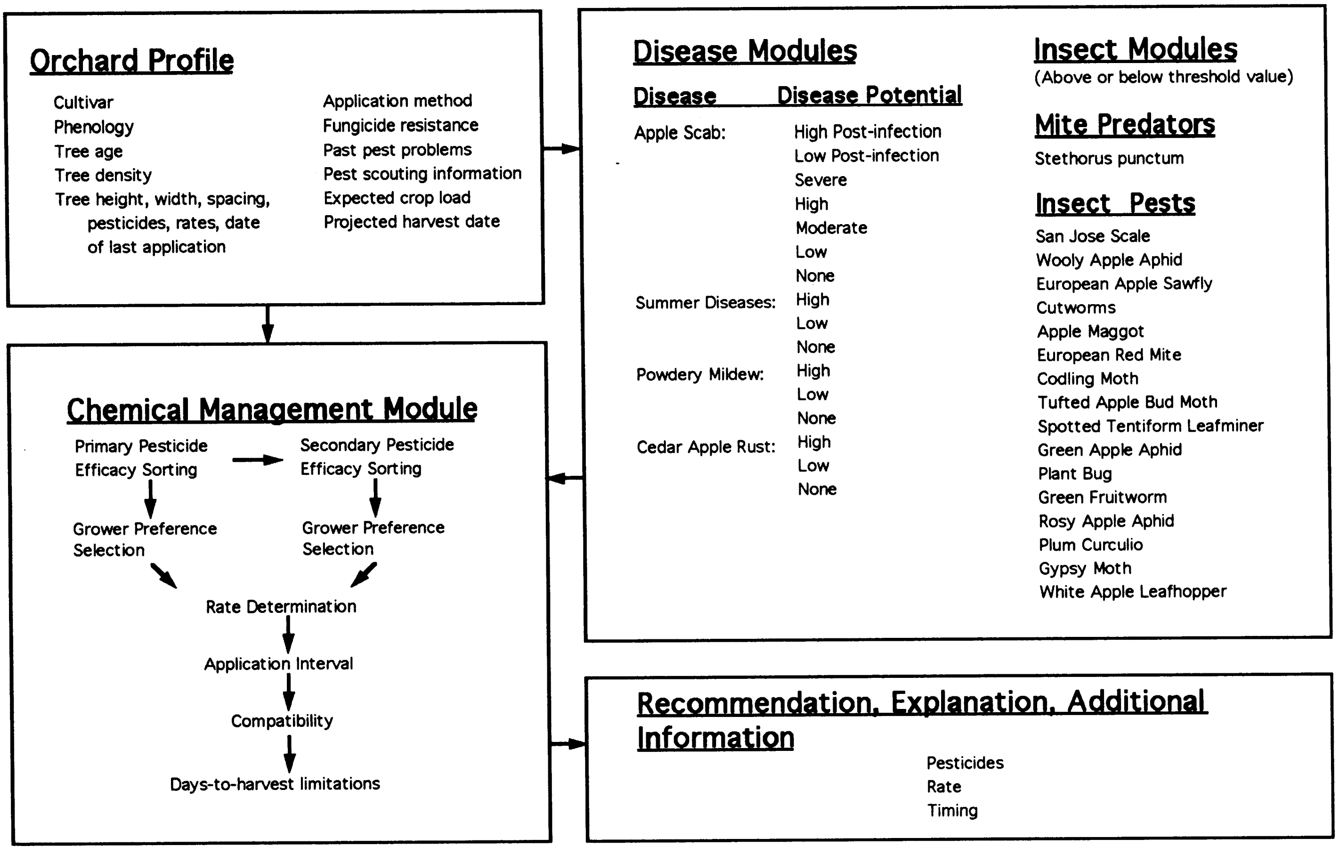

Fig. 1. Information flow within the apple pest management module of the Penn State Apple Orchard Consultant expert system.

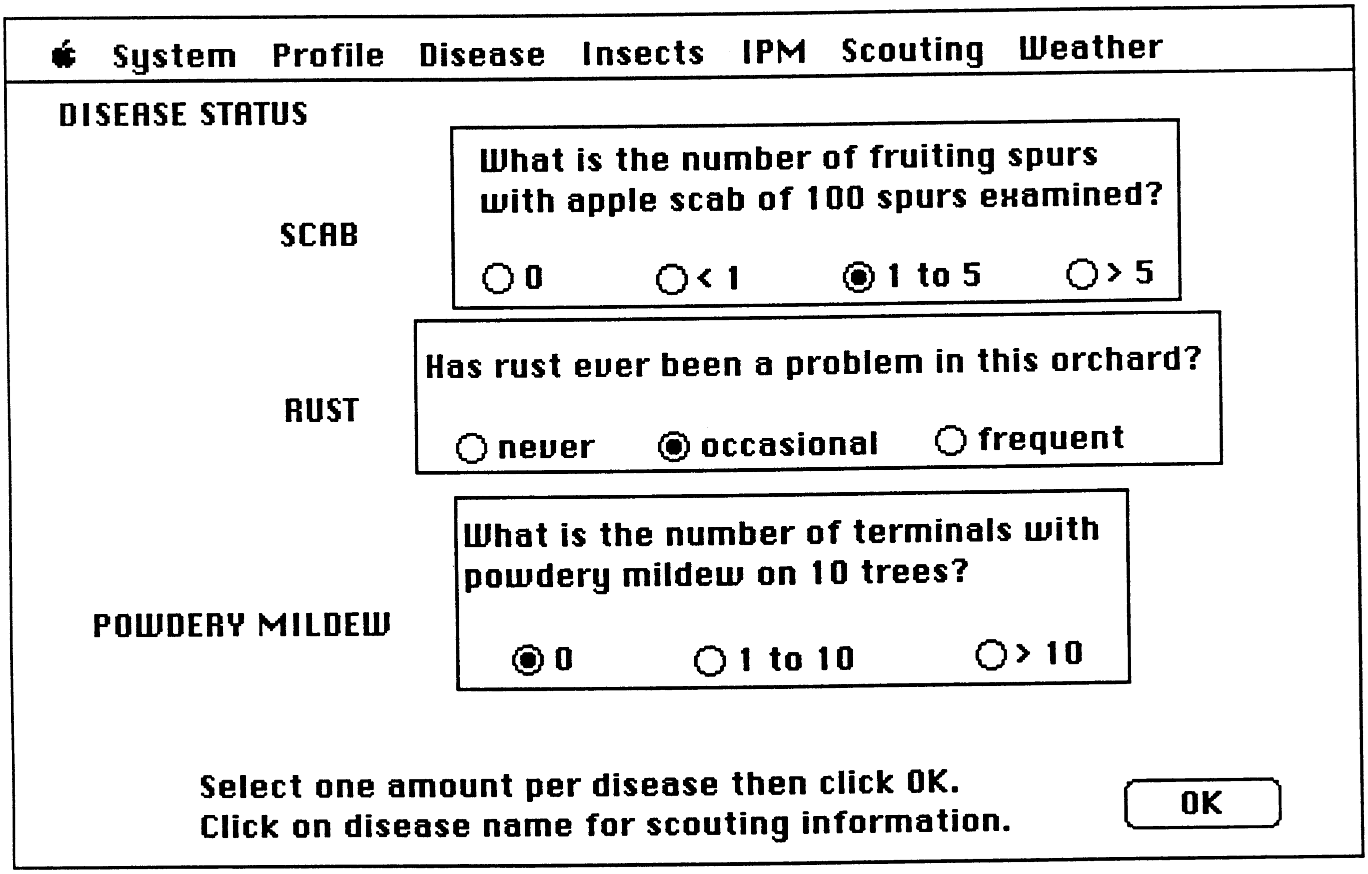

Fig. 2. Input for current disease status.

mine the pests and level of severity and the beneficial organisms; and 3) the chemical management modules, which determine the chemicals and rates that are appropriate for each circumstance and the intervals between applications. Compatibility of the chemicals and days-to-harvest limitations also are determined.

The orchard profile (Fig. 1) is separated into characteristics that do not change and those that may change within the season. Long-term characteristics may be updated once each year, but temporal characteristics can be updated daily (Fig. 2). The user may enter data: 1) by highlighting active zones on the screen, 2) by scrolling to the correct response, or 3) by keyboarding. For example, to enter the name and application rate of a fungicide, the user can "click" the mouse button to the chemical's name and enter the rate by scrolling to the correct amount or by keyboarding the numerical value into the box to the right of the scroll bar (Fig. 3). Information within the orchard profile can be utilized by all modules of the system at any time.

The system also has an autotutorial feature by which the user can obtain additional information about a disease, an insect, or a chemical. For example, when the cursor is placed on the word "scab" (Fig. 2) and clicked, scouting instructions for apple scab and its disease cycle appear along with illustrations of fruit and leaf symptoms. Instructions for scouting diseases and insects vary as the season progresses.

Disease Potential Modules

Apple scab. This module determines the potential for apple scab in the orchard since the last fungicide application. The disease potential levels are qualitative: none, low, moderate, high, and severe, with severe indicating certainty of disease. Low postinfection (infection period occurred with low disease potential) and high postinfection (infection period occurred with high disease potential) are also recorded. None, low, moderate, and high rate the disease potential since the last spray if no new infections occurred, whereas low and high postinfection rate the disease potential when there was a possibility of infection since the last application. For apple scab, this determination is based on four factors (Fig. 4): the stage of plant development, cultivar susceptibility, incidence of scab at present and last season, and potential for infection since the last fungicide application. Stage of development is determined from the orchard profile according to a standard classification system. Cultivar susceptibility (determined from published information [1,7–9] and through personal communication with growers, orchard consultants, and university personnel) is obtained from the orchard profile data and assigned by the system. Current and past incidences of scab are supplied by the grower within the orchard profile.

The potential for apple scab infection since the last fungicide application is determined in a submodule that involves the amount of rainfall (<5 cm, ≥5 cm) since the last fungicide application, application to one or both sides of the tree, days since the last fungicide application that the infection period occurred, and infection period calculations based on Mills (11) and Jones et al (10). The relationship of these factors to each other determines if an infection period has occurred. The output of postinfection potential (yes, no) is utilized in the apple scab module to determine disease potential level.

The specific relationship of the factors that describe the apple scab module is displayed in a dependency network, which is a type of decision tree. Dependency networks are valuable because they display disease management principles and allow disease management specialists and computer programmers to communicate. The pest management modules in PSAOC contain 135 dependency networks. For example, severe disease potential may result from one of two situations shown in Figure 4. In the situation represented by the darker lines, disease potential can be severe from the green tip to the second cover stage of development if cultivar susceptibility is low, the current incidence of apple scab is greater than 1%, and there has been

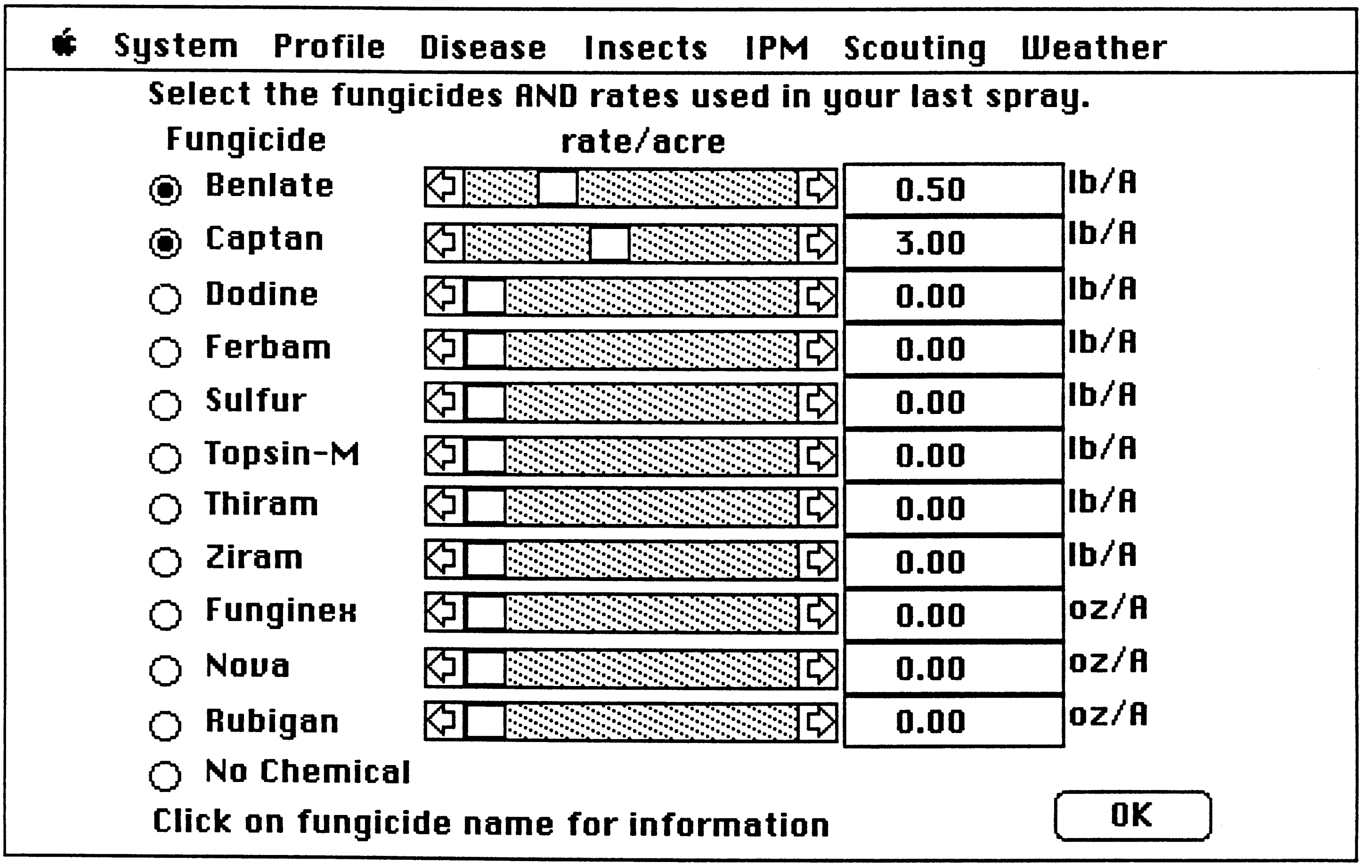

Fig. 3. Information entry screen from Penn State Apple Orchard Consultant expert system orchard profile.

no infection potential since the last fungicide application.

The network describing the severe goal for apple scab is relatively simple, involving only two distinct situations (Fig. 4). Some networks display many situations.

Powdery mildew. Powdery mildew has three potential levels in the PSAOC: none, low, and high. The disease has fewer disease potential levels than apple scab because it has lower impact as an apple pathogen in Pennsylvania orchards. The factors describing powdery mildew are stage of development, cultivar susceptibility, and disease severity during the current and last seasons. In the orchard profile, the grower is asked to indicate the severity of mildew in the orchard, last year's severity if the stage is prior to pink, and this year's severity if the stage is later than pink. For example, high disease potential would be expected from tight cluster stage to second cover stage if cultivar susceptibility is high and more than one terminal per tree shows mildew symptoms. Dependency networks display the disease potential scenarios.

Cedar apple rust. Cedar apple rust also has three potential levels: none, low, and high. The descriptive factors are stage of development, cultivar susceptibility, infection period, and incidence in the recent past. Calculations for infection period are based on those described by Aldwinckle et al (2). In Pennsylvania orchards, cedar apple rust may be a problem never, occasionally, or frequently. A frequent problem usually indicates that the alternate host (*Juniperus* spp.) is nearby. The potential for cedar apple rust is high at the pink to petal fall stages if the cultivar is highly susceptible, there has been an infection period, and the disease has been an occasional to frequent problem in the orchard.

Insect Threshold Modules

Depending on the stage of tree development, several criteria determine the presence and severity of insect and mite pests and the mite predator *Stethorus punctum* (LeConte). PSAOC queries the profile to determine the present growth stage and constructs a list of insects and mites that can be a problem at that time. Pertinent questions are asked about each to determine if the pest species is over its action threshold (the population density where control must be initiated to prevent economic loss). Some information is obtained from the user and some from the profile. The identities of the insect and mite species over the action threshold then are passed along to the chemical management module. For instance, the following information is used in decisions affecting the European red mite (*Panonychus ulmi* (Koch)): growth stage and age of trees, projected crop load at harvest, amount of rainfall, number of mites per leaf, and number of *S. punctum* per 3-minute count. This information is used to measure the potential for a given mite population to affect yield, quality, and bloom in subsequent years. Mites feed on leaves, not fruits, and their effects must be measured as an interaction with the tree's physiological functions. Moreover, enumeration of the predator beetle *S. punctum*, a commercially reliable biological control for mites in Pennsylvania, is required. Often, enough beetles are present to keep the mites below the action threshold.

Chemical Management Module

The chemical management module (Fig. 1) also functions at several levels: the chemical selection module, the chemical rate module, and the spray interval module.

Chemical selection module. Dependency networks describe the registered insecticides, acaricides, and fungicides effective for control of the pests identified as potential problems by the pest modules. Critical factors contributing to selection of a chemical are: growth stage of trees, array of insects over threshold, disease levels in the orchard, pathogen infection potential since the last spray, pesticides used in the last application, known fungicide or insecticide resistance, and number of days until harvest of the crop. For example, two basic scenarios describe the appropriate use of benomyl for control of apple scab. As a protectant, benomyl is recommended from green tip to second cover when disease potential is moderate to severe, there has been no infection potential since the last application, a DMI fungicide was not used in the last application, resistance to benomyl has not been found in the orchard, and the harvest date is more than 7 days from the present. The postinfection scenario is the same except that an infection period has occurred within the previous 24 hours. Then follows a list of insecticides, acaricides, and fungicides that control the pests determined by the system under the conditions described.

Chemical rate module. After the chemicals have been selected, the rate to be used is determined (Fig. 1). For example, to control scab early in the season, two or more chemicals are generally recommended to prevent resistance and to take advantage of multiple modes of action. Late in the season, however, only one fungicide, generally a protectant, is recommended. A high rate is recommended from tight cluster through prepink, when the apple scab severity level is highest, and the recommended chemical is used in combination with another fungicide. A table lists the rates for each chemical, with the exception of myclobutanil. Myclobutanil is labeled for use according to tree row volume (automatically calculated from information in the profile) and disease potential.

Spray interval module. The date of the next pesticide application is determined by growth stage, disease potential rating, occurrence of an infection period since the last spray, grower's spray interval preference, amount of rainfall since the last application, and chemical used in the last application. Early in the season, requirements for controlling apple scab mandate timing of application. After second cover, weather conditions affecting summer apple diseases and requirements for controlling insects dictate timing. Grower preferences are influenced by the ability to spray an orchard at short notice and on a regular schedule in order to manage labor. This option allows growers to adjust spray intervals according to pest and weather circumstances or to plan applications on the basis of labor requirements. When a routine schedule is selected, spray intervals can be adjusted if postinfection applications are needed. The effect of rainfall on chemical residue is determined by the rule of thumb that

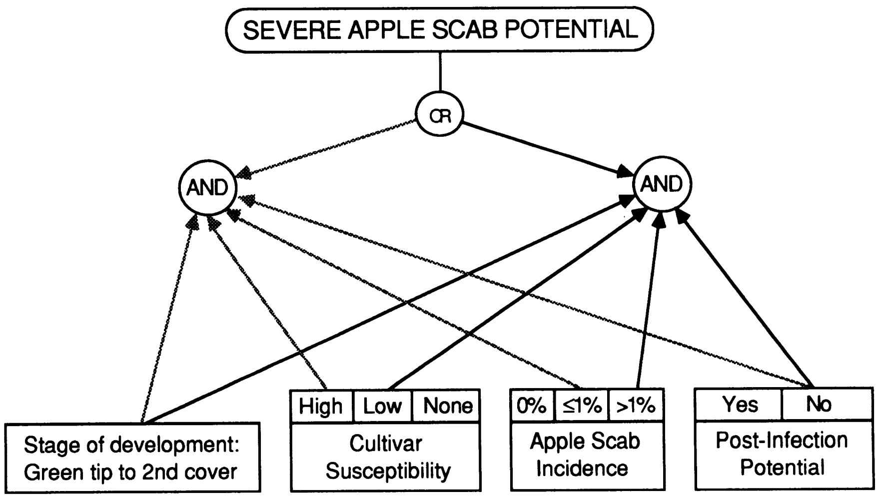

Fig. 4. Dependency network of factors that contribute to severe apple scab potential.

less than 2.5 cm of rain does not affect spray residue, 2.5–5.0 cm reduces spray residues by one-half, and 5.0 cm or more removes all spray residue. Sometimes, early in the season, the next pesticide application is recommended within 5 days of the last if disease potential is low, there was no infection potential since the last application, rainfall was 2.5–5.0 cm since the last application, a DMI fungicide was not applied after an infection period, and an alternate-side application was the last one used. All possible situations that lead to spray intervals are described within dependency networks.

Compatibility and days-to-harvest limitations. Pesticides selected are checked for compatibility before being recommended, and dependency networks describe which chemicals should not be mixed. Chemicals are checked against the computer's calendar to determine the interval between application and harvest.

A Typical Session with PSAOC

From the menu on the start-up screen, the user can gain access to any module. Either the pest management program can be initiated directly from the orchard profile, in which case all profile information will automatically be loaded into the program, or the user is asked whether a profile needs to be loaded. Typically, an orchard contains many "blocks" or "management units" for which management differs slightly. In such a case, each block has its own profile. The user can either choose a previously defined profile or create a new one. The user can look at an individual pest problem or run the IPM module, which considers the entire orchard block as a system and integrates disease and insect recommendations. For the disease modules, PSAOC first determines the disease potential in the block for apple scab, powdery mildew, cedar apple rust, and summer diseases (Fig. 5). PSAOC identifies the fungicides that are available to control scab under the circumstances and asks the user to indicate preferences. Once the user selects the primary scab fungicide, the system lists the compatible fungicides that are

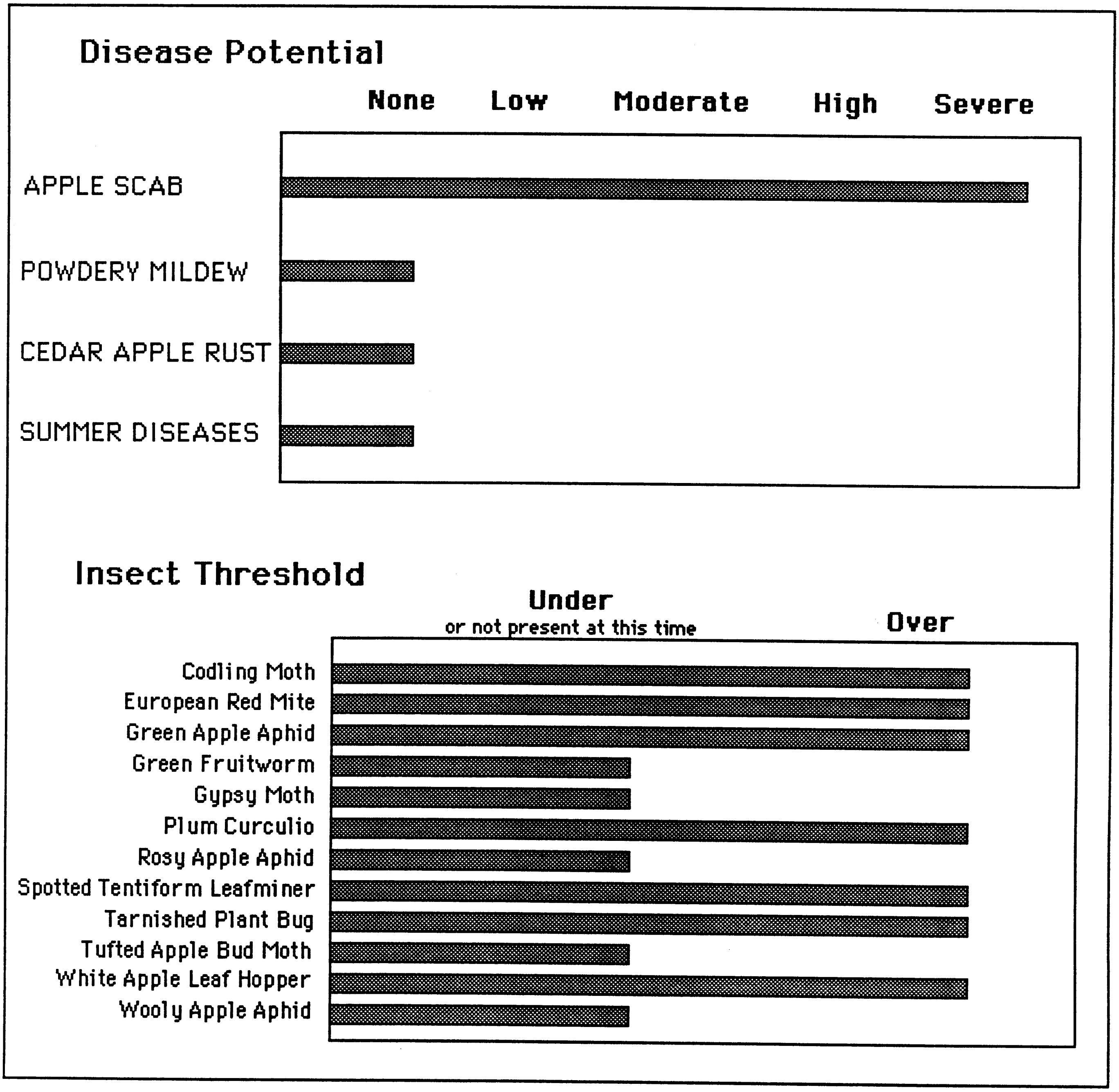

Fig. 5. Graphs displayed by the Penn State Apple Orchard Consultant expert system of the orchard disease potential and insect threshold.

recommended to prevent resistance buildup and provide additional control of powdery mildew or rust, if necessary. Similar questions are asked about mites, insects, and predators.

PSAOC then calls the chemical management module to establish pesticide application priorities. If the mite population is over threshold and predators are not sufficient to control the mites, miticide rates are determined. Insecticides and rates are then determined for the primary (i.e., most damaging) insect over threshold. Users are given the options of selecting a different primary insect pest and, if several insecticides control the primary insect pest, of choosing which one. If the material appropriate for primary insect control is effective for all secondary insects, no other insecticides will be considered. Otherwise, the module determines other compounds and rates to control the secondary insects. The recommendation is then given for each chemical selected (Fig. 6). In addition, spray incompatibility warnings are displayed. If the user opts to select other chemicals, a new IPM recommendation is given. If the user asks for an explanation of the recommendation, PSAOC reviews each aspect of the decision-making process. The user can also request detailed information about any chemical or pest included in the recommendation. The recommendation, explanation, and profile information can be printed.

Adoption of PSAOC

The knowledge provided by the PSAOC pest management module can eliminate unnecessary routine spraying practices. The ecosystem is spared the application of unnecessary pesticides, and the grower realizes an economic savings derived from fewer pesticide applications. Moreover, the yield and quality of the crop are maintained because pest problems are managed with little economic loss.

PSAOC is potentially effective for apple production for at least seven reasons. The system: 1) delivers IPM-derived information and solutions to pest management problems; 2) provides this information in an up-to-date and site-specific fashion unattainable by traditional information delivery systems; 3) is readily available to any grower having access to a computer and the software, relieving dependence on the accessibility of literature or human experts; 4) provides reduced and optimal use of chemicals, thereby reducing the negative impacts of apple production on the ecosystem and human health; 5) teaches the grower IPM procedures and strategies; 6) increases grower profits and enables incorporation of new methods of production management; and 7) enables rapid incorporation of new management practices.

It remains to be seen whether apple producers generally will adopt this agricultural innovation. The adoption of computer technology by growers is predicated on successful linkage between a particular farm operation and the accessibility of new technology (3). These access conditions are determined, in part, by the development of the technology and by private and public diffusion infrastructures. The development of diffusion strategies that consider grower needs and capabilities relative to specific access conditions will accelerate the adoption of these new technologies.

Because of its interactive nature and potential impact on farm decision making, PSAOC was designed with the cooperation of several commercial orchardists, and its impact on farm decisions was assessed during a 2-year field test (12). During regular extension educational meetings in 1988, apple growers were asked to volunteer for on-farm field testing of the expert system. More than 140 growers volunteered to participate in the first phase of the evaluation. Of those, 26 apple growers were selected as a pilot test group. These growers represented the spectrum of apple production characteristics in Pennsylvania, including farm size, geographic location, and experience with computers. These pilot

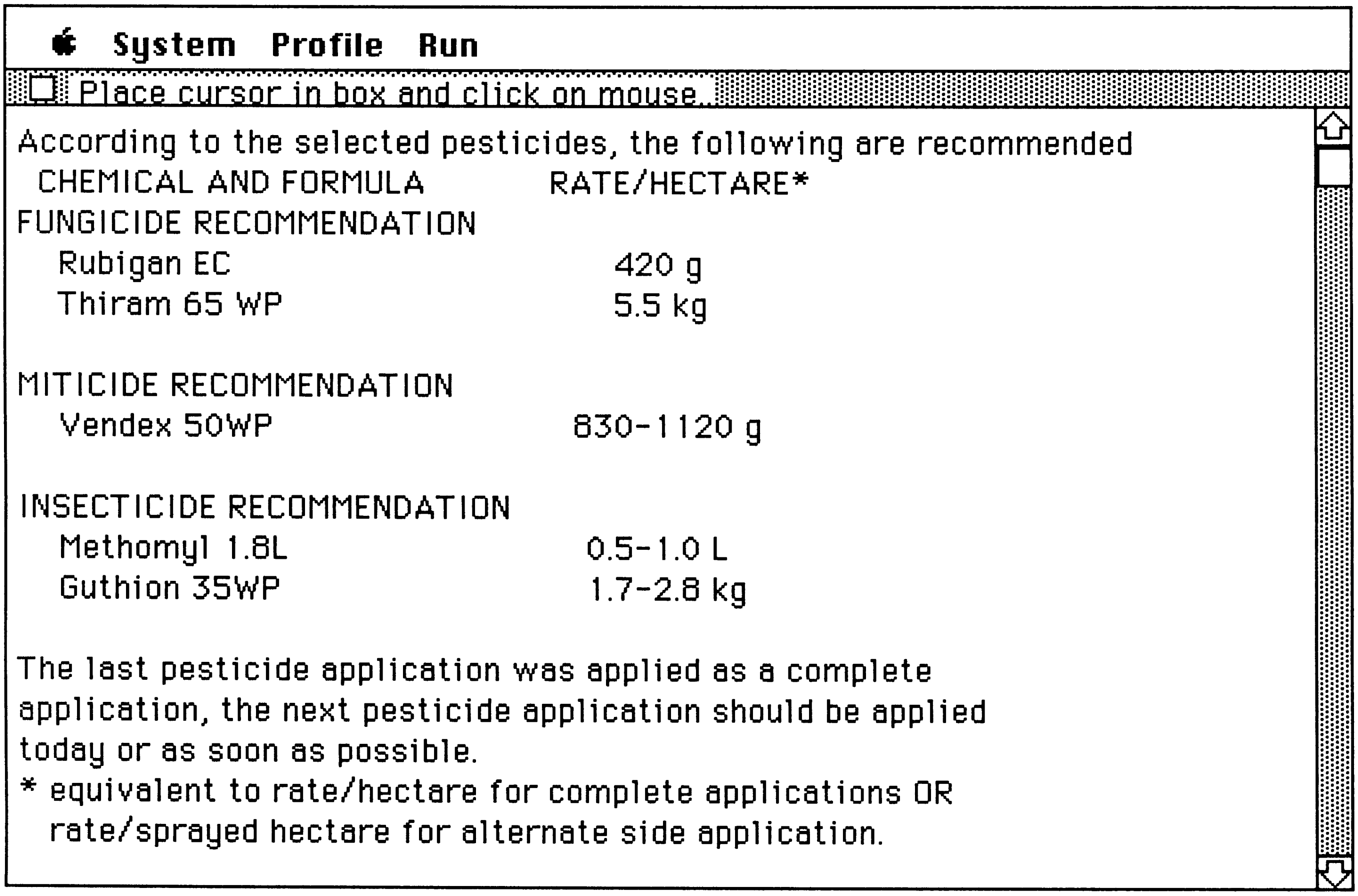

Fig. 6. Pesticide recommendation for an IPM response to disease and insect problems identified by grower and specific to current orchard conditions.

test participants met with the study organizers for a day and were given instructional training and software. Macintosh computers were loaned to 14 growers who did not own computers.

Growers agreed to use PSAOC and to record their experiences, suggestions for improvement, and usage patterns. The data were collected monthly by telephone for an 8-month period during 1988–1989. (For a complete report of results, see Bowser [4] and Rajotte and Bowser [12].)

Table 1 shows two measures of the frequency of use of PSAOC: the total number of times growers accessed the system and the total number of hours they used the system. The first measure shows that 7.7% of the growers did not use PSAOC at all, 53.8% used the system fewer than 16 times in 8 months (two times per month), and 23.1% used it four times or more each month. The second measure shows that 42.3% of the growers utilized the system for 6 hours or less and 26.9% used it for 10 hours or more.

Table 1. Use of the Penn State Apple Orchard Consultant (PSAOC) expert system by 23 apple growers in Pennsylvania in an 8-month period during 1988–1989

Use of PSAOC	Percentage of growers
Total times accessed	
0	7.7
1–9	19.2
10–15	34.6
16–29	15.4
30–110	23.1
Total hours of use	
0	7.7
1–3	26.9
4–6	15.4
7–9	23.1
10–40	26.9

Total use of PSAOC varied widely by year and time of year (Fig. 7). The growers received PSAOC for use in late July 1988, and many accessed the system during August 1988 (73.3%) because they were trying it for the first time. Few used the system during October (34.8%) or November (10.3%) 1988. During 1989, after the growers were able to review PSAOC throughout the winter months, system use was high in the spring period of pest management when wet conditions favor fungal and bacterial diseases and when insect and mite populations are beginning to build and are vulnerable to management actions. System use gradually decreased throughout the summer as need for information declined.

Early in the growing season, growers used the system fewer times but for longer periods than later in the season, which reflects the differences in types of information needed at different points. Early in the season, growers schedule for the season's work and require more intensive and in-depth use of information sources. More important, pest problems (especially diseases) are much more complex in the spring than in the summer, and extracting a recommendation from the computer requires more time. During summer, growers are more involved in crop maintenance and troubleshooting and in double-checking their own knowledge.

Although the number of times PSAOC is accessed shows how frequently the system is being used, the actual amount of time spent using the system may be a more significant indicator of adoption. Growers who use the system primarily to validate their own decisions may report a high number of accesses but a low number of hours. Conversely, growers who more fully engage the logic of the system in their decision-making process or use PSAOC as a teaching device may report fewer accesses but more hours.

Table 2 shows that during the 8 months, 65.2% of the growers made one to three changes in their production practices as a result of using PSAOC. Also, 82.6% reported that the system stimulated them to increase pest monitoring, ranging from once in 26.0% to seven times in 4.4%. Because most pest monitoring is done during April, May, and June, these numbers are more significant when viewed as a subset of the eight monthly observations.

The economic impact of PSAOC on cooperators' operations and net income was estimated in 1989. A questionnaire was developed from the pesticide record and crop history log sheet of a major commercial apple processor to collect data on orchard characteristics, apple yields, and prices, and questions were added to aid comparison of PSAOC users and nonusers. Both groups scouted for mites in the postbloom period, but users tended to monitor for European red mites earlier in the season than did nonusers (Fig. 8), who were less aware of a new prebloom monitoring practice recommended by PSAOC that may reduce pesticide usage later in the season. The 1989 apple-growing season in Pennsylvania was poor, but preliminary results from the survey show that PSAOC users and nonusers had roughly similar yields. Further work is needed for more precise

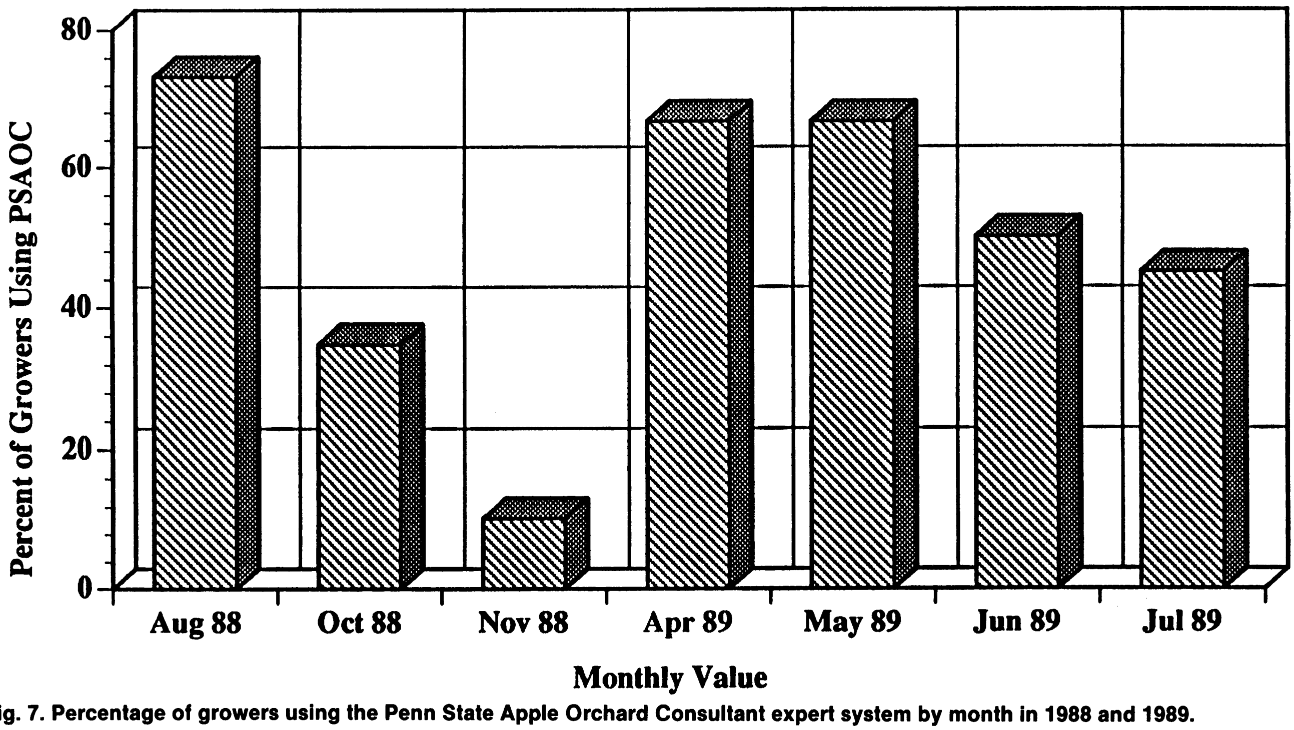

Fig. 7. Percentage of growers using the Penn State Apple Orchard Consultant expert system by month in 1988 and 1989.

determination of the economic benefits of PSAOC.

The evaluation of PSAOC's impact is the first published example of a field test of an agriculturally oriented expert system comparing user and nonuser practices. Two characteristics seem particularly noteworthy. First, PSAOC is primarily an information delivery system. Although it contains production information (such as weather), it requires input of reliable, site-specific information in order to formulate recommendations for the user. The apple producer must form questions and look at problems in a manner unlike that of previous information delivery systems used in apple production. This transition will not occur automatically; some growers indicated that they still do not "trust" the system to make decisions for them. This attitude is appropriate. PSAOC is not a substitute for good management but rather is a source of information to guide and enlighten the grower's decisions. Distrust also could result from incongruence between the grower's perception of the PSAOC "view" of orchard management and the grower's traditional management system. Because information technology in the expert system differs intrinsically from more familiar information technologies, the kinds of practical and educational experience a user has may affect how well the system is understood and adopted.

Second, the expert system is a technology inherently connected to microcomputers. In order for growers to use PSAOC, they must have access to a microcomputer capable of running the system and they must be able to operate the computer proficiently. Although people with little or no computer experience can use the software, growers with the least experience also had the lowest rates of use.

By substituting information for some chemical inputs, the PSAOC expert system can contribute to more sustainable apple production systems in the northeastern United States through introduction of more information-intensive, low-input IPM practices. Traditional production practices change as growers substitute information for purchased inputs, such as pesticides, and the expert system enables users to collect, integrate, and interpret the information rapidly. However, the potential value of this technology will be diminished unless access is linked effectively to the farming operation.

An agency providing new educational programming should train and orient computer use for farming operations in general and agricultural expert systems in particular. Training sessions should be held locally and taught by persons familiar with expert systems and the cropping system being discussed. Training should provide an overview of the gradual modification of existing production systems to incorporate sustainable methods. This training should focus on the needs and responsibilities for reducing pesticide use as well as on the

Table 2. Influence of Penn State Apple Orchard Consultant (PSAOC) expert system on management practices of 23 apple growers in Pennsylvania in an 8-month period during 1988–1989

Changes in practices	Percentage of growers
Number of changes	
0	34.8
1	21.7
2	26.1
3	17.4
Number of times pest monitoring increased	
0	17.4
1	26.0
2	4.4
3	21.7
4	21.7
6	4.4
7	4.4

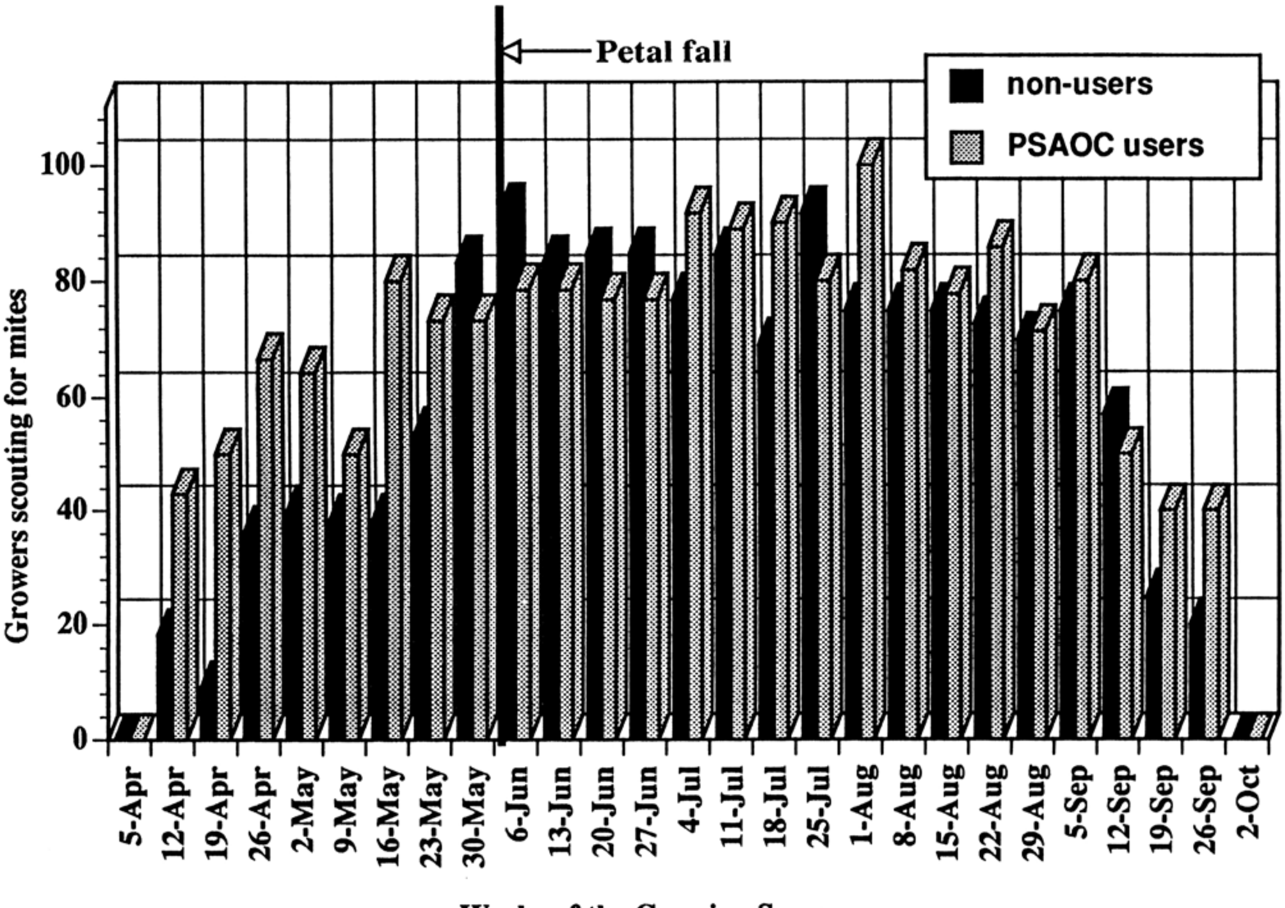

Fig. 8. Percentage of growers scouting for mites among users and nonusers of the Penn State Apple Orchard Consultant expert system, 1989–1990.

long-term benefits at the farm level for doing so. A network of "local experts" could provide a resource for growers experiencing difficulties with the computer or expert system. Continual updating of system capabilities is essential to keeping recommendations scientifically current and appropriate. Training of extension specialists and agents can familiarize them with the possibilities and potentials of the system. The process must begin with delineation of the criteria and goals for modern sustainable agriculture attainable with expert systems as a tool. Scientists can then design production systems for agricultural operations of all sizes that provide flexibility in response to dynamic production conditions, thus enabling the specific recommendations of the expert system to be implemented.

Literature Cited

1. Aldwinckle, H. S. 1974. Field susceptibility of 51 apple cultivars to apple scab and apple powdery mildew. Plant Dis. Rep. 58:625-629.
2. Aldwinckle, H. S., Pearson, R. C., and Seem, R. C. 1980. Infection periods of *Gymnosporangium juniperi-virginianae* on apple. Phytopathology 70:1070-1073.
3. Audirac, I., and Beaulieu, L. J. 1986. Microcomputers in agriculture: A proposed model to study their diffusion/adoption. Rural Sociol. 51(1):60-77.
4. Bowser, T. 1990. Adoption of expert systems by apple growers: A test of a new model. M.S. thesis. The Pennsylvania State University, University Park. 120 pp.
5. Denning, P. J. 1986. The science of computing: Expert systems. Am. Sci. 71:18-20.
6. Hayes-Roth, F. 1984. Knowledge-based expert systems. Computer 17:263-273.
7. Hickey, K. D. 1977. Disease occurrence on three cultivars sprayed with fungicide treatments, 1976. Fungic. Nematicide Tests 32:20-21.
8. Hickey, K. D., Lalancette, L., Jr., and Davis, A. E. 1980. Fungicide performance on three cultivars against scab, 1979. Fungic. Nematicide Tests 35:10-11.
9. Hickey, K. D., and Lewis, F. H. 1977. Scab development on three apple cultivars sprayed with different fungicides. Fungic. Nematicide Tests 32:19.
10. Jones, A. L., Lillevik, S. L., Fisher, P. D., and Stebbins, T. C. 1980. A microcomputer-based instrument to predict primary apple scab infection periods. Plant Dis. 64:69-72.
11. Mills, W. D. 1944. Efficient use of sulfur dusts and sprays during rain to control apple scab. N.Y. Agric. Exp. Stn. Ithaca Bull. 630. 4 pp.
12. Rajotte, E. G., and Bowser, T. 1991. Expert systems: An aid to the adoption of sustainable agricultural systems. Pages 406-427 in: Sustainable Agriculture Research and Education in the Field. National Academy Press, Washington, DC.
13. Travis, J. W., Rajotte, E., Crassweller, R., Hickey, K. D., and Hull, L. A. 1990. Penn State Apple Orchard Consultant. The Pennsylvania State University, University Park.
14. Travis, J. W., Crassweller, R. M., Rajotte, E. G., Hull, L. A., Hickey, K. D., Greene, G. M., Halbrendt, J., Brittingham, M. C., Kelly, J., Hock, W., Heinemann, P., Daum, D., Clarke, G., Harper, J., and Becker, J. D. 1990. Pennsylvania Tree Fruit Production Guide. The Pennsylvania State University, University Park. 160 pp.
15. Yaghmai, N. S., and Maxin, J. A. 1984. Expert systems: A tutorial. J. Am. Soc. Inf. Sci. 35:297-305.

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