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Apple Pest Management Research in Michigan

Fig. 1. Characteristic symptoms of scab on leaves and fruit of McIntosh apple.

Several related events during the late 1960s and early 1970s led to integrated pest management (IPM) for apple at Michigan State University. Because of grower interest in alternative nonpesticidal methods for controlling plant-feeding mites, a state-supported position in insect IPM was created in the Department of Entomology in 1969. Two years later, a national extension project for implementation of apple IPM was funded in the state. This program brought plant pathologists and entomologists closer together in their research and allowed them to collectively monitor the incidence and forecast the severity of several important disease and insect problems. Almost simultaneously, two federal grants targeted to interdisciplinary research were awarded to a team comprised of at least one horticulturist, entomologist, plant pathologist, weed scientist, and systems scientist. Research on interactions among different pest groups—eg, how disease control programs alter insect or mite populations and control, how orchard ground cover management systems influence biological control programs for plant-feeding mites—was given high priority.

A research team focusing on improving apple ecosystem design and management was formed, with strong emphasis on utilizing a systems science approach to solving IPM problems. Systems science methods give researchers a much broader look at the interrelationships between crop production and pest control. The need for using models to identify important areas of research, to design and evaluate IPM systems, and to implement IPM extension programs was stressed.

Environmental and Biological Monitoring—A Key Element

In developing an IPM system for apple in Michigan, considerable emphasis was placed on closely relating environmental and biological conditions in the field to the biology and population levels of major disease and insect pests. Obtaining current information on these conditions and using it rapidly for decision making was considered a key element in improving the overall management system. This approach, termed "on-line control," was put forth initially by Haynes et al (10) and was refined for the apple system through periodic discussions with systems scientists.

Alarm system for scab. Primary apple scab infection (Fig. 1) requires ascospores of the scab fungus (*Venturia inaequalis* [Cke.] Wint.) and sufficiently long wet periods for spores to germinate and infect susceptible tissue. Initially, procedures were developed for obtaining the environmental data needed to identify apple scab infection periods, as determined by Mills at Cornell in the 1930s and early 1940s (14). Hygrothermographs were used to monitor temperature. DeWit leaf wetness meters (Fig. 2) and Small's electronic wetness system (18) were used to monitor the duration of wet periods. In addition, spore traps were evaluated for monitoring the discharge of scab ascospores and for estimating

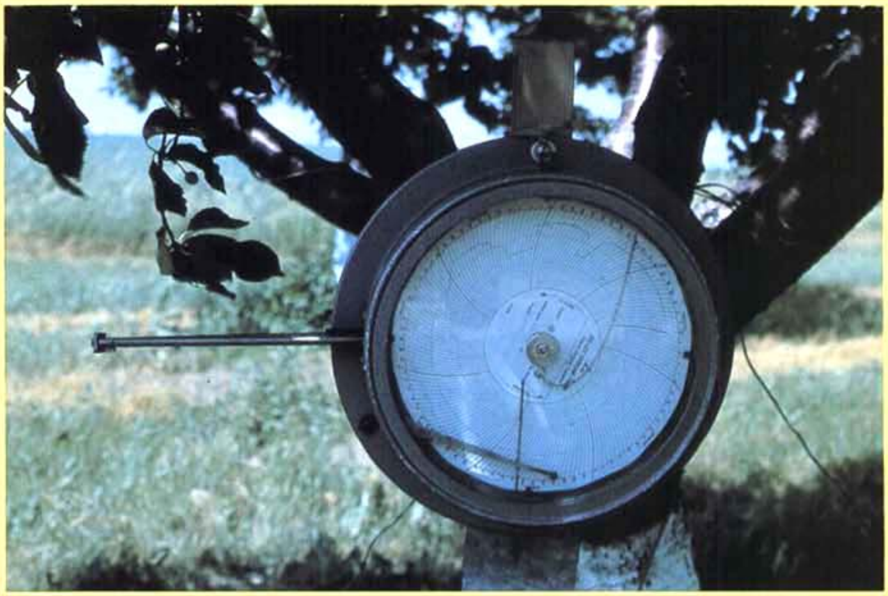

Fig. 2. DeWit leaf wetness meter for monitoring wet periods in alarm system for apple scab.

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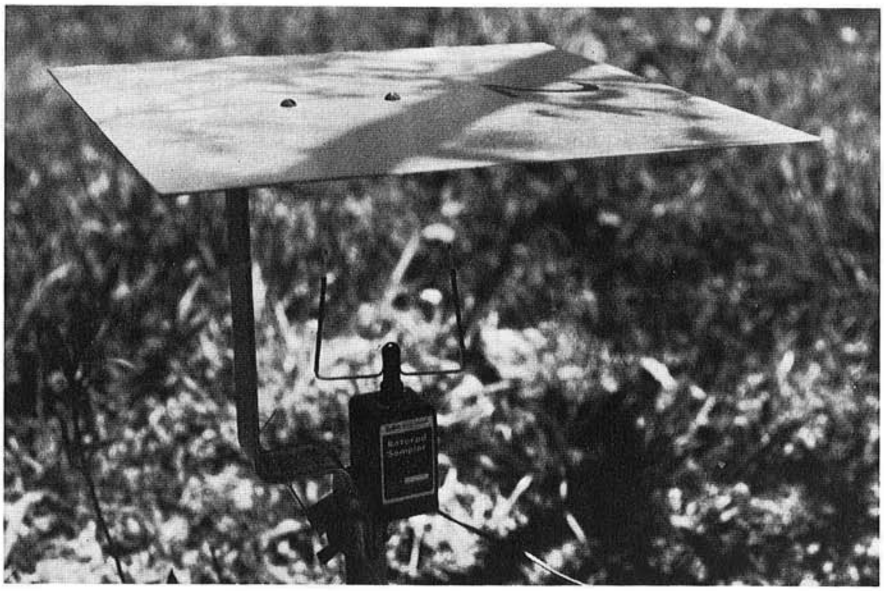

Fig. 3. Rotorod spore sampler for detecting discharge of scab ascospores in apple orchards.

Fig. 4. Tractor-driven duster applying fungicides during rain after prediction of apple scab infection.

ascospore densities in apple orchards (19). Rotorod samplers (Fig. 3) were selected for routine monitoring of apple scab ascospores by pest management assistants. Equipment for environmental and biological monitoring was placed in 12 locations in the Lake Michigan fruit belt.

Results from the monitoring program were disseminated quickly to growers with self-answering telephones (Code-A-Phones) that automatically pass on prerecorded messages from extension personnel in each region. During spring, counters on the Code-A-Phones indicate a large number of calls, especially after rainy periods. The use of Code-A-Phones for delivering pest management information on a regional basis was pioneered by the apple IPM project in 1973. In 1980, about 15 phones were in operation and several cropping systems in addition to fruit were included.

Information on apple scab development and infection periods is utilized by growers for timing the first fungicide application in spring and for deciding when primary inoculum is no longer a problem so spray intervals can be extended from 7 to 14 days and fungicide rates reduced by 25 to 50%. Some growers use monitoring data for timing postinfection or eradicant sprays and for tightening their protective program when weather and inoculum levels are unusually favorable for infection (Fig. 4). Growers are keenly interested in the program because of potential cost savings, particularly where the crop is grown for processing.

Current research on experimental sterol-inhibiting fungicides indicates that their postinfection control and curative properties will reduce the risks involved with apple scab predictive programs.

Mite-monitoring program. Plant-feeding mites were used as a model for studying the design of biological monitoring systems for IPM. The initial sampling methods were developed to determine spatial distributions of pests, variations in population levels within orchards and trees, and the optimal number of samples required for decision making (7). Thereafter, simulation analysis was used to describe the environment's effect on the buildup of mite populations. A simulation model was developed to estimate the potential for biological control in situations where a field-developed model lacked precision. The efficiency of processing mite samples was also examined by equipping a mobile van with standard mite-monitoring equipment, models for optimum sampling and counting efficiency, and telecommunications equipment for accessing the computer model at a central site when more critical analysis was needed (20). Also considered in selecting the best sampling design were variability within field sampling units, intensity of monitoring operations, and risk to growers in using the methods. A general methodological approach to pest monitoring was then developed and evaluated (20).

Pheromone trapping for timing insecticides. Insect traps baited with synthetic sex lures (pheromones) (Fig. 5) were evaluated in several ways for monitoring selected apple insect pests. Critical catch features termed biofixes or biological fix-points are events, such as first emergence and peak emergence, that are closely related to the efficacy of control actions (17). Biofixes were used directly for timing insecticide applications to control adult insects or as synchronizers in models for forecasting subsequent developmental stages of the pests (21). Cumulative trap catches and degree-day values were used to estimate development stages, potential infection levels, and timing of insecticide sprays. Pheromone traps were also used for estimating the density of pest populations and, once a critical population level was detected, suggesting control (16). Threshold levels were developed for the codling moth (*Cydia pomonella* [L.]); when 5–7 moths were caught per trap per week, insecticide sprays were suggested.

Biological Control Measures Include Predatory Mites

Biological control programs for plant-feeding mites have been developed in many apple production states, including Michigan. Similar programs for insects, pathogens, and weeds are not in use on apple, with the exception of reducing the incidence of crown gall with *Agrobacterium radiobacter* strain 84, a standard practice in Michigan tree fruit nurseries. Development of allopathic cover crops to control weeds in orchards is progressing rapidly, however, (15) and the feasibility of using biological agents to control powdery mildew, aphids, and leafhoppers is being studied.

The initial approach to IPM in Michigan apple orchards centered on 1) plant-feeding mites and their predators and 2) pesticides that were not toxic to beneficial species (1,5). Predatory mites, particularly *Amblyseius fallacis*, were found to control spider mites in grower orchards, provided the management program ensured their survival. In cooperative studies conducted over 5 years, the selection of fungicides to control apple scab or powdery mildew often determined the success or failure of biological mite control programs. For example, predatory mites failed to become established in orchards sprayed with benomyl. Standard laboratory tests indicated benomyl was not toxic to the active stages of predatory mites, but more critical studies showed that egg hatch and reproduction of mites were substantially reduced by benomyl treatment. Because predatory mites did not move into apple trees until early summer, fungicides toxic to the mites were used to control primary scab, then nontoxic fungicides were used to control secondary scab and powdery mildew (1).

Experiments in collaboration with weed scientists showed that killing wide strips of vegetation under apple trees with herbicides reduced movement of predatory mites from the ground cover into the trees (Fig. 6). By reducing the width of control strips and leaving some vegetation around the tree trunks, movement of predatory mites into the trees was increased and biological control improved.

Detection of fungicide resistance and development of some interesting approaches to management of mite pests with insecticide-resistant natural enemies were outgrowths of the IPM effort in Michigan. Early detection of benomyl resistance in the apple scab fungus (13), followed by less intense use of the compound, no doubt lengthened the effective life of benomyl in the United States and in many instances saved growers from extensive losses. Resistance developed rapidly after 2 years of severe scab pressure and exclusive season-long use of benomyl by many Michigan growers. Strains of *V. inaequalis* resistant to both dodine and benomyl were also detected. The propensity of *V. inaequalis* for developing resistant strains when under extreme selection pressure with specific-site inhibiting fungicides suggests that populations of the pathogen should be monitored closely for possible changes in fungicide sensitivity when the sterol-inhibiting fungicides are introduced for scab control.

Some of the first attempts to utilize insecticide-resistant phytoseiid mite predators were made in Michigan (2), either by managing native species or by releasing and establishing the mites in areas where they did not occur naturally or resistance had not developed. Resistance allowed predators to survive otherwise toxic insecticide treatments and helped to maintain the predator:prey ratios necessary for successful biological control (1). Because organophosphate resistance has not been reported for any of the major insect pests of apple but is widespread among many secondary pests and is increasing among their natural enemies, continued use of organophosphate insecticides is recommended to control key insect pests and maintain several biological mite control programs (3,4). Careful monitoring for organophosphate resistance in species such as the codling moth is critical. Croft and Hoyt (4) propose only limited use or a careful phasing in of the new pyrethroid insecticides because they are highly disruptive to biological mite control programs and may have a propensity for selecting resistant strains of key pests in the field (4).

Prototype Models for Apple Pests

In the late 1960s and early 1970s, several groups of engineers and biologists at Michigan State simultaneously developed interest in applying systems science concepts to applied pest control problems (6). The earliest work focused on modeling the cereal leaf beetle (*Oulema melanopus*), but the next prototype systems were apple pests: the European red mite (*Panonychus ulmi* Koch), the codling moth (*C. pomonella*), and apple scab (*V. inaequalis*). These models have served as foundation research for what is expected to be a relatively complete model-based system for apple IPM.

European red mite. Plant-feeding mites are secondary pests of apple, and of the three important species in Michigan orchards, the European red mite is the most common. Often these pests are controlled by the insecticide-resistant predatory mite *A. fallacis* (Fig. 7), provided growers use selective sprays for controlling other pests of apple (5).

In the early stages of a biological control program, growers must decide if a special miticide spray is needed for adjusting predator:prey ratios. A population dynamics model was developed to assist growers in making this decision. The discrete-time model quantitatively tracks the development of five life stages of both mite species in the orchard at 1-day steps (8). Each species model contains features of development, consumption, oviposition, and mortality. The model's spatial component mimics the predator-prey interaction process and describes how biological control occurs in orchard trees. The model has been implemented with computer-generated charts that indicate control actions pest managers might use. For specific control suggestions, the model can be run interactively with current weather data.

Codling moth. The codling moth is a key pest of apple that can be tolerated only at levels below 1% infested fruit at harvest. A relatively simple phenology timing model was developed for predicting precise timing of population development based on environmental information and field population data taken from pheromone traps. The basic biological components and data requirements for this type of model were determined (15). Since the initial model was constructed, a generalized timing model for many apple insect species was developed and given the acronym PETE, from *P*redictive *E*xtension *T*iming *E*stimator System (21). PETE allows researchers to construct developmental models for crops, pests, natural enemies, etc., by supplying a minimum set of biological parameters, including developmental rates, temperature thresholds, initial maturity distributions, oviposition functions, and population variance components. To date, the PETE system has been used to develop timing models for the San Jose scale, tufted apple budmoth, redbanded leafroller, obliquebanded leafroller, codling moth, oriental fruit moth, white apple leafhopper, and tentiform leafminer. Currently, these models are being validated and additional apple pest timing models are being developed. The PETE system has been validated in several fruit-producing states (eg, California, New York, North Carolina, Oregon, Utah, Washington) and has been proposed as the basis for a national apple insect forcasting system. It has also been applied to apple, pasture, rice, and corn pests in other countries with good success.

Fig. 5. Insect trap baited with pheromones helps establish timing of insecticide sprays.

Fig. 6. Killing wide strips of vegetation under apple trees reduces movement of predatory mites into trees and lessens chances for biocontrol of plant-feeding mites.

Apple scab. Apple scab is an excellent example of a disease where the timing of control measures is based on knowledge of the disease cycle. Mills' system for predicting infection based on hours of wetting and average temperature during the wet period continues to be used by apple growers in many parts of the world. However, much is known about the development of apple scab that is not reflected in the infection curves of Mills (14). A computer simulator for apple scab was developed to provide a logical framework around which to organize the bits and pieces of biological information found in published works and relevant to the prediction of apple scab. Although too complex for use as a management model, the model pinpoints several areas of research needed to improve scab prediction. James and Sutton (the latter is one of the authors of the apple scab model) have made rapid progress on a model to predict the development of scab perithecia during the winter (11), a major component missing in the simulator. At Michigan State, a modified scab model was combined with a microcomputer for use on individual farms to identify scab infection periods and predict disease severity (12).

Plans for increasing the model base for apple IPM include: 1) expanding PETE to include all major insect pests of apple, 2) incorporating disease models into the system, and 3) implementing the models more fully with appropriate computer-based delivery systems. Currently, both of us are involved in a national EPA/USDA-sponsored project to develop IPM systems for major crops. Apples, cotton, alfalfa, and soybeans are the four prototype systems being studied. Work on the project is also being done in New York, Pennsylvania, North Carolina, California, and Washington. In Michigan, the effort currently involves plant pathologists, entomologists, weed scientists, horticulturists, agricultural economists, and systems scientists.

Implementation Delivery Systems: Central, Distributed, Single

To facilitate development of apple pest management at Michigan State University, a central computer-based IPM implementation delivery system was devised in the mid 1970s. This executive implementation delivery system (PMEX) included computer programs for utilizing communication features, weather gathering and data summarizing programs, pest survey information, and means for handling predictive models. Remote send-receive terminals and telephone playback devices used in combination with the central computer processing programs constituted the communication network.

The centralized PMEX system was widely evaluated in the state by nearly 100 users, including extension specialists, county agents, pest managers, and growers. Some 6,000–9,000 accesses of the system were made annually. Developmental costs were about $90,000 and annual operational costs, about $25,000. Benefits of the program included rapid, two-way communication of IPM information, direct interrogation of computer-based data and models, and faster response to field problems. Some problems encountered were limited reliability and availability, excessive size of the computer for some operations, and high communication costs (6).

Because of these constraints, a second-generation IPM delivery system based on a network of smaller distributed computer processors was begun in the late 1970s (6). This system is based on a variety of linked computers (eg, minicomputer, microprocessors, calculators) that serve several levels of operations, including national ↔ statewide ↔ regional ↔ countywide ↔ farm, for IPM and other types of agricultural management. Although the system is still in the initial stages of development, many drawbacks of the centralized system have already been eliminated and the ability to serve IPM needs at each level has been improved.

Advances in electronics led to research on automated electronic predictive instruments for apple growers. Specifically, Fisher et al (9) designed a general-purpose microcomputer-based instrument that collects and analyzes in-field weather data, makes on-site infection predictions for apple scab, and forecasts the hours remaining to achieve eradicant control with each of five fungicides (Fig. 8). Instructions for monitoring the weather and identifying infection periods are contained in a computer model stored in the instrument. In field tests, the microcomputer accurately identified apple scab infection periods (12). Control of apple scab with eradicant fungicide sprays timed with the instrument was comparable to that with a protective schedule of the type used commercially in Michigan. In each of 3 years, fewer sprays were required with a program scheduled with the microcomputer than with standard protective schedules, with no loss in control.

Models to predict apple scab infection, powdery mildew severity, codling moth development using PETE, and phenological development of apple trees are being integrated into a single instrument. As the library of programs is expanded, the instrument will accommodate a wider variety of pest management applications.

Fig. 7. Predatory mite attacking European red mite.

Fig. 8. Microcomputer in apple orchard is programmed to identify apple scab infection periods and to time fungicide sprays.

Total Crop Production System: From Preplanting to Consumer

In the past, integration of new control methods or tactics, such as a new fungicide, into commercial apple production was the responsibility of the appropriate pest discipline. How the method was used was largely left up to the grower. The IPM concept brought recognition of the need to better relate new control strategies with current production practices, but crop production scientists outside the pest control disciplines often had limited input into this process. If current trends continue, the next 10 years will see crop production scientists and pest managers working much closer together, not only on pest control problems but also on other crop production problems.

At Michigan State, several groups of scientists have developed an interest in total crop production systems. As a beginning, scientists working on deciduous tree fruit production have defined a typical tree fruit production system from before trees are planted through distributing and marketing the crop to consumers (Fig. 9). The model focuses on efficient and economic utilization of energy and minimal disruption of environmental quality. After particular resource needs are identified, discipline-oriented researchers interested in orchard design, pest management, equipment systems, fruit storage, processing, marketing, etc., can consider ways for balancing costs and energy first at the production level rather than at specific subcomponents. The result may be adoption of a costly or energy-consuming practice at one level but a net reduction in cost or energy throughout the system. Understanding where and how these factors interact could determine the direction of the fruit industry over the next 15 to 25 years.

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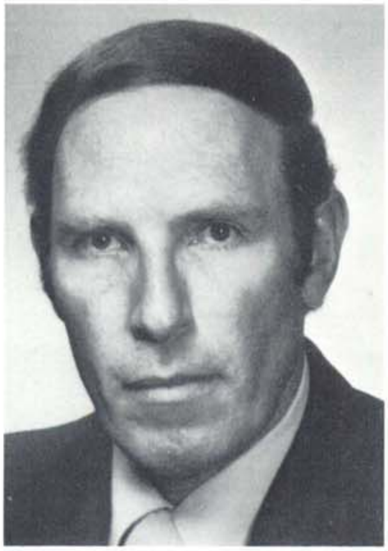

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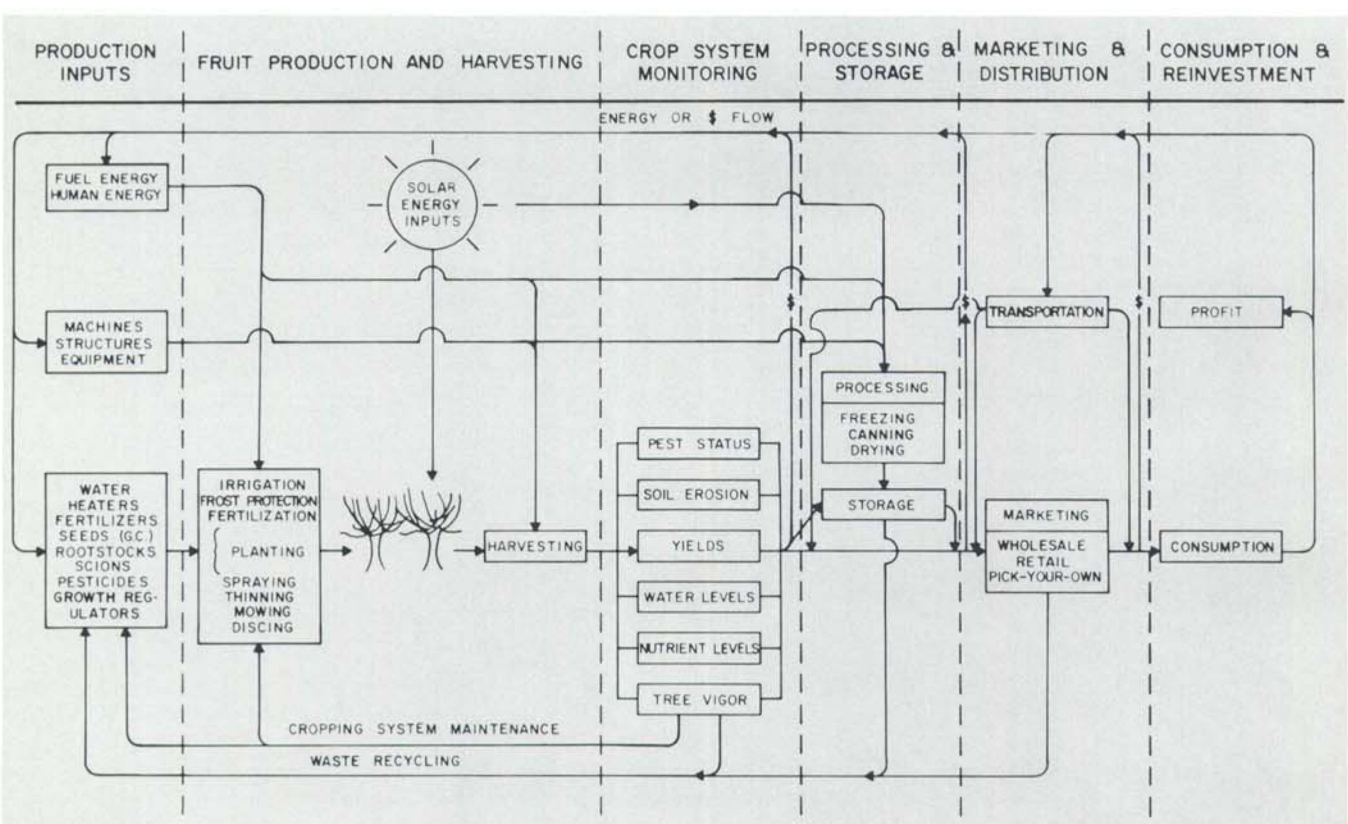

Fig. 9. Conceptual model of deciduous tree fruit production system, with energy and cost components flowing through various levels.

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