Integrating Management Decisions for Several Pests in Fruit Production

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Few farmers are so fortunate as to grow crops threatened by only a single pest. Most plant pathologists are somewhat more fortunate in that they have the relative luxury of focusing their research on one pest system at a time. Single pest systems provide scientifically satisfying work and can be professionally rewarding. Interactions among the pest, crop, and environment can be studied in detail, and eventually a program that optimizes control of the pest may be developed. In grape and apple pest management, several environmentally driven models have been developed independently to forecast maturation and discharge of inoculum, infection, sporulation, and secondary increase by many of the major pathogens (3,4,11,12,14,16). There are far fewer examples of unified programs for the simultaneous management of multiple pests.

In the inception of a program to manage a single pest, the targeted pest is usually considered apart from the complex of pests that may threaten the crop. This allows the researcher to focus on the development of a program that optimizes control and perhaps minimizes pesticide use against the pest under investigation. This focused effort, of course, speeds the progress of the investigation and publication of the results and may provide a better understanding and management of the single pest. However, when dealing with fruit crops where pesticides may be intensively used against several different pests, it is difficult to manipulate individual pest populations

Presented 18 August 1991 for the symposium "Food and the Environment: IPM Meets the 21st Century" at the annual meeting of the American Phytopathological Society, St. Louis, Missouri.

Accepted for publication 2 November 1992.

as if they were discrete units rather than parts of a complex of many pests. This is where the difficulty generally occurs in applying the programs developed for single pests to production of crops attacked by several pests.

Unless unified programs are developed to simultaneously manage multiple pests, or the single-pest programs are adapted to work within existing commercially used practices, there may be very little change in pest management programs outside of research plots. For example, there has been a considerable research effort expended to forecast primary infection periods of the apple scab pathogen, *Venturia inaequalis*. A number of schemes have been developed to time postinfection fungicide sprays on the basis of forecasted infection (11,13,14). By adopting such programs, a 50% reduction in the number of fungicide applications can often be demonstrated over a protectant spray program. However, such a program is maddeningly difficult to apply to the multiple pest system in apple orchards of the northeastern United States (5). For example, if an apple scab infection period occurs at the pink stage of fruit bud development, the postinfection fungicide must be used within 96 hr for *optimal* results. However, the timing of this fungicide application may not coincide with an oil spray required for *optimal* control of mites, or an insecticide for *optimal* control of tarnished plant bug, apple blotch leafminers, or spotted tentiform leafminers. The sterol-inhibitor fungicide that must be used for postinfection control of apple scab will not provide *optimal* control of calyx end rot (11).

Difficulties in integrating pest control schedules develop because the timing of pesticide applications to control a particular pest is often based on unique criteria designed to optimize control of that pest. As control measures for each pest have been refined, the timing of control measures has become more critical, compounding the problem of integrating control measures for multiple pests.

A Program for Apple Pests

A unified program was developed for apples in the northeastern United States that offered a greater degree of flexibility in timing pesticide applications (5). An important feature of the program was the integration of the control programs for the various insects and diseases (5). The program had three major objectives: 1) reduce to a minimum the number of pesticide applications per season by timing pesticide applications to control the complex of economically important pests present at certain key times during the growing season, 2) maintain or exceed current levels of insect and disease control, and 3) when practical, use forecasting and monitoring systems to increase the lead time for control decisions and actions.

Figure 1 (5) depicts the major pest complex for apples in the northeastern United States, and the knowledge represented is an important component of the management program for apples. It is very useful to know when the pests enter and leave the system and also what the relative numbers of the pests are at various times during the growing season. Surprisingly, this is not known in sufficient detail for many of the major pathogens of fruit, and our ignorance in this area often limits our ability to construct such a figure with great confidence in its accuracy.

As an example of how the pest complex was managed before bloom, consider that prior to the tight cluster to pink stage of fruit bud development, pesticide applications are directed solely at apple scab. Eliminating these early-season sprays would provide an opportunity to maximize the control of multiple pests with a single pesticide application at tight cluster to early pink (Fig. 1). Recently, it was reported that prepink fungicide sprays for apple scab were not needed if inoculum dose in the orchard was below a critical level and that this level was rarely exceeded in commercial orchards (4,5). A fall assessment of apple scab incidence and severity provided the information on whether that critical level was exceeded or not. If it was not, then all of the prebloom pests were controlled in a single application (a fungicide plus other necessary pesticides) between the tight cluster and pink growth stages. The exact composition of the materials applied was determined by: 1) regional severity of a pest or disease, 2) scouting for and trapping of pests, and 3) host susceptibility. The key to the success of the program was the identification of crucial periods when a single action had the potential to control multiple pests. Other opportunities for integration of disease and insect control occurred throughout the growing season (5). Cooperating growers in New England and New York who follow the described management program, or a similar program described by Wilcox et al (18), use approximately four to seven pesticide applications per season to control the entire pest complex in apples. There has generally been a substantial (about 30–50%) reduction both in the number of applications and in the total kilograms of pesticide used per hectare in the first year that growers adopt one of these management programs.

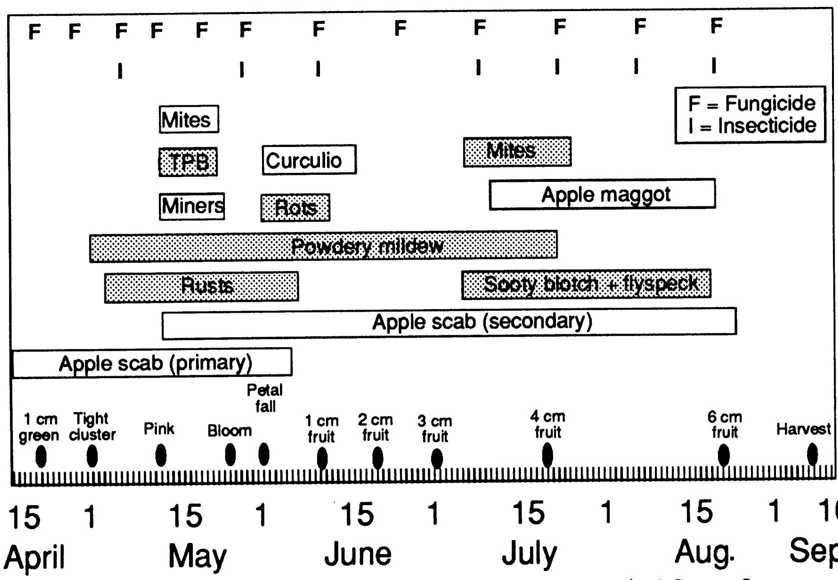

Fig. 1. The major pest complex for apples in the northeastern United States. Letters at the top indicate the approximate timing of pesticide applications in a conventional protectant spray schedule. Each bar indicates the period during which a pest is usually controlled, although the pest may be present at times other than indicated. White bars are for pests that are routinely controlled in most orchards, and shaded bars are for pests whose presence at damaging levels varies with location or year. Fruit phenophases are approximations for the cultivar McIntosh. (Adapted from Figure 6 in Gadoury et al [5])

A Program for Grape Diseases

In New York, the few insect pests that pose a serious threat to grapes are easily addressed through nonpesticidal means (1) or through the inclusion of an insecticide in a summer fungicide application (10). A unified program for the management of the major diseases of grapevine in New York was developed from earlier research (7) on the simultaneous management of grape powdery mildew, caused by *Uncinula necator*, and black rot, caused by *Guignardia bidwellii*. These two diseases at first appeared to be quite different. Powdery mildews are xerophytic, and rainfall was supposedly detrimental to disease development (16). Black rot was favored by high rainfall and extended leaf wetness (16). One disease is caused by an obligate parasite that is almost wholly external to the host; the other is caused by a facultative parasite that causes an internal rotting of the fruit. The black rot pathogen overwintered in mummified fruit; the powdery mildew pathogen was thought to overwinter as mycelium in dormant buds (16).

However, *U. necator* was not overwintering in buds in New York (15). It was instead surviving as cleistothecia on the bark of the vine (6). Furthermore, these cleistothecia released their ascospores and infected during rain events, at nearly the same time of year and under the same environmental conditions as the black rot pathogen was releasing its ascospores (2,8,9,16). Thus, two of the major grape pathogens appeared to be quite similar in the seasonal maturation of primary inoculum and in the environmental conditions for inoculum release and infection. We developed a set of simple rules to define the criteria for infection by either pathogen. Both pathogens were released by rain events, but *U. necator* required at least 2.5 mm of rain for release and temperatures above 10 C for successful infection (8,9). The rules then became rainfall of 2.5 mm or more with temperatures above 10 C for a powdery mildew infection period and any amount of rain with favorable leaf wetness and temperature for black rot infection. An infection period by either pathogen would require control through the application of a fungicide. The fungicide we used was myclobutanil, which inhibited a demethylation step in sterol biosynthesis. Myclobutanil was active against both powdery mildew and black rot and was effective if applied within 96 hr of a black rot infection. It also provided up to 14 days of protection against black rot and powdery mildew infection. No information was available at the start of the experiments on how myclobutanil would work as a postinfection material against ascospores of *U. necator*, but we assumed it was equal to the postinfection activity demonstrated for black rot.

The prototype program was to start at the 2.5-cm stage of shoot growth, because that is when the first primary inoculum for powdery mildew and black rot was available (7,15,16). Once an infection period for either black rot or powdery mildew occurred, myclobutanil was applied within 96 hr. For 14 days thereafter, a vineyard was protected from subsequent infection events. After the 14 days had elapsed, the vineyard was again treated within 96 hr of the next infection period, and this cycle continued for the remainder of the season.

The program provided complete control of powdery mildew and black rot on the cultivar Aurore, with a 40% reduction in the number of fungicide sprays compared with the conventional protectant program. However, downy mildew defoliated the vineyard shortly after harvest in 1989. The defoliation occurred because we had ignored control of downy mildew, which is not affected by myclobutanil. The reported tolerance of this cultivar for downy mildew may have been largely due to the use of broad-spectrum protectant fungicides in programs for black rot. Fortunately, this defoliation occurred after harvest, and there was no yield loss, but this defoliation could affect bud survival and productivity the following year and would not be tolerated in commercial grape production. It provided a lesson for us in the risks of optimizing control for two out of three diseases.

The next step in the evolution of the grape disease management program was to integrate control of downy mildew within the framework of the existing program. This would be a necessary step if the program was to be expanded to include cultivars that were highly susceptible to downy mildew. Several obstacles existed, not the least of which was the spectrum of activity of the available fungicides. Myclobutanil and similar sterol demethylation-inhibiting fungicides are ineffective against downy mildew. There also are no postinfection fungicides for downy mildew registered for use in the United States. The modifications would therefore involve the use of a protectant fungicide active against downy mildew. The question was, how could we best use this material without sacrificing the gains made in the integration of the black rot and powdery mildew programs? One option was to routinely include a protectant material for downy mildew in all of the postinfection applications for powdery mildew and black rot, and this was done in 1990. The program resulted again in excellent control of powdery mildew and black rot with a reduced number of fungicide applications and controlled downy mildew as well. However, observations of disease progress on untreated vines indicated that many of the fungicide applications did not contribute to control of downy mildew.

Several important changes were made in the program for 1991. The changes were based on the following observations: 1) Records of oospore maturity and disease occurrence indicated that initial downy mildew infection occurred approximately 1 mo later than initial black rot or powdery mildew infection; 2) 3 yr of trials indicated that black rot did not increase in vineyards when the fungicide program was halted so long as the disease was held at trace levels until shortly after fruit set; and 3) the same trials indicated that after fruit set, powdery mildew increased rapidly on foliage in the absence of fungicidal suppression but increased slowly on fruit. In fact, we determined the rate of increase for several grape cultivars, and we can use these rates to estimate the probable levels of disease at future dates from the disease levels on the current day, with or without suppression of disease. The rainfall threshold for initiation of a black rot primary infection period also was increased from 0.25 to 2.5 mm, on the basis of a report that rainfall in excess of this amount was associated with major releases of ascospores of *G. bidwellii* (2).

A review of historical weather data, disease occurrence, host susceptibility, and periods of inoculum maturation and release by the pathogen complex indicated that postinfection fungicide sprays would be most appropriate for combined control of powdery mildew and black rot early in the season, prior to bloom and the initial maturation of oospores of *Plasmopara viticola*. During this period, the timing of fungicide applications would be driven by the need to control black rot and powdery mildew. Thereafter, there would be a brief transition period near bloom during which all three diseases must be controlled. This would require the inclusion of a protectant material for downy mildew in any postinfection application that occurred during the transition period. After fruit set, the emphasis of the program shifted to the timing of protectant fungicides for downy mildew control. The lack of any postinfection fungicide for downy mildew required that applications of a protectant fungicide be aimed at forecasted periods of sporulation of the pathogen (12) rather than infection. This might have entailed some additional risk, because the interval between sporulation and infection can sometimes be a matter of only a few hours (12,16). However,

Table 1. Control of powdery mildew, black rot, and downy mildew on Aurore grapevines in 1991 by protectant fungicide sprays and by fungicide applications timed according to a program for management of multiple diseases

	Infected leaves per shoot			Percent clusters with berry infection		
Treatment[y]	Powdery mildew	Black rot	Downy mildew	Powdery mildew	Black rot	Downy mildew
Protectant	0.24 a[z]	0.05 a	0.02 a	0.0 a	0.0 a	0.0 a
Management	0.48 a	0.01 a	0.40 a	0.0 a	0.0 a	0.0 a
Unsprayed	1.57 b	1.15 b	0.02 a	0.0 a	60.8 b	0.0 a

[y]Protectant treatments were applied on 14 and 28 May, 11 and 26 June, and 12 July. Under the management program for multiple diseases, fungicides were applied following infection periods for powdery mildew and black rot on 14 May and 5 June and a sporulation period for downy mildew on 8 July.

[z]Values within columns followed by the same letter do not differ significantly at $P = 0.05$.

we believed that the protection provided against secondary infections would be sufficient to prevent an epidemic of downy mildew, and forecasting sporulation allowed treatments to be witheld during environmental conditions when there was no activity by the pathogen. On the basis of previous studies, black rot was no longer a threat to the crop if controlled prior to fruit set, and no further action was taken against this disease. Powdery mildew was controlled by the inclusion of sulfur in the sprays directed against downy mildew. Although less effective than myclobutanil against powdery mildew, sulfur is sufficiently effective to hold the disease to tolerable levels on the foliage and to trace levels on the fruit. The fruit then rapidly becomes resistant to powdery mildew as it accumulates sugar in late summer (16). The change to sulfur fungicides also is desirable to decrease selection for resistance to the sterol demethylation-inhibiting fungicides.

The program required that growers have some capability to monitor rainfall, leaf wetness, and temperature within a vineyard, and there are many commercial units available that can perform these functions. Each commercial cooperator in New York has been provided with a microprocessor-based instrument (Envirocaster, Neogen Corporation, Lansing, MI) to collect and process these data. Growers are trained in the operation of the instrumentation and in making the rule-based decisions on fungicide applications from the weather data.

In 1991, the current version of our management program provided control of powdery mildew, black rot, and downy mildew that was equivalent to a conventional program of five protectant fungicide applications on the cultivar Aurore (Table 1). The equivalent control was achieved with three fungicide applications that were targeted to control the three major diseases. Similar results were obtained in five commercial vineyards of *Vitis labruscana* 'Concord'. The management program is presently being evaluated in commercial vineyards of *V. vinifera* 'Riesling', which is more susceptible to powdery mildew and downy mildew than Aurore or Concord. Limited implementation (six commercial vineyards) of the program was begun in 1992 by Cornell University and the New York State Integrated Pest Management Program.

Summary and Conclusions

Common ground exists between the programs developed for multiple diseases of apple and grape. First, both programs require that the major parts of the pest complex be sufficiently understood so it can be stated with certainty when each pest enters and leaves the system. Second, a substantial amount of basic and applied research was needed to develop the rules that are the foundation of each system. Ironically, the resulting rules, although utilitarian, may appear simplistic. Consider that 4 yr of research on the physiology of ascocarp dehiscence and ascospore release in *U. necator* (8,9) produced the following rule: Ascospores are released and infect following 2.5 mm of rain between bud burst and bloom if temperatures are above 10 C. A similar simplistic but useful model was the result of several years of investigation on the influence of inoculum dose on apple scab epidemics (4,5).

While the rules that form the framework of unified programs for multiple pests may be simple, the integration of the rules to synthesize a management program for multiple pests may be more complex. Expert systems (17) that can be run on personal computers have great potential in the application of management programs for multiple pests. However, expert systems will not synthesize a unified management program for multiple pests; they will only facilitate the delivery of such a system once it is reduced to a base of rules (17). Not all unified management programs will require sophisticated technology or equipment. In fact, many of the components of our programs for apples and grapes can be implemented with only a simple rain gauge and a maximum-minimum thermometer.

For several aforementioned reasons, researchers usually investigate single diseases of a crop in isolation from other diseases of the crop. The details of these investigations are critical components of unified management programs for multiple pests. However, the assembly of the components is an area that merits more attention than is reflected by the scarce examples of such programs. Eventually, specific models and recommendations must be reconciled to multiple pest systems if they are to have a positive impact on agriculture. It is not realistic to expect growers or advisors to synthesize a control program from the output of several separate models or sets of recommendations for several separate diseases.

ACKNOWLEDGMENTS

The research on apple scab was conducted in collaboration with William E. MacHardy of the University of New Hampshire and David A. Rosenberger of Cornell University. Roger C. Pearson and Robert C. Seem of Cornell University and Eun Woo Park of Seoul National University were collaborators in the work on management of multiple diseases of grapevines. Financial support for the research on apple scab was provided by the USDA-CSRS Special Grants Program NE-156. Research on grape disease management was supported by the New York Wine and Grape Foundation, the New York Grape Production Research Fund, the Kaplan Foundation, the New York State Integrated Pest Management Program, and Neogen Corporation.

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