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# Integration of Pesticide Application Schedules for Disease and Insect Control in Apple Orchards of the Northeastern United States

Apple growers in the northeastern United States face a formidable array of pests. Couple this diversity of pest problems with a low tolerance for blemishes on top grades of fresh fruit and it should be no surprise that apples are one of the most intensively sprayed crops in the United States. In the last 15 years, the concepts of integrated pest management (IPM) in apples have been widely discussed and promoted. Significant progress has been made, most notably in entomology in pest monitoring and establishing action thresholds for control measures (generally pesticide sprays) and in plant pathology in adjusting application schedules to more accurately reflect exposure to inoculum. The recently introduced sterol biosynthesis-inhibiting fungicides promise improved postinfection, antisporulant, and eradicant activity against some of the most important apple diseases: apple scab, powdery mildew, and cedar apple and quince rusts.

Improvements in control programs for a single pest are often more impressive in research reports than in commercial orchards, however, because of our inability (or reluctance) to deal with the entire array of pests and diseases as a complex (as a commercial grower must deal with them) rather than as discrete units that can be manipulated without regard to other parts of the complex. For example, a disease management program initiated in New Hampshire in 1977 stressed the use of weather and pathogen monitoring and used the Mills infection period table (9) to schedule postinfection sprays to control apple scab. This approach resulted in a 30–50% reduction in the number of fungicide applications made to control apple scab. Grower enthusiasm over the reduced number of applications was dampened, however, by the frequent need to choose between the optimal timing of postinfection sprays for apple scab and the timing of a much needed spray for another disease or insect.

Clearly, IPM control measures for specific disease or insect problems must be integrated into the overall pest control and orchard management program before commercial growers can be expected to adopt the strategies. To provide a framework to achieve this goal, we begin with the following objectives:

1. Reduce to a minimum the number of pesticide applications per season by optimizing the timing of 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.

3. Insofar as practical, use forecasting and monitoring systems to increase lead

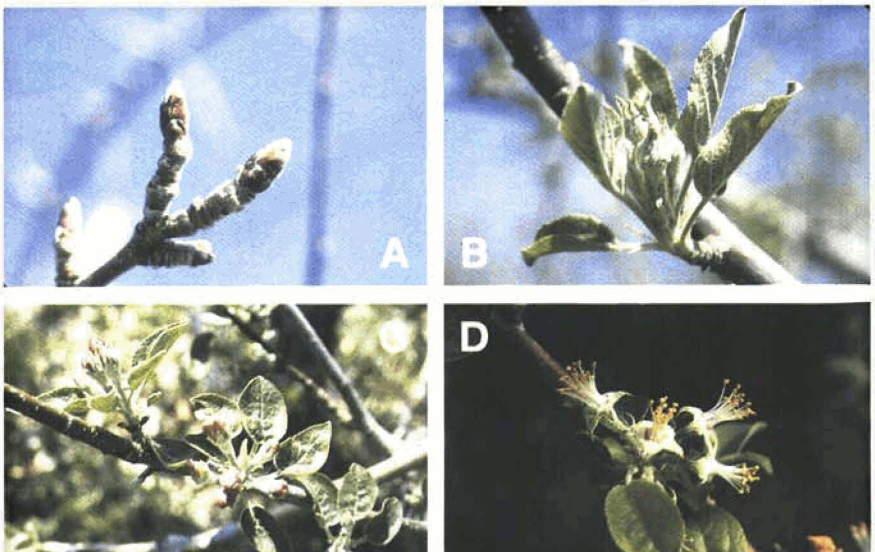



**Fig. 1. Fruit bud phenophases used to time pesticide applications: (A) Bud break, (B) tight cluster, (C) pink, and (D) petal fall.**

time for control decisions and actions.

The program we present is by no means complete, but ongoing research will provide some of the biological data needed to fill the gaps in our present knowledge. Despite its incompleteness, we believe the basic concepts of the program have been tested sufficiently and should be presented now, so they can be evaluated and perhaps implemented by others.

Before discussing our approach to integrating apple pest control measures, we will summarize the major pest and disease complex for apples in New Hampshire and New York.

## The Insects and Mites

**Tarnished plant bug.** The tarnished plant bug (*Lygus lineolaris* Palisot de Beauvois) is a hemipterous insect with piercing-sucking mouthparts. Although it is present and active in orchards shortly before bud break (Fig. 1A), economic damage results primarily from abortion of fruit or retention of fruit deformed by feeding at the late tight cluster (Fig. 1B) and pink (Fig. 1C) stages of fruit bud development. In New Hampshire, this insect is ubiquitous and sufficiently abundant that routine control is required to prevent significant loss. In New York, however, control measures may not be economically justified in all orchards (15). Since the introduction of synthetic pyrethroid insecticides, tarnished plant bug is controlled when necessary by a single application of an insecticide at late tight cluster to pink.

**Apple blotch and spotted tentiform leafminers.** The apple blotch leafminer (*Phyllonorycter crataegella* Clemens) and the spotted tentiform leafminer (*P. blancardella* F.) are the larval stages of moths. The larvae mine the mesophyll tissue of apple leaves (Fig. 2A), and severe infestations can result in fruit softening and early fruit drop. Three generations occur per year in the northeastern United States. Control decisions are based on the number of mines per leaf and the generation of the insect and, sometimes, on the severity of the infestation during the previous year. Chemical control of first-generation larvae is generally warranted if there are one or more mines of the apple blotch leafminer per cluster or one or more mines of the spotted tentiform leafminer per leaf (13,14). The first generation is often controlled by an insecticide application at pink.

**European red mite.** The European red mite (*Panonychus ulmi* Koch) lays its eggs in bark crevices of apple trees. The eggs hatch shortly before bloom, and the young mites feed on the emergent foliage. Over time, the mite population can build to damaging levels and cause bronzing of leaves (Fig. 2B) and stunted and deformed growth. European red mite can be controlled by a superior oil spray at the late tight cluster stage. Such sprays are ovicidal and have the added advantage of being less harmful to mite predators than miticides applied later in the growing season. On certain cultivars, and in general in southern New York, additional acaricide sprays may be needed during July or August if sufficient mite predators are not present.

**Plum curculio.** The plum curculio (*Conotrachelus nenuphar* Herbst) is one of the most damaging insect pests. Adults move into orchards at or shortly after bloom to feed on and lay eggs in the young fruit (Fig. 2C). Feeding and

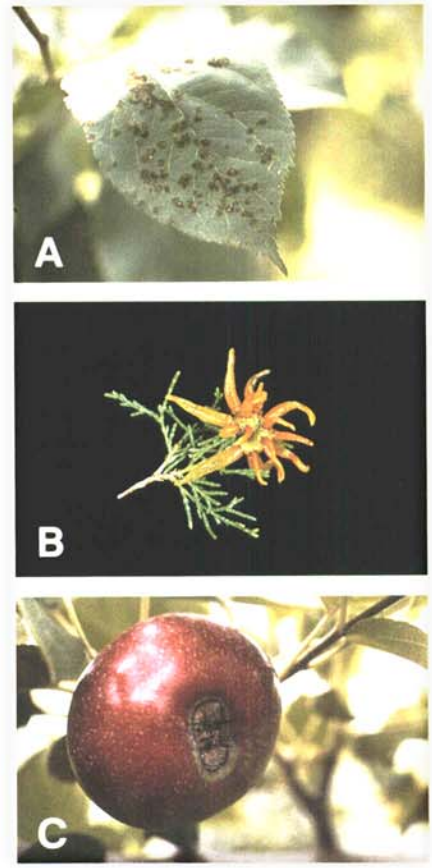



**Fig. 3. Diseases of apple fruit and foliage: (A) Foliar lesions caused by *Venturia inaequalis*, (B) telial horns of *Gymnosporangium juniperi-virginianae* on gall from red cedar, and (C) infection of calyx end of apple by *Sclerotinia sclerotiorum*.**

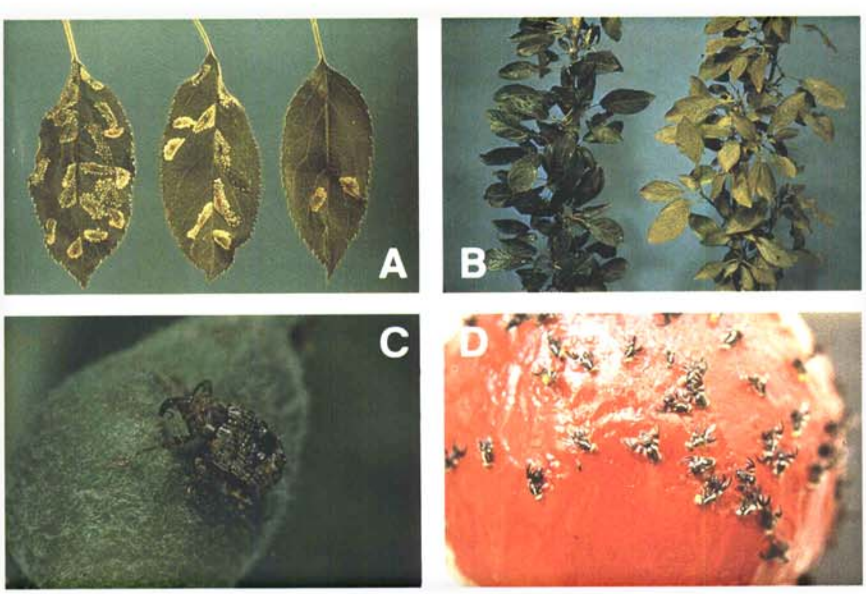



**Fig. 2. Mite and insect pests of apples in the northeastern United States: (A) Leaves showing mining of the mesophyll tissues caused by feeding of spotted tentiform leafminer larvae, (B) healthy foliage compared with foliage bronzed by feeding of the European red mite, (C) adult plum curculio feeding on young apple, and (D) apple maggot flies trapped on the adhesive surface of a spherical visual trap.**

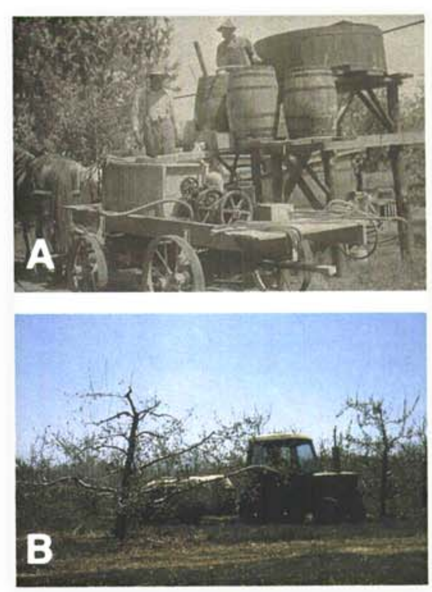



**Fig. 4. Control of apple scab (A) in 1910 and (B) in 1988. Fungicides, timing of applications, and equipment have been greatly improved in the last 80 years, but the basic strategy employed to control apple scab has remained the repeated application of fungicides directed against the primary inoculum.**

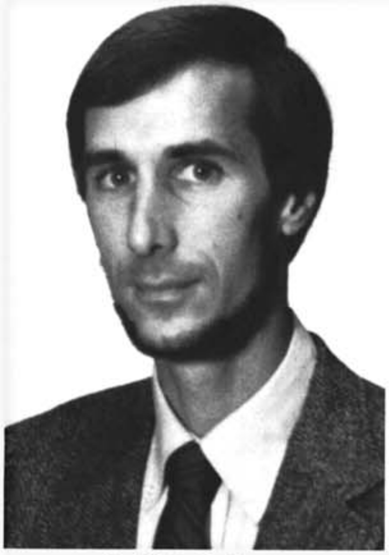
oviposition scars make fruit unmarketable, even though most larvae hatching in apple fruit are quickly crushed by the developing fruit and do not survive. Currently, pest population levels are not used to initiate control measures. Instead, fruit are protected by an insecticide application at petal fall (Fig. 1D) and again 7–10 days later. Pyrethroid insecticides applied at pink for tarnished plant bug can also suppress early-appearing curculio during late bloom.

**Apple maggot.** The apple maggot (*Rhagoletis pomonella* Walsh) is the larval stage of a fly, the adults of which emerge in mid- to late summer. Adults lay eggs in the maturing fruit, and economic damage occurs when the larvae tunnel throughout the maturing apple. Apple maggots can be detected in commercial apple orchards by visual trap catches (Fig. 2D). Insecticide sprays are applied at 10- to 14-day intervals to control apple maggots, beginning when the first adults are trapped, or in late July if traps are not used. In New Hampshire, the date of the first catch in certain orchards has varied from 6 July to 10 August during the last 6 years.

**Miscellaneous insect pests.** Insects that sometimes require special insecticide applications include rosy apple aphid, apple aphid, white apple leafhopper, potato leafhopper, San Jose scale, codling moth, green fruitworm, lesser appleworm, redbanded leafroller, and obliquebanded leafroller. Many of these pests occur only sporadically and are generally controlled by the insecticides applied to control the major insect pests.

## Diseases

**Apple scab.** Apple scab (Fig. 3A), caused by *Venturia inaequalis* (Cke.) Wint, is the most destructive disease of apples in North America. Primary infection is by ascospores released from pseudothecia in overwintered leaves. The ascospores are released only during rain and can infect only in the presence of free water. The number of hours of continuous leaf wetness required for infection is dependent on temperature and has been described by Mills (9). A number of authors have investigated the overwintering stage of this pathogen, and from these investigations we have learned a great deal about maturation and discharge of ascospores that has allowed us to schedule fungicide sprays to more accurately reflect the threat of infection. Apple scab remains a troublesome disease, however, and despite our refinements in fungicides, timing of sprays, and application technology, it is still controlled today much as it was 80



**David M. Gadoury**

Dr. Gadoury received his B.S. (1978) degree from the University of Rhode Island, Kingston, and his M.S. (1981) and Ph.D. (1984) degrees in botany from the University of New Hampshire, Durham. In association with William E. MacHardy, he has published several research articles on *Venturia inaequalis*, the apple scab fungus. Since 1985, he has worked as a research associate with Roger C. Pearson of the Department of Plant Pathology, Cornell University, at the New York State Agricultural Experiment Station in Geneva. Dr. Gadoury's principal research interests are the epidemiology of fruit diseases, the survival of plant pathogens during the intercrop period, modeling pathogen populations, and developing integrated pest management programs. Recent research projects have dealt with the role of pathogen population size in the development of epidemics of apple scab and grape powdery mildew.

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Dr. MacHardy is a professor of plant pathology at the University of New Hampshire, Durham. He received his B.S. and M.Ed. degrees from the University of Maine, Orono, his M.S. degree from the University of Nebraska, Omaha, and his Ph.D. (1970) degree from the University of Rhode Island, Kingston. He conducted postdoctoral research on water relations and mechanisms of resistance in vascular wilt diseases at the University of Rhode Island and University of Guelph, Canada, and continued this research for several years after joining the University of New Hampshire in 1972. Since 1978, he has been involved in the development of IPM programs, with a major emphasis on the epidemiology and management of apple scab and the biology of *Venturia inaequalis*, and is currently writing a monograph on apple scab for the American Phytopathological Society.

**David A. Rosenberger**

Dr. Rosenberger is an associate professor of plant pathology at Cornell University. He received his B.A. (1969) degree from Goshen College, Goshen, Indiana, spent 2 years working in international agriculture (Algeria), and completed his Ph.D. (1977) degree at Michigan State University, East Lansing. Since 1977, he has been the research and extension tree fruit pathologist at Cornell's Hudson Valley Laboratory in Highland, New York. His research interests include the epidemiology and chemical control of foliar and postharvest diseases of apples. A major emphasis in his research has been the refinement of control programs for apple diseases through the investigation of protectant, postinfection, antisporulant, and eradicant properties of fungicidal chemicals.

years ago (Fig. 4): by repeated applications of fungicides aimed at preventing primary infection (8).

**Cedar apple rust and quince rust.** Cedar apple rust (*Gymnosporangium juniperi-virginianae* Schw.) and quince rust (*G. clavipes* Cke. & Pk.) are diseases of minor importance in New Hampshire, causing only slight foliar infection and very rare fruit infection of most cultivars, even in the absence of control measures. Both diseases cause severe losses on susceptible cultivars in New York's Hudson Valley, especially when extended prebloom wetting periods contribute to a high incidence of fruit infection. In both diseases, infections develop from basidiospores released from telial galls borne on red cedars (Fig. 3B) near orchards. The galls release spores during rainy periods beginning at the tight cluster to pink stage of fruit bud development and continue to release spores under suitable conditions for approximately 2 weeks (10). In orchards of rust-susceptible cultivars, control is achieved by fungicides applied during the period of basidiospore release.

**Powdery mildew.** Powdery mildew (*Podosphaera leucotricha* Ell. & Ev.) can be a serious disease in certain areas of New York and may require special fungicide applications. The disease is especially troublesome in some years because the environmental requirements that favor disease increase (warm, humid weather) differ markedly from ideal weather for other major diseases. Timing fungicide applications by environmental conditions conducive to apple scab or rust can lead to inadequate control of powery mildew. Also, the fungicides most commonly used for control of scab, rust, and fruit rots are not as effective for control of powdery mildew, and vice versa. When necessary, the disease is controlled by applications of sulfur or dinocap at 10- to 14-day intervals, beginning at the tight cluster stage, or by certain sterol-inhibitor fungicides applied at 14- to 21-day intervals, beginning at pink or bloom. When disease is severe, fungicidal protection is maintained until terminal shoots cease growth in midsummer. Powdery mildew is rarely seen in New Hampshire, where presumably the tissue on which the pathogen overwinters (infected dormant buds) is unable to survive winter (3).

**Fruit rots.** These are most commonly caused by one of two fungi: *Physalospora obtusa* (Schw.) Cke., which causes black rot, and *Sclerotinia sclerotiorum* (Lib.) dBy., which causes calyx-end rot (Fig. 3C). *S. sclerotiorum* is primarily a pathogen of fruit, whereas *P. obtusa* may also cause leaf spots and cankers (Fig. 5). Black rot and calyx-end rot can be destructive in some years, particularly when wet conditions persist through bloom and petal fall. Infection is thought to occur at this early stage of fruit development, but in the case of calyx-end rot, the etiology of the disease is poorly understood. Nonetheless, control measures consist of fungicide sprays applied at petal fall and again in 7–10 days.

**Sooty blotch and flyspeck.** Two diseases that can cause late-season problems in some orchards are sooty blotch (*Gloeodes pomigena* (Schw.) Colby) and flyspeck (*Zygophiala jamaciensis* Mason). The damage they cause is cosmetic but economically significant. In general, prevalence of these diseases increases as one moves from north to south in the northeastern United States, but disease occurrence from orchard to orchard can be highly variable. In some orchards, sooty blotch and flyspeck are yearly problems, while in others they are rarely seen, even on unsprayed trees. Thus, the need for control is frequently gauged from past incidence of these diseases. The epidemiology of sooty blotch and flyspeck has not been thoroughly investigated in the northeastern United States, but work in Pennsylvania indicated that infections occurred from mid-June through August (7). In the northeastern United States, commercial problems with these diseases are usually related to early termination of summer fungicide applications. In orchards where sooty blotch and flyspeck are perennial problems, they are controlled by the use of appropriate fungicide sprays during July and August.

## An Overview of the Traditional Pesticide Application Schedule

Figure 6 depicts the periods during a growing season when various pests and diseases are active and may require specially timed control measures. Both an approximate time and a phenological scale are included, because both are important in scheduling control measures. Fungicide sprays are generally applied between bud break and pink to control apple scab, and a prepink oil spray may be used to reduce populations of European red mite, rosy apple aphid, and San Jose scale. At or shortly before pink, the fungicide(s) applied must, at times, simultaneously control apple scab, cedar apple rust, quince rust, and powdery mildew. Tarnished plant bug, tentiform leafminers, rosy apple aphid, San Jose scale, and European red mite may also be controlled by pesticides applied at this time. Approximately 10–12 days later, at petal fall, the fungicide(s) used must not only control scab, and sometimes rusts and mildew, but also black rot and calyx-end rot. Plum curculio, a major insect pest, and many of the minor insect pests, including green fruitworm, red-banded leafroller, European apple sawfly, rosey apple aphid, and San Jose scale, may require control at petal fall. A spray 7–10 days after petal fall is generally needed to control apple scab, plum curculio, and codling moth. Powdery mildew, rusts, fruit rots, and several minor pests may also require treatment at this time, dependent on location, weather, and the effects of earlier treatments. Thereafter, there can be a period of 4 weeks or more when major insect pests do not threaten fruit and apple scab is the only disease that must be controlled. Occasional insecticide sprays may be required during June and July to control specific pest problems, but the need for such treatments is usually determined on a case-by-case basis after an evaluation of pest, and sometimes predator, populations in the orchard.

In mid- to late summer, insecticides are required in virtually all orchards to control apple maggot and, occasionally, second-brood codling moth. Fungicidal protection against apple scab is continued, but the choice of materials may be influenced by a need to control sooty blotch and flyspeck. In all, approximately 12 fungicide sprays and five to seven insecticide and acaricide sprays are applied during a single year in a protectant spray program. The pesticides may be applied in as many as 15 separate trips through an orchard. Fungicides are applied at approximately 7-day intervals during the primary apple scab infection season, i.e., while ascospores of *V. inaequalis* are present. Thereafter, the interval between fungicide sprays is increased to approximately 14 days. Prior to petal fall, insecticides are usually applied in combination with the fungicide application that falls closest to the appropriate date or phenological stage used to time insecticide application. After petal fall, the timing of insecticide and acaricide sprays often determines when fungicides are applied. As mentioned previously, combining fungicide and insecticide applications can be more difficult if postinfection sprays are used to control apple scab. An unexpected rain may force growers to apply a postinfection spray for apple scab only 2 or 3 days after an insecticide application.

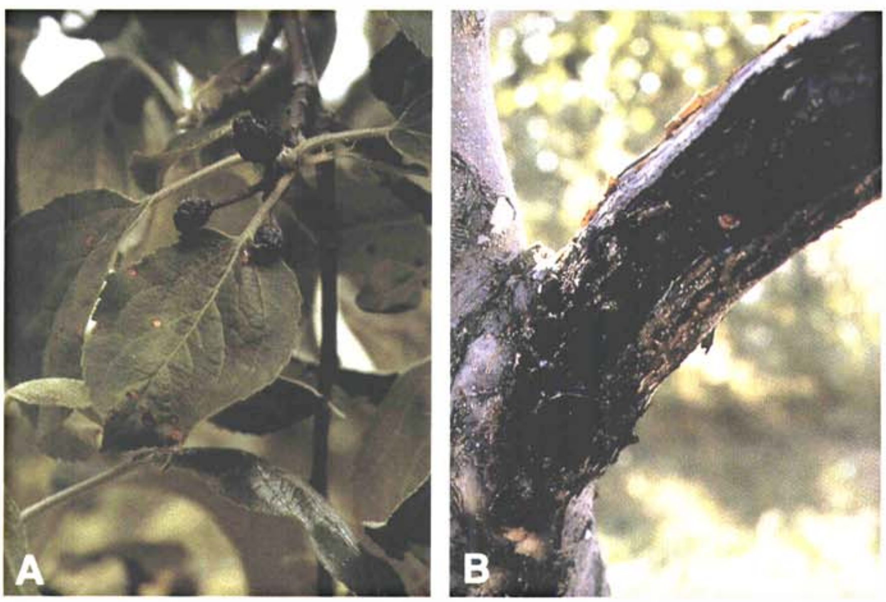


**Fig. 5. (A) Mummified fruit and leaf spots and (B) canker caused by *Physalospora obtusa*.**

## Synchronizing Control Measures for Multiple Pests

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. Fungicide sprays for apple scab are applied weekly during the primary infection season or before predicted rain or after infection periods. Optimal timing of sprays to control other diseases is based on periods of inoculum production (rusts) or of host susceptibility (fruit rots). Insecticide and acaricide sprays are timed to minimize economic damage at certain phenophases (tarnished plant bug), a period of pest susceptibility to the control measure (oil sprays for mites and insecticides for leafminer larvae), or the time of pest emergence and migration to the orchard (plum curculio and apple maggot). As control measures for each pest have been refined, the timing of control measures has become more critical, compounding the problem of integrating pest control schedules. A greater degree of flexibility in timing pesticide applications is needed for effective integration of control measures. To illustrate where and how this can be accomplished, we return to Figure 6.

Prior to the tight cluster to pink stage of fruit bud development, pesticide applications in most New Hampshire and New York orchards are directed solely at

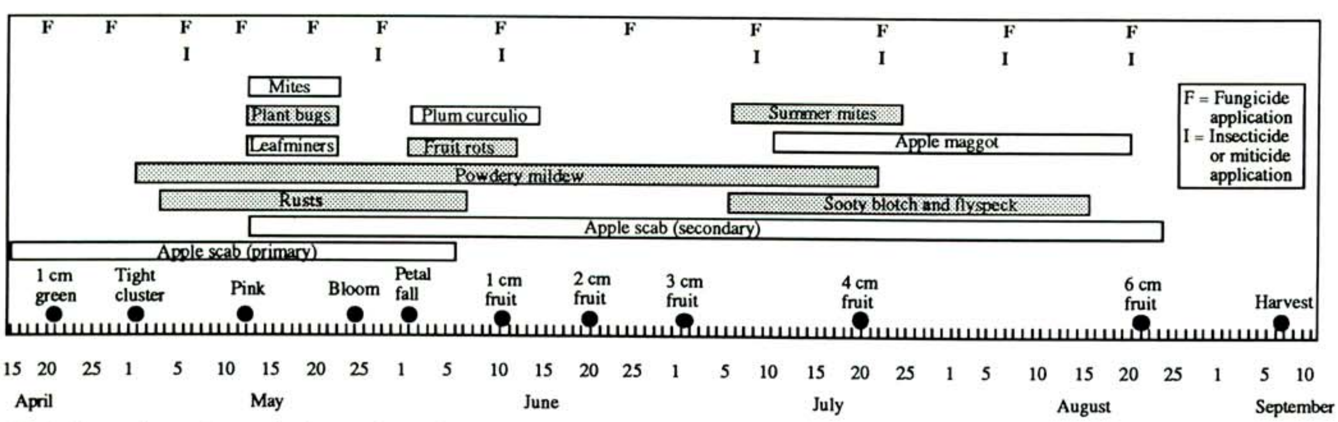


**Fig. 6. The major pest complex for apples in the northeastern United States. Letters at the top indicate the approximate timing of pesticide applications in a traditional protectant spray schedule. Each bar indicates the period during which a pest is usually controlled, although the pest may be present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

apple scab (Fig. 6). Eliminating these early-season sprays would provide an excellent opportunity to maximize control of multiple pests and diseases at tight cluster to early pink. A single combined fungicide, insecticide, and oil application at tight cluster could control apple scab, rusts, tarnished plant bug, leafminers, and mites.

Early-season fungicide applications for control of apple scab have been recommended for many years on the basis of trials conducted in research orchards with large overwintering populations of the apple scab fungus. A recent study (5) has questioned the need for these sprays in modern commercial orchards with minimal amounts of overwintering inoculum. The relationship between differences in the amount of overwintering inoculum and the early progress of an apple scab epidemic can be expressed mathematically (12) as: $dt = 1/r \ln X_o/X_{os}$, where $dt$ = the delay of an epidemic or the shift in time of a disease progress curve due to differences in the amount of overwintering inoculum, $r$ = the rate of infection, and $X_o/X_{os}$ = the ratio of the difference in inoculum between two orchards. Gadoury and MacHardy (5) recently described a method to quickly and easily obtain an estimate of the potential ascospore dose (PAD, expressed as ascospores per square meter per year) in commercial orchards. To illustrate how we have used forecasts of PAD to determine when early-season fungicide sprays for apple scab could be omitted, we assumed first that weekly applications of a protectant fungicide, beginning at bud break, would effectively control apple scab in an orchard where PAD = 100,000 ascospores per square meter per year (approximately 10% foliar infection at the time of leaf fall). We based this assumption on over 20 years of fungicide trials in New Hampshire, where weekly applications of protectant fungicides such as captan, dodine, and mancozeb have provided excellent control of apple scab in research orchards where PAD was at least 100,000 ascospores per square meter per year (W. E. MacHardy, *unpublished*). Our second assumption was that in commercial orchards with low values of PAD, $dt$ could be computed by using 100,000 as $X_o$ and the PAD of the commercial orchard as $X_{os}$. Finally, we assumed that the infection rate of an apple scab epidemic could not exceed 0.40 per unit per day, based on a minimum latent period of 10 days (12). The value of $dt$ computed is a minimum value and does not consider that $r = 0$ prior to the first infection period and that one latent period must elapse before disease can increase because of secondary infection. However, the utility of the estimated value outweighs the errors in this admittedly simplistic epidemiological approach.

In most growing seasons, there are about 20 days between bud burst and early pink in the northeastern United States. To delay the first pesticide application until pink, $dt$ would have to equal at least 20 days. If $dt$ was less than 20 days, some action would be required to reduce $X_{os}$ and increase $dt$. This could be achieved by a postharvest spray of urea formaldehyde, a benzimidazole or sterol-inhibitor fungicide, or a spore suspension of a fungal antagonist that

**Fig. 7. The northeastern United States is famous for its early-spring mud season. Melting snow, saturated soils, and spring rains frequently combine to make travel through some orchards difficult or impossible.**

**Table 1.** Effects of various fungicides applied at the time of leaf fall on the production of pseudothecia and discharge of ascospores of *Venturia inaequalis* on apple[w]

| Treatment | Concentration (mg/L)[x] | Pseudothecia/cm² | Ascospores discharged/cm² |
|---|---|---|---|
| Flusilazol | 9 | 0 a[y] | 0 a |
| Diniconazole | 19 | 0 a | 0 a |
| Myclobutanil | 75 | 0 a | 0 a |
| Penconazole | 300 | 0 a | 50 a |
| BAY HWG 1608[z] | 101 | 0 a | 75 a |
| Bitertanol | 75 | 1.3 a | 0 a |
| Triadimefon | 150 | 3.0 b | 324 b |
| Triflumizole | 75 | 7.8 c | 2,216 c |
| Triforine | 150 | 12.3 c | 2,341 c |
| Thiophanate-methyl | 338 | 0 a | 0 a |
| Benomyl | 113 | 0 a | 0 a |
| Dodine | 293 | 4.9 c | 2,963 c |
| Chlorothalonil | 1,250 | 17.4 d | 7,321 d |
| Captan | 600 | 19.1 d | 6,474 d |
| Control | ... | 39.0 d | 7,495 d |

[w] Compounds were applied to heavily scabbed leaves of apple cultivar McIntosh trees at leaf fall. The leaves were overwintered on the orchard floor, after which the number of ascocarps per square centimeter and the number of ascospores produced per square centimeter were determined.

[x] Formulated products were dissolved or suspended in water; concentrations given are for active ingredient.

[y] Treatment means followed by the same letter are not significantly different at $P = 0.10$ according to Duncan's multiple range test.

[z] An experimental fungicide, α-[2-(4-chlorophenyl)ethyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol.

**Table 2.** Effects of benomyl, bitertanol, and etaconazole sprays applied at various times before leaf fall on ascospore production of *Venturia inaequalis* on apple[y]

| Fungicide | Percent reduction of ascospore production[z] | | |
|---|---|---|---|
| | 52 days before leaf fall | 22 days before leaf fall | 1 day before leaf fall |
| Benomyl, 113 ppm | 100 (0) | 100 (0) | 100 (0) |
| Bitertanol, 75 ppm | 64 (3.1) | 94 (1.2) | 90 (2.0) |
| Etaconazole, 19 ppm | 0 (0) | 40 (3.6) | 100 (0) |

[y] Heavily scabbed leaves on apple cultivar McIntosh trees were treated on 15 August, 14 September, and 5 October, collected on 6 October, and overwintered on the orchard floor; ascospore production was measured on the following spring. Leaves treated with distilled water on each date served as control.

[z] Mean and standard error of three replications.

**Table 3.** Fruit scab on apple trees left unprotected during early-season infection periods in an orchard at Woodman Horticultural Farm, Durham, New Hampshire[w]

| Year | Percent leaf scab previous year | Potential ascospore dose (PAD) | | $dt^x$ | Infection periods[y] before pink | Days from bud burst to pink | Percent fruit scab | |
|---|---|---|---|---|---|---|---|---|
| | | Before eradication | After eradication | | | | Unsprayed until pink | Unsprayed entire season |
| 1983 | 0.03 | 227 | 2.27 | 27 | 3 (S,S,S) | 23 | 0.7 | 3.0 |
| 1984 | 0.26 | 197 | 1.97 | 27 | 4 (S,S,M,M) | 23 | 0.0 | 43.0 |
| 1985 | 0.20 | 151 | 1.51 | 27 | 1 (L) | 17 | 0.8 | 31.0 |
| 1986 | 0.50 | 496 | 4.96 | 25 | 3 (M,M,S) | 24 | 0.4 | nd[z] |

[w] Amount of foliar scab and PAD were determined in autumn, before application of a postharvest eradicant fungicide.
[x] Delay of apple scab epidemic, computed on basis of PAD in the orchard.
[y] S = severe, M = moderate, L = light infection periods according to infection period table developed by Mills (9).
[z] No data.

**Table 4.** Incidence of fruit and foliar scab on apple cultivar McIntosh trees in an orchard with a large overwintering population of *Venturia inaequalis* (greater than 10% foliar infection by the time of leaf fall the previous year)[y]

| Treatment and concentration | Percent terminal leaves scabbed on 15 August | Percent fruit scab on 25 August |
|---|---|---|
| Benomyl (113 ppm) + mancozeb (720 ppm) | 1.6 a[z] | 0.3 a |
| Fenarimol (80 ppm) | 4.5 a | 0.7 a |
| Flusilazol (9.4 ppm) | 4.3 a | 0.3 a |
| Mancozeb (1,440 ppm) | 7.1 a | 5.8 b |
| Control | 74.7 b | 50.3 c |

[y] Trees were left unsprayed during two infection periods in a 26-day interval between bud break and bloom, then were treated with fungicides with eradicant and antisporulant activity; concentrations given are for active ingredient. Compounds were applied in three dilute sprays at approximately weekly intervals beginning at bloom; thereafter, protectant applications of the fungicide metiram were given.
[z] Means followed by the same letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test. Means were angular-transformed before analysis.

would reduce the number of pseudothecia that formed or survived winter (2,4,6). At least two sterol-inhibitor and two benzimidazole fungicides have been reported to suppress ascocarp production (4,11). We recently evaluated several sterol inhibitors, benzimidazoles, and other fungicides and found many to be effective in reducing ascocarp formation in *V. inaequalis* when applied at leaf fall (Table 1). Bitertanol was effective when applied 22 days before leaf fall, and benomyl was effective when applied 22 or 52 days before leaf fall (Table 2).

We first tested this strategy of delayed spraying in a 1-ha block of dwarf McIntosh, Cortland, and Delicious trees in Durham, New Hampshire. Each fall, we measured the PAD of the orchard and computed *dt*. Each year it was necessary to apply a postharvest spray of thiophanate-methyl at 0.57 kg a.i./ha to reduce PAD by approximately 99% and to increase *dt* to 25–27 days. In none of the 4 years of the experiment was there any reduction in control of apple scab when trees were left unsprayed until pink, as compared with trees that were sprayed beginning at bud break, even though in most years there were three or more Mills infection periods prior to pink (Table 3).

In 1986, we expanded the trials to include four New Hampshire and three New York commercial orchards. Again, PAD was measured in the fall, but no postharvest eradicant treatments were used, even when *dt* was less than 20 days. In the New Hampshire orchards, there were no significant differences ($P = 0.01$) in fruit scab at harvest between trees sprayed beginning at bud break and those left unsprayed until pink. Because early spring was unusually dry, trees in the New York orchards were left unsprayed until bloom. Only trace amounts of fruit scab occurred on these trees.

As an alternative to postharvest eradication of pseudothecia to reduce $X_0$, a fungicide with eradicant or antisporulant properties could be used to eradicate or deactivate infections occurring in the interval between the elapse of *dt* and the pink stage of fruit bud development. Experiments conducted in New York in 1986 demonstrated the potential for using eradicant fungicides to deactivate scab infections that occurred when the initiation of the spray program was delayed. Two sterol-inhibitor compounds, flusilazol and fenarimol, and the benzimidazole benomyl in combination with mancozeb were applied at tight cluster to McIntosh trees with established infections in a high-inoculum orchard. Despite the occurrence of two infection periods in the 26-day interval between bud burst and the date of the first fungicide application, and even though the value of *dt* in this orchard was nil, fruit infection remained at acceptable levels (Table 4). The incidence of fruit scab was significantly higher on trees sprayed with mancozeb alone, a protectant fungicide with little or no eradicant or antisporulant activity. Thus, using fungicides with eradicant and antisporulant activity after delaying the onset of the fungicide spray program adds assurance that scab will not cause serious losses in the orchard even if errors were made in forecasting PAD or if the first application was delayed beyond *dt*.

We concluded that forecasting PAD and *dt*, the use of postharvest eradicant treatments to increase *dt*, and the use of eradicant or antisporulant fungicides to deactivate scab infections that occur before the onset of a delayed spray program are valuable tactics that will allow an apple scab control program to be delayed to coincide with the need to control other diseases and pests at tight cluster or pink.

## The Second Opportunity for Integration

A second opportunity to control multiple pests and diseases occurs at the petal fall stage (Fig. 6). A combined fungicide and insecticide spray at this time would control apple scab, rust, fruit rots, plum curculio, and miscellaneous insect pests. The period between pink and petal fall, however, can be 10–12 days, a period that exceeds the duration of protectant activity against apple scab provided by most fungicides. Therefore, either the fungicide used at pink should have extended protectant activity, as was achieved by high application rates of captafol (16), or a compound with extended postinfection activity (16) should be used at petal fall to eradicate infections occurring late in the interval between pink and petal fall. No fungicides with extended protectant activity are currently available to commercial growers, but sterol-inhibitor fungicides are perhaps the ideal compounds for application at this stage, on the basis of their spectrum of activity and potential for postinfection control of scab, rust, and mildew. In the last 4 years of trials in New Hampshire, we have not encountered the situation where extended protectant or postinfection activity was needed in the pink or petal fall sprays. Instead, we selected a fungicide based on its efficacy in controlling the diseases likely to occur at that time.

## Synchronizing Control Measures for Remainder of the Season

Approximately 10 days after petal fall, a third fungicide spray is required to protect against fruit rots, rusts, and occasionally apple scab. The need for this spray coincides with that for control of plum curculio (Fig. 6) and other miscellaneous insect pests. Approximately 10 days after this third spray, primary apple scab and rust inoculum are generally exhausted, and a grower can choose to continue to apply protectant or postinfection sprays for control of apple scab if disease incidence in the orchard is above an action threshold (e.g., more than one lesion per 200 leaves). However, if an examination of the orchard at this time fails to show significant levels of apple scab and if none of the sporadic insect or disease problems are present, spraying can be suspended until the appearance of apple maggot in mid- to late summer (Fig. 6). In areas where sooty blotch and flyspeck are problems, the interval between fungicide sprays can be extended to 30 days if ethylenebis-(dithiocarbamate) fungicides are used (1). Once apple maggots have been trapped in an orchard, a second examination to detect apple scab can be made. On the basis of results of this examination, a grower may decide to apply only an insecticide to control apple maggots in subsequent sprays if apple scab is at trace levels, or a fungicide could be applied with the maggot sprays to prevent the increase of apple scab and protect from sooty blotch and flyspeck (Fig. 6). Generally, one to three sprays are applied to control apple maggots.

The foregoing program has controlled all major and minor diseases and pests both in carefully monitored research orchards and in commercial orchards in New Hampshire and New York. Excellent control of mites, insects, and diseases other than apple scab in this program was not surprising, for the sprays were specifically timed for that purpose. The unique feature is the consistent, simultaneous control of multiple pests and diseases in a reduced spray schedule.

## Summary

The idealized chemical control program we have outlined calls for approximately five or six pesticide applications during the growing season and possibly one postharvest eradicant treatment. Early-season sprays targeted only for apple scab have been eliminated, allowing the integration of the first apple scab spray with the need to control other diseases and pests. The decision to eliminate the early-season fungicide sprays is based on inoculum potential, simple epidemiological principles, and the use of fungicides that can deactivate established infections. The rules for making the decision are simple and have been explained to and used by commercial growers. Integrating the insect and disease control schedules reduces costs for labor, equipment, and materials in crop production, reduces the total number of pesticide applications, and reduces or eliminates the operatation of equipment in orchards during early spring when travel through some orchards is difficult because of wet soil conditions (Fig. 7). Eliminating entire applications results in a saving of approximately $10 per acre in labor and variable equipment costs (M. Castaldi, *personal communication*).

Our approach to developing the preceding strategy was based on selecting those key points in the season where increased flexibility in timing control measures for the major pest complex would allow pesticide applications to be combined. This flexibility is achieved by measuring and, when necessary, reducing inoculum potential for apple scab; by deactivating, when necessary, established apple scab infections; and by selecting chemical compounds based not just on efficacy or cost but primarily on the properties that would allow them to be used effectively at key points for pest and disease control. This is particularly true of the fungicides used at pink and petal fall. The recent registration of broad-spectrum sterol-inhibitor fungicides may allow a degree of flexibility in timing and integration of pesticide applications never before available in apple disease control. In other apple growing regions of the United States, some major diseases and pests differ from those in New Hampshire and New York. We believe, however, that certain components of the strategy or the approach we used in developing it can be applied despite these differences.

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