Factors Limiting IPM-Compatibility of New Disease Control Tactics for Apples in Eastern United States

David A. Rosenberger, Department of Plant Pathology, New York State (Geneva) Agricultural Experiment Station, Cornell University’s Hudson Valley Laboratory, P.O. Box 727, Highland, NY 12528.

Corresponding author: David A. Rosenberger. dar22@cornell.edu


Introduction
This paper focuses on integrated pest management (IPM) and IPM-compatibility of new disease-control technologies in commercial production of apples in eastern United States (Fig. 1). Much of the discussion may also apply to other tree fruit crops, and some of it may be broadly relevant for other horticultural crops as well. However, the author’s experience, examples, and opinions are derived from 25 years of interaction with apple producers and apple IPM consultants.

In this paper, “IPM-friendly” technologies are defined as those that promote, or at least do not harm, the broadly held IPM objective of reducing agricultural inputs and practices that have the potential to harm human health or the environment. “IPM-compatible” technologies, however, must also be cost-effective for the agricultural producer.

In a free-market system, agriculture survives as a commercial enterprise only so long as there is potential for such enterprises to generate a profit. Steven Blank (2) has effectively characterized the economic constraints faced by agricultural producers in the United States and in other developed countries. These economic constraints have significant trickle-down impacts on farmers’ perspectives and on their abilities to adopt new technologies. IPM cannot be divorced from economics: farmers cannot implement IPM strategies that are not cost-effective. New technologies that are not cost-effective must be judged as currently incompatible with IPM regardless of how safe, elegant, or admirable those technologies may be.

Stating that some (perhaps many) new technologies are economically incompatible with IPM does not mean that those technologies are devoid of value. Nor does it mean that they will be forever economically non-viable. Technologies that are economically impractical for one crop in one location or country may still prove economically practical for a different crop in a different...
Furthermore, economic parameters are constantly changing as a result of the constant shifting and re-balancing that occurs in the international marketplace. Usefulness of both new and older IPM-friendly technologies must be constantly re-evaluated based on current and projected market conditions. Technologies that are scientifically promising but cost-prohibitive today may be adopted as standard IPM practice in the future if changing economic conditions allow them to become cost-effective.

The technologies discussed in this paper have been grouped into three broad categories: (i) new fungicides, biological control products (biocontrols), plant activators, and plant growth regulators; (ii) cultural changes and technologies that impact IPM; and (iii) plant disease models and related information dissemination. The specific technologies discussed and the literature cited were selected to illustrate various aspects of IPM technology as it applies to apples production and are not intended as a comprehensive review of all relevant literature. Some of the perspectives presented, although derived from the author’s observations and experiences, are only opinions that will hopefully serve to stimulate further discussion or research.

**New Fungicides, Biocontrols, Plant Activators, and Plant Growth Regulators**

Farmers evaluating new technologies often favor technologies that cause minimal disruption to current production systems. Thus, new products that can be applied as sprays often are accepted quickly because they can be incorporated into production systems without increasing labor costs, changing cultural methods, or expending additional capital for new equipment.

Several new categories of sprayable disease-control products have been developed for commercial use over the past ten years. In addition to new fungicides, introductions have included biocontrols, plant activators that control diseases by triggering the natural defense systems in plants, and plant growth regulators that make plants resistant to diseases by changing host metabolism or physiology.

**Fungicides.** Dependence on fungicides and other agrichemicals is sometimes viewed as being incompatible with advanced IPM systems (12). Negative perspectives about the role of agrichemicals usually emanate from biological or sociopolitical assessments of IPM programs. When economic impacts of disease control programs are included in the decision process for selecting IPM strategies, then fungicides become critical components of most disease management programs for apples as well as for many other horticultural crops grown in humid climates because fungicides often provide the most consistent and least expensive option for managing diseases.

The introduction of strobilurin fungicides (azoxystrobin, trifloxystrobin, and kresoxim-methyl) illustrates the complexity of determining if, when, and how new fungicides should be incorporated into IPM strategies. Strobilurin fungicides are very active against many plant pathogenic fungi. They have very low toxicity to birds, earthworms, beneficial insects, predaceous mites, and mammals (including humans). They break down quickly in soil (32). The environmental and human safety profiles for these fungicides make them IPM-friendly, especially when they are used to replace older fungicides such as mancozeb, metiram, captan, or chlorothalonil that are classified by the U.S. EPA as potential carcinogens.

Although azoxystrobin, trifloxystrobin, and kresoxim-methyl have similar chemistry and modes of action, each of these fungicides has unique limitations. Azoxystrobin is phytotoxic to some apple cultivars, kresoxim-methyl is phytotoxic to some sweet cherry cultivars, and trifloxystrobin is phytotoxic to some grape cultivars (Fig. 2). The phytotoxicity issues create interesting dilemmas for IPM programs. Azoxystrobin is labeled for use on ornamentals, stone fruits, grapes, and many vegetable crops, but it causes necrosis on leaves and fruit of apple cultivars such as McIntosh and Gala. Apples can be damaged by inadvertent exposure to very small amounts of azoxystrobin including exposure to spray drift from adjacent crops or to residues left in application equipment. As a result, the labels for azoxystrobin dictate that sprayers used to apply this fungicide must never be used to spray apples.
Is azoxystrobin an IPM-compatible technology for diversified farms that include apples? The answer depends on the specific farm situation, but for most farms that include apples along with other crops, this IPM-friendly fungicide will fail the economic test for IPM compatibility. The costs involved in owning separate spray equipment for apples and for applying azoxystrobin to other crops will make this a cost-prohibitive technology.

Trifloxystrobin and kresoxim-methyl are registered for use on apples in the U.S. They provide excellent control of apple scab, sooty blotch, flyspeck, black rot, and white rot and acceptable control of powdery mildew and bitter rot (16,30). However, the cost of these fungicides may limit their IPM-compatibility for apple farmers. The suggested retail prices provided by G.W Koehler (8) illustrate the cost differential among various fungicide programs. If a grower applies the equivalent of 200 gallons of dilute spray per acre to cover medium-size apple trees, then substituting trifloxystrobin or kresoxim-methyl for mancozeb in an early season spray for apple scab would increase costs by approximately $15 per acre. Similarly, using one of these new fungicides to replace a standard summer application of captan plus thiophanate-methyl would increase costs by $5.70 per acre. Although these differences may appear relatively small for a high-value crop, using trifloxystrobin or kresoxim-methyl just twice during the season (once for scab and once during summer) could result in increased costs of $6,210 for a grower with 300 acres of apples. Apple growers in New York have experienced nearly a decade of low apple prices that often resulted in negative returns on investment (28). Because growers have little control over many input costs (e.g., taxes, interest rates, utilities, and perhaps labor), they focus considerable attention on areas such as pest control where their choices can affect costs. Given these economic constraints, trifloxystrobin and kresoxim-methyl cannot be considered IPM-compatible unless these fungicides provide an economic advantage that is absent in the less expensive fungicides that they are replacing.

The fact that trifloxystrobin and kresoxim-methyl provide both protectant and post-infection activity against apple scab, sooty blotch, and flyspeck could justify higher pricing for these fungicides as compared to protectant-only fungicides like mancozeb or captan. Fungicides with postinfection activity can theoretically be applied after infection periods have occurred, thereby eliminating unnecessary sprays that would otherwise be applied ahead of predicted rains that fail to develop. However, postinfection applications have significant drawbacks. Both the strobilurin and DMI fungicides (fenarimol, myclobutanil, and triflumizole) must be applied within 96 hours after the beginning of an infection period for effective postinfection control of apple scab. Weather systems that bring scab infection periods are frequently followed by windy conditions that make spraying inadvisable or impossible for several days. Furthermore, the stringent timing required for such applications limits options for combining fungicides and insecticides in the same application and may result in greater application costs over the course of a season. Better integration of all pest control measures is possible if fungicide timing is adjusted to fit
insecticide timing whenever possible (4). Post-infection spraying can also speed
selection of fungicide-resistant populations for some pathogens (9). Because of
these factors, few apple growers routinely depend on post-infection applications
of strobilurin and DMI fungicides to control apple scab even though
postinfection timing of fungicide sprays initially sounded like a good IPM-
strategy for scab management. If the value of their postinfection activity is
discounted due to other complications, then the added costs for strobilurin and
DMI fungicides (as compared to captan or mancozeb) becomes more difficult to
justify. Determining exactly when these more expensive fungicides are justified
poses a challenge for IPM practitioners.

Biocontrols have an environmental cachet that makes them particularly
attractive to those seeking alternatives to chemical controls. However,
identifying, formulating, registering, and distributing effective biocontrols for
plant diseases has been much more difficult than most proponents are willing to
admit. Many organisms have biocontrol potential when evaluated using
laboratory-grown cultures that are harvested and immediately applied to plants
under laboratory conditions. Commercialization, however, requires a consistent
formulation with a functional shelf life that can be marketed at reasonable cost.
Relatively few biocontrols have met those requirements.

Development of biocontrols for postharvest pathogens has been an attractive
research target for more than 20 years. The defined environment (i.e., controlled
temperature and relative humidity) in postharvest storages theoretically makes
this setting ideal for survival of biocontrol organisms. Storage operators have
economic incentives for minimizing postharvest losses because of the relatively
high value of the stored product. For apples, fungicide residues attributable to
postharvest treatments with traditional fungicides account for a high proportion
of the total detectable pesticide residues in market basket surveys (10). These
factors should have favored rapid development and commercialization of
biocontrols for postharvest diseases. However, biocontrols have not yet had a
significant impact on commercial management of postharvest apple diseases in
the U.S. The yeast *Candida oleophila* was registered by the U.S. EPA for
prevention of storage decays of apples, but it proved ineffective (19,20).

Commercialized formulations of *Pseudomonas syringae* that were registered for
postharvest use on apples and pears have never been distributed in production
regions of eastern United States, presumably because the manufacturer knew
that this biocontrol would be not be cost-effective in eastern United States where
postharvest fungicides are usually mixed in large volumes of water and applied
as a recirculating drench. In western United States, where postharvest
biocontrols are sometimes applied as low-volume non-recirculating sprays, high
product costs have less impact because less of the biocontrol product is used to
treat each bushel of apples.

Complications encountered in commercializing biocontrols for postharvest
environments increase when biocontrols are applied to above-ground portions
of crops in the field. Biocontrol organisms applied to leaf, flower, and fruit
surfaces are routinely challenged by adverse conditions that reduce their
survival and effectiveness. Johnson et al. (5) reported that *Pseudomonas
flourescens* Strain A506 provided effective control of fire blight in one year of
testing, but not during the second year. A strain of *Bacillus subtilis* was recently
registered by the U.S. EPA for control of numerous diseases on apples, but it was
ineffective against fungal diseases in two years of testing in New York (18,21). In
Virginia, the same product provided good control of bitter rot but failed to
control other fungal diseases (30). Biocontrols that are effective against only one
disease cannot compete with broad-spectrum fungicides on crops such as apples
that are attacked by numerous fungal pathogens. Thus, the future for plant
disease biocontrols in apples remains questionable.

Plant activators have so far found limited applications in commercial
agriculture. Acibenzolar-S-methyl and harpin protein are two plant activators
that have been registered by the U.S. EPA. These products cause plants to
become more resistant to attack by fungal and bacterial pathogens by inducing
systemic acquired resistance (SAR). SAR inducers often provide only partial
control of diseases on highly susceptible crops. For this reason, SAR inducers
may prove most effective when combined with low rates of fungicides (24).
Crop responses to SAR inducers have been highly variable, presumably due to interactions caused by other plant stresses and environmental factors. Both acibenzolar-S-methyl and harpin protein suppressed fire blight on apples in university trials (1,7), but neither of the plant activators was more effective than the less-expensive streptomycin standard. Acibenzolar-S-methyl is effective for controlling bacterial diseases of tomatoes (11), and it is being used successfully by fresh-market tomato producers in southeastern United States despite potential problems with reduced yields in fields that are treated with SAR inducers (15). Because of their high costs, plant activators are likely to prove IPM-compatible primarily for controlling bacterial diseases in high-value crops where growers have few alternative control options.

**Plant growth regulators** are usually considered production aids rather than pest management tools, but the recent introduction of prohexadione-calcium (P-cal) is providing apples growers with a unique combination of horticultural and disease-control benefits. P-cal inhibits biosynthesis of gibberellin, a natural plant hormone essential for cell elongation. In apple trees treated with P-cal, growth of vegetative shoots slows within 10 to 14 days after application. The reduced growth rate makes the growing shoot tips less susceptible to infection by *Erwinia amylovora*, the bacterium that causes fire blight. P-cal does not control the blossom blight phase of fire blight, so it is not a substitute for streptomycin sprays that are applied during bloom. However, P-cal applied near petal fall can significantly reduce secondary spread of fire blight to shoot tips (Fig. 3), thereby reducing both the severity of fire blight during the crop season and the amount of inoculum that persists for the following year (6,29,31). Unfortunately, P-cal must be applied before fire blight infections are visible because applications made after symptoms appear do not reduce disease (22). Despite its high cost, P-cal may be an IPM-compatible technology for managing fire blight in mature orchards where much of the product cost can be recovered via reduced costs of pruning treated trees.

![Fig. 3](image-url)
Cultural Changes and Technologies That Impact IPM

Cultural controls encompass such diverse strategies as avoidance (preventing contact between the crop and the pathogen), sanitation (removing inoculum), and adopting horticultural systems that either reduce plant disease or make disease control easier. Within existing cropping systems, cultural controls are often more difficult and expensive to implement than agrichemical-related technologies. As a result, cultural controls in apples have been implemented most effectively against diseases for which there were no alternative control methods.

Virus certification programs that were developed during the 1940s and 1950s provide an interesting historical example of effective cultural controls for tree fruit diseases. Scientists recognized that viruses were being transmitted to new plantings via virus-contaminated propagating materials. Pesticides have no direct impact on viruses, so farmers and scientists were forced to seek alternative measures. Individual scientists, state agencies, and national working groups designed programs that eliminated viruses from propagating material, maintained blocks of virus-free stock that could be accessed by propagators, and promoted production and purchase of virus-free planting stock for apples, pears, and most stone fruit crops. A national program for maintaining virus-free propagating stock for deciduous fruit trees is continued today as the National Research Support Project 5 (27). Virus certification programs for tree fruits have been so effective that many virus diseases are now rare in commercial orchards (Fig. 4).

![Fig. 4. Virus certification programs have effectively protected commercial orchards from virus and virus-like diseases such as dapple apple, a viroid disease that causes uneven fruit coloration (Fig. 4A), and apple mosaic virus (Fig. 4B).](image)

Other sanitation-based control strategies may receive more attention in the next decade than they have in the recent past, especially in cases where fungicide-based controls fail or become cost-prohibitive. Already, apple packinghouse operators are finding that improved sanitation is their only option for reducing losses to postharvest decays caused by fungicide-resistant isolates of *Penicillium expansum* (17). Development of fungicide resistance in *Venturia inaequalis* may eventually force apple growers to use sanitation measures to reduce the amount of apple scab inoculum surviving in orchards. Over-wintering populations of *Venturia inaequalis* can be reduced by chopping fallen leaves, treating leaf litter with urea or lime, or perhaps by using biocontrols to enhance leaf decomposition (3,23,25). All of these methods might be IPM-friendly, but costs associated with adopting these strategies and the incomplete control provided by most sanitation strategies have limited their adoption. Sanitation is rarely 100% effective for controlling apple scab, so some fungicide sprays are still needed to control scab in spring after sanitation measures have been applied. Sanitation may prove cost-effective in years when diseases subsequently reach epidemic proportions, but sanitation is unlikely to be cost-effective in dry years when there is little disease pressure. Fungicide strategies for controlling scab can be adjusted based on seasonal development and weather predictions, but the entire cost for sanitation work is incurred before the growing season begins. The fact that farmers will never know in advance which year is the “right year” to use sanitation makes this technology difficult to sell.
On-going changes in apple production systems have provided some unanticipated benefits for IPM. Over the past 25 years, apple growers have gradually removed old orchards that contained from 40 to 120 trees per acre and planted high-density orchards with 250 to 500 trees per acre (Fig. 5). When spraying large trees in old orchards, 400 gal of dilute spray per acre usually were required to achieve complete coverage whereas the smaller trees in high-density systems often can be covered using only half as much pesticide per acre. At the same time, productivity of mature high-density orchards is usually greater than for older orchards. As a result, the amount of pesticide required to produce a pound of apples has been reduced by at least 50% and perhaps by as much as 75%.

Fig. 5. Changes in production systems impact IPM practices: Replacing large old apple trees (Fig. 5A) with smaller, more productive trees (Fig. 5B) allowed apple growers to increase productivity and adopt new sprayer technology while reducing the quantity of pesticide applied to each acre of trees.

Most cultural changes that enhance pest management are employed at the farm level, but some of them are employed, either purposefully or inadvertently, as a result of national and international policies. National and international policies that result in crop production shifts from humid production regions to arid or semi-arid regions can reduce the need for fungicides. Fungicides are critical to production of apples and many other horticultural crops in eastern United States just as irrigation water is critical for production in arid climates. However, federal regulatory policies and food safety activists (e.g., promoters of organic farming) have generally highlighted the potential adverse effects of fungicides while paying scant attention to the environmental and social costs associated with arid-land production systems. Increasing costs associated with risk management for fungicides contribute to higher fungicide prices for farmers and may gradually limit production of some crops in humid production regions. Loss of regional production may result both in increasing costs for transportation of produce from arid regions to eastern population centers and in quality reductions attributable to the time and conditions required for long-distance transport.

**Plant Disease Models and Information Dissemination**

Plant disease models provide a structure for understanding disease development as it is influenced by environmental factors and host phenology. Computer-based plant disease models that encompass multiple aspects of crop production are often called expert systems or decision support systems. Complexities and limitations involved in developing, supporting, and commercializing decision support systems have been ably reviewed by Magarey et al. (14). Magarey and co-authors are optimistic about the feasibility of eventually developing a computer-based “super-consultant” that will provide real-time recommendations directly to farmers. However, given current constraints on public funding for developing, maintaining, and regularly updating computerized decision support systems, this technology is unlikely to displace the IPM consultants who currently provide a similar level of decision support on a more personalized basis.
During interactions with apple growers in New York and other parts of northeastern United States, I have observed that disease models often function best when they are invisible to the farmers who benefit from them. Most apple farmers lack either the time, the interest, or the background needed to understand and remember the details involved in complex plant disease models. They may even forget to run the models at critical times if they find themselves with too few hours in a day. Plant disease models are most compatible with farm-level IPM when crop consultants use the model output to formulate specific recommendations for the apple farmer (Fig. 6). For example, field extension specialists in New York State use the MaryBlyt model (26) to monitor for weather conditions that might favor blossom infections by *Erwinia amylovora* at one or more representative sites within their production regions. At the same time, they may monitor depletion of the seasonal supply of ascospores of *Venturia inaequalis*, the apple scab fungus, using the degree-day model developed by MacHardy and Gadoury (13). Information from these models and from other models that predict the emergence of apple insect pests in eastern United States is adjusted to fit regional needs (e.g., disease susceptibility of the predominant cultivars grown in the region, disease severity the previous year, etc.) and is then disseminated to growers via code-a-phones, fax, web sites, or e-mail. In this scenario, the disease models are nearly as invisible to the end-users as weather models are to those who rely on weather forecasts.

It is the author’s opinion that the greatest limitation on effective use of new apple disease models may be the gradual disappearance of the “experts” who traditionally have provided the final interface between models and farmers. Many of the skilled private consultants who originated from farms or from farm families are retiring and taking with them their accumulated wealth of applied knowledge. Decreased funding for cooperative extension programs and loss of applied-science positions at universities have reduced the pool of publicly funded experts. The decreasing number of university faculty engaged in field research also is compromising the ability of universities to train students for applied positions in pest management. Finding and hiring qualified crop consultants and IPM experts may become increasingly difficult in the future and could become a major constraint in the continued implementation of IPM.

Continued availability of trained IPM and crop consultants is critical to continued development and implementation of IPM. Economic constraints in agriculture work to the disadvantage of new technologies that diverge significantly from existing practices. The initial phases of implementing new technologies are seldom cost effective even if the technology later proves cost effective in the long run. Crop consultants can smooth the transition to new technologies because they benefit from repeating the introduction process with different clients. It is the author’s opinion that crop consultants also are ideally positioned to evaluate new IPM technologies because they see the technology applied across more diverse conditions than any individual farmer or scientist. Every day they spend on the job allows crop consultants to expand their...
experiential knowledge as they integrate economic, scientific, and observational data into real-life recommendations for farmers. Technological advances will enhance the capabilities of IPM and crop consultants in the future, but technology is unlikely to replace consultants.

**Conclusion**

Economic constraints in the production of apples and perhaps other horticultural crops limit the adoption of many new IPM-friendly technologies. New agrichemicals, more efficient production systems, better disease-control models, and new technologies for information transfer to farmers or crop advisors are all essential components of IPM, but not all new technologies are cost-effective. Because of the diminishing profit margins for apples and other horticultural crops, and because of the complexities involved in evaluating new technologies, farmers will increasingly turn to crop consultants for advice on when and how to integrate new disease-control technologies into their production systems. Consultants, whether they are self-employed, publicly funded, or employed by corporate farm enterprises, will become the ultimate arbiters of IPM-compatibility.

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**Literature Cited**


