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Integrated Pest Management Programs for Strawberries in the Northeastern United States

In 1987, Massachusetts and New York each introduced integrated pest management (IPM) programs for strawberries. Several factors fostered these introductions, including the relatively high value per acre of strawberries and the presence of established IPM programs on other commodities. For instance, apple IPM programs in each state had already developed tactics for management of two key arthropod pests that also attack strawberries, tarnished plant bug (TPB, *Lygus lineolaris* (Palisot de Beauvois)) and two-spotted mite (TSSM, *Tetranychus urticae* Koch), showing the potential for transfer of useful IPM methods from the apple to the strawberry agroecosystem. Additionally, significant information relevant to an IPM system for managing the region's primary strawberry disease, gray mold (*Botrytis cinerea* Pers.:Fr.), was being generated in New York, Ohio, and Ontario. Thus, the combination of appropriate IPM methods for management of key strawberry pests and the opportunities offered by publicly supported IPM funding led specialists at the University of Massachusetts and Cornell University to independently decide they should develop strawberry IPM programs in their respective states.

The fundamental concepts underlying IPM programs are similar, and Dover (13) summarizes them well: (i) optimization of pest control in an ecologically and economically sound manner; (ii) emphasis on coordinated use of multiple tactics to enhance stable crop production; and (iii) maintenance of pest damage below injurious levels while minimizing hazards to humans, animals, plants, and the environment. Although IPM programs generally are based on these goals, over the past 20 years, the emphasis has changed. Specifically, the most common motivations behind IPM projects in the 1970s and early 1980s were to develop cost-saving production techniques or to reduce the chance that pests would become resistant to pesticides; whereas the recent emphasis has focused on food safety and environmental sustainability (41). The importance of applicator safety has also increased (Fig. 1). Despite this shift in the forces driving IPM, the typical pattern of program development is often similar among individual commodities.

Generally, the first step in developing an IPM program is to move from preventive, calendar-based pesticide applications to pesticide applications made only when there is potential for significant crop damage (e.g., 19,37,47). Potential for damage is determined using regular observations of pathogens or arthropods in the field and environmental monitoring to establish criteria for treatment (e.g., action thresholds). Action thresholds may be based on any of several parameters, including pest abundance, environmental conditions, host phenology, or pest development. Using such data, this approach often maximizes the efficiency of effective crop protection chemicals. Reducing pesticide applications and selecting materials that are less harmful to predators and parasites may encourage the development of natural biological control, particularly for phytophagous mites. This further decreases the need for pesticide applications, developing a momentum toward decreased pesticide use, although the IPM program remains firmly based on chemicals. As IPM programs evolve, policy makers, growers, and researchers expect that additional reductions in chemical use will ensue, although such reductions are increasingly difficult to attain. To address this problem, IPM programs recently have placed increased emphasis on more biologically and culturally based alternatives to chemical control (18,55).

We will describe aspects of the development and implementation processes for strawberry IPM programs in New York and Massachusetts. We also will describe methods we used in dealing with a number of economically important strawberry diseases, insects, and mites. Finally, we will present data evaluating the impact of our programs and information on the costs and benefits of running them.

Development of Priorities for Strawberry IPM Programs

Strawberries are attacked by a large number of pests (31). Specific types of agroecosystems will have a typical pest complex in a given area, in which some pest species play a more prominent role than others. Rather than deal with all pest management problems in a given agroecosystem, it usually is more efficient to prioritize problems and develop an IPM program around the most important, or key, pests. Key pests can be determined using several factors: (i) the potential for economic damage, (ii) the relative amount of management needed (particularly chemicals), and (iii) the availability of some form of alternative management technique.

For strawberries, we established a list of major pests and grower management prac-

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tices using two different approaches. In New York, an approach that could be classified as top-down was used. We first talked to research and extension personnel to identify pest problems and their relative priority, and the availability of protocols that could be implemented immediately. In Massachusetts, we conducted a survey of strawberry growers in 1987, then judged the relative importance of a given pest using estimates of damage generally experienced by growers, the expected damage if no pest management was employed, and the extent and frequency of treatments needed for its control. General expected pesticide use patterns were determined from the existing extension management recommendations.

The strawberry pest control recommendations at that time indicated that growers using a strict, calendar-based schedule might make from eight to 14 fungicide applications for a number of diseases, four to eight insecticide–miticide applications for several arthropod pests, one to three herbicide applications to manage weeds, and might fumigate soil before planting. The Massachusetts survey obtained 32 responses from approximately 25% of the growers who were sent forms, which showed that in a year typical for weather and pest pressure, this group of strawberry growers averaged 5.6 fungicide applications (range 0 to 15); 2.0 insecticide + miticide applications (range 0 to 7); and 2.7 herbicide applications (range 0 to 5). Apparently, growers had already realized that the calendar-based recommendations were excessive.

The same survey showed that growers considered gray mold their most important problem, and that it was the target of most, and often all, fungicide applications in a given season. Gray mold was followed in importance by TPB, TSSM, and strawberry bud weevil or clipper (SBW, *Anthonomus signatus* Say). Black root rot, a disease complex involving the lesion nematode, *Pratylenchus penetrans* (Cobb) Filip. & Stek, binucleate *Rhizoctonia* spp., *Pythium* spp., and abiotic stress (53), also represented an important disease problem. While there are many arthropods and pathogens that can cause significant damage to strawberries in the Northeast, only these arthropods and pathogens present significant problems to most growers in most years (Table 1). Weeds, as a general category, also were identified as a major pest problem in strawberries, but we did not attempt to determine which species might be most important.

Next, we sought established IPM methods to control the key pests. On this basis we concluded that in Massachusetts, the best chance for rapid introduction of IPM methods involved management of *Botrytis*, TPB, and TSSM. Monitoring and treatment options for SBW were not well developed, but because SBW occurred frequently and could be devastating, the Massachusetts program also monitored it in the first years of the program. Similarly, *Botrytis*, TPB, TSSM, and SBW were the major pests addressed by the New York program. Other pests monitored were the meadow spittlebug (*Philaenus spumarius* (Linnaeus)) and root weevils. Both programs identified black root rot and weeds as significant problems, but at that time monitoring and treatment options did not exist for either.

Development of Management Practices for Key Pests

Botrytis. In 1960, Powelson (38) showed that gray mold of strawberry fruits (Fig. 2) often results from the expansion by *B. cinerea* from latent infections of the floral parts into the receptacle. He concluded that the calyx is the primary pathway of infection for the pathogen and suggested that the disease control provided by a captan spray program in the Wil-

Fig. 1. Pesticide application for strawberry bud weevil (*Anthonomus signatus*) on strawberries made ca. 1940, when applicator safety and environmental protection were not believed to be important issues.

Table 1. List of major strawberry arthropod and disease pests in New York and Massachusetts, with key pests marked by a bullet

Common name	Binomial
Arthropods	
•Strawberry bud weevil	*Anthonomus signatus*
•Tarnished plant bug	*Lygus lineolaris*
•Two-spotted mite	*Tetranychus urticae*
Black vine weevil	*Otiorhynchus sulcatus*
Cyclamen mite	*Steneotarsonemus pallidus*
Green leaf weevil	*Polydrusus sericeus* or *P. impressifrons*
Leafroller	*Ancylis comptana fragariae*
Meadow spittlebugs	*Philaenus spumarius*
Strawberry aphids	*Chaetosiphon* spp.
Strawberry sap beetle	*Stelidota geminata*
White fly	*Traileurodes packardi*
Pathogens	
Anthracnose	*Colletotrichum* spp.
Black root rot	*Rhizoctonia* spp., *Pythium* spp., *Pratylenchus penetrans*
Crown rot	*Phytophthora cactorum*
•Gray mold	*Botrytis cinerea*
Leaf blight	*Phomopsis obscurans*
Leaf scorch	*Diplocarpon earliana*
Leaf spot	*Mycosphaerella fragariae*
Leather rot	*Phytophthora cactorum*
Lesion nematode	*Pratylenchus penetrans*
Powdery mildew	*Sphaerotheca macularis*
Red stele	*Phytophthora fragariae*

lamette Valley of Oregon was due to the protection of this infection court by the fungicide. Published reports from Belgium in 1959 (20) and England in 1978 (26) also demonstrated that season-long fungicide programs derived most, if not all, of their efficacy from the applications made during bloom.

Nevertheless, in the mid-1980s, we found that these reports were generally unknown or disregarded by most strawberry growers and their advisors: fungicide labels and extension publications typically recommended that gray mold sprays not only begin at early bloom, but continue at regular intervals until the completion of harvest. Discussions with individual growers and the aforementioned Massachusetts pesticide use survey both suggested that these recommendations were generally being followed, resulting in approximately five to seven fungicide applications to manage gray mold. Consequently, spray timing experiments were initiated in New York in 1986 to determine whether a reduced number of fungicide sprays applied only during the bloom period could control gray mold as effectively as a season-long program under local conditions. The resulting data unequivocally supported this hypothesis (51), and the New York IPM program quickly adopted the recommendation that the fungicidal component of a gray mold management program consist of only two sprays, i.e., at early bloom and approximately 10 days later. Similarly, tests on commercial farms in Massachusetts in 1988 compared one to three bloom sprays to growers' normal season-long fungicide programs on the same farms, showing that under a variety of conditions, bloom applications controlled gray mold as well as did a season-long program (45).

Substituting host phenology for detailed monitoring of pathogen development and/or environmental variables is simplistic, but it is a concept that is easy for growers to grasp and implement. It is also effective (45,49,51), helping strawberry growers in our states achieve economically acceptable levels of gray mold control while limiting the number of fungicide

Fig. 2. Advanced stage of gray mold showing infected berry covered with characteristic masses of *Botrytis cinerea* conidia, and early stage showing necrotic lesion expanding from sepals into the receptacle.

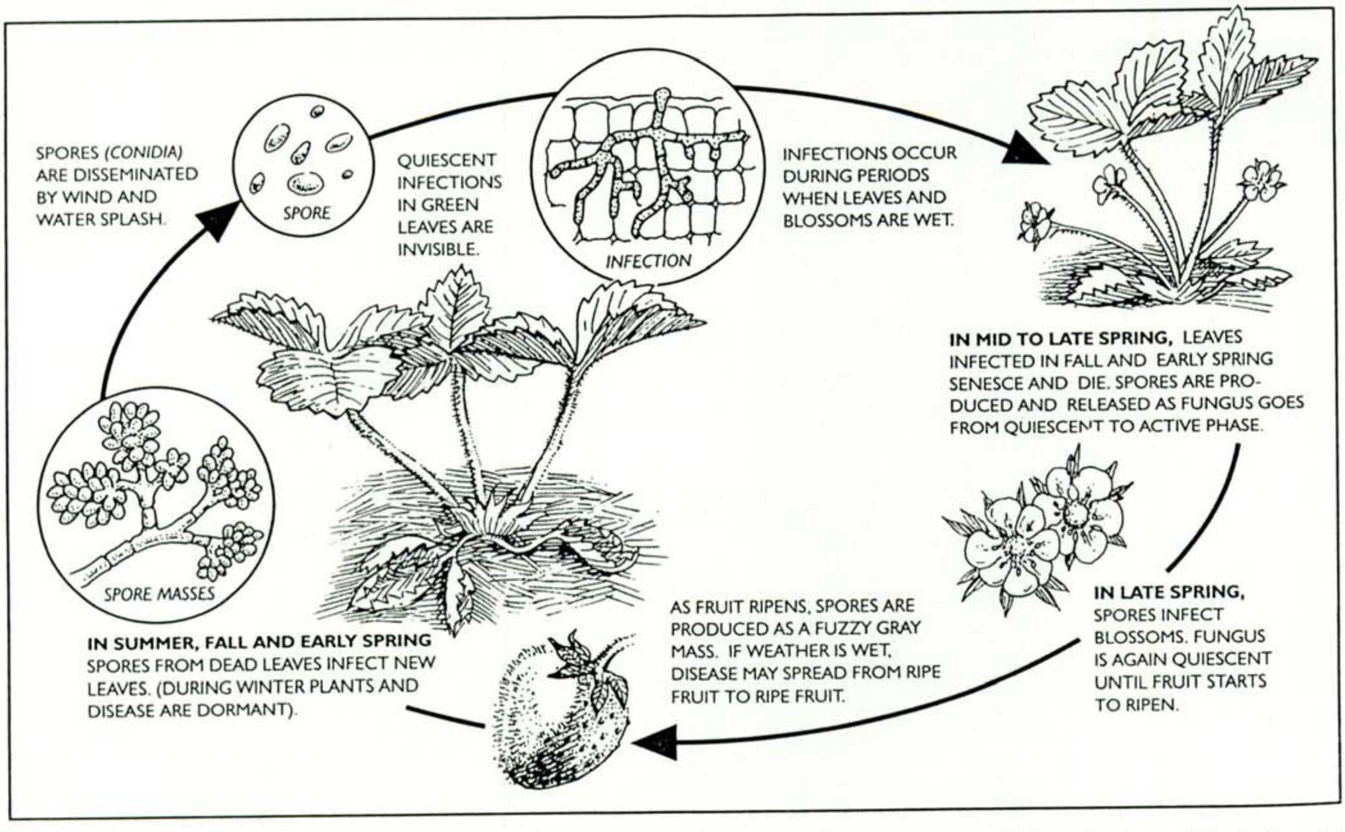

Fig. 3. A grower-oriented representation of the disease cycle of gray mold of strawberry, caused by *Botrytis cinerea* (9), designed to emphasize the importance of foliar and bloom infections.

applications and, presumably, residues on the fruit at harvest. Relatively recent data concerning the influence of environmental variables on infection and disease development (5,51) may allow a further refinement of this program by more precisely identifying the times during bloom when fungicidal protection is needed.

Research on the gray mold disease cycle (Fig. 3) suggests that it may be possible to interrupt it even before blossoms are available for infection by suppressing the production of pathogen inoculum. Although *B. cinerea* is a cosmopolitan organism, nearly all inoculum responsible for initiating the floral/fruit infections of strawberries originates from strawberry leaves within the same field (3). Typically, the fungus establishes quiescent infections in young leaves, which subsequently expand and sporulate as the leaves senesce and die (4). Thus, stages of growth when new leaf production is high could be targeted for fungicide applications to protect against these initial infections, or senescing or dead leaves could be targeted to suppress sporulation. Both strategies have been tested elsewhere with some success (2,48).

In a replicated experiment in 1989, we (D. R. Cooley and S. G. Schloemann) tested protection and destruction of leaves in the fall as a means of reducing the availability of inoculum during the subsequent flowering and fruiting season. Plants were treated in one of the following ways: mowed to approximately 10 cm high, then raked to remove debris; flamed using a hand-held propane torch, which generated enough heat to incinerate dead leaves; or sprayed with vinclozolin (Ronilan 50 WP) at 1.12 kg a.i./ha. Positive controls received three applications of vinclozolin at 1.12 kg a.i./ha at early, mid-, and late bloom; negative controls received no fungicide. At harvest, incidence of gray mold on fruit in a 1-m segment of row was assessed. As with previous work (2,48), the single fungicide applied in the fall controlled gray mold as well as a series of three fungicide applications at bloom (Table 2). However, leaf destruction did not reduce gray mold incidence from levels in untreated controls. Flaming actually increased disease incidence, perhaps because it injured leaves and predisposed them to infection.

Standard cultural practices also can have a tremendous influence on gray mold development. In fact, we found that variations in disease incidence among growers were associated with differences in cultural practices more often than with differences in fungicide programs. Good aeration around host tissues often minimizes the incidence and severity of diseases caused by *B. cinerea* (e.g., 17), and our observations indicated that factors promoting air circulation within the strawberry canopy were a critical part of a gray mold management program. Thus, we strongly encouraged site selection to promote air drainage, maintenance of row widths no greater than 60 cm (NY) or 70 cm (MA), and excellent weed control.

Additionally, one of us (W. F. Wilcox) recently concluded a 3-year study showing that supplemental prebloom applications of nitrogen at 33.6 and 67.2 kg/ha increased gray mold incidence by 141 and 198%, respectively, relative to the standard application of N at renovation only (52); since there is no documented yield benefit from these supplemental N applications, we are now discouraging them as part of an integrated approach to gray mold management.

Applying IPM to gray mold has consisted of making fungicide timing more efficient and using cultural management components to decrease the need for fungicides. We have also integrated management of gray mold with management of mites by recommending that benomyl be avoided because this fungicide may sterilize predator mites and interfere with mite biocontrol (10).

While some old references on strawberry disease management (e.g., 1) suggest that a heavy mulch layer may increase gray mold development, more recent research has failed to support such a relationship. Thus, we judged the benefits of organic mulch were substantial in a strawberry IPM program. Mulching is a standard practice used to reduce winter injury as well as to control weeds. An organic mulch layer, usually consisting of wheat or rye straw, between the soil and fruit greatly reduces splash dispersal of *Phytophthora cactorum* (Lebert & Cohn) J. Schröt and therefore can significantly reduce leather rot development (32).

Mites. Although it is agreed that TSSM can reduce strawberry yield and growth, there has been no general agreement on what constitutes an economic injury level (EIL) or an appropriate action threshold. The strawberry literature reports EILs that vary from 20 to 100 mites per leaflet (35,42). Growers treat with miticides but vary widely in what they feel is a potentially damaging population of mites. The scarcity of miticides labeled for strawberries further complicates TSSM management. Finally, resistance to miticides is common and may develop rapidly (21). It was apparent to us in developing our programs that alternatives to the few chemical miticides registered for strawberry would enhance mite management.

The predatory mite *Amblyseius fallacis* (Garman) occurs naturally in strawberry plantings in the Northeast and can control TSSM populations in various crops, including strawberries (11). *A. fallacis* is also reared and sold commercially (e.g., Stanley Gardens, Belchertown, MA). In both New York and Massachusetts, we attempted to foster natural biocontrol of mites by limiting use of chemicals that might be harmful to predators, in particu-

Table 2. Various treatments compared to a standard fungicide program for control of gray mold on strawberry cv. Sparkle in Massachusetts in 1989 and 1990

Treatment	Disease incidence (%)[v]
Flaming[w]	31.9 a
Leaf removal (mowing and raking)[x]	16.2 bc
Fall vinclozolin (1.12 kg a.i./ha)[y]	10.7 c
Fungicide standard (vinclozolin, 1.12 kg a.i./ha, 3 bloom applications)[z]	11.5 c
Control (no treatment)	19.9 b

[v] Values represent the means from four replicate plots per treatment. Means not followed by a common letter are significantly different at $P \leq 0.05$ by Fisher's LSD.

[w] Performed in mid-November 1989 using a hand-held propane torch for sufficient time to incinerate dead leaves under the flame.

[x] Plants were mowed in mid-November 1989 to approximately 10 cm height using a rotary mower, and the debris was raked from the row by hand and removed.

[y] Vinclozolin (Ronilan 50 WP) applied in mid-November 1989 using a hand-pumped sprayer applying suspension at approximately 935 liters/ha.

[z] Vinclozolin (Ronilan 50 WP) applied in 1990 when 10% of the blossoms had opened, again when 50% of the blossoms had opened, and when 90% of the blossoms had opened, using a hand-pumped sprayer applying suspension at approximately 935 liters/ha.

Fig. 4. Typical tarnished plant bug damage to strawberry fruit, where the apex of the fruit exhibits poor development and a dense layer of seeds relative to the calyx end of the berry.

lar synthetic pyrethroids, carbaryl, dicofol, and benomyl. In Massachusetts, if this approach failed, we would recommend *A. fallacis* releases of 25,000 predators per hectare when weekly TSSM population monitoring indicated an average of two TSSM per leaf and no resident mite predators were found. If predators were found, the action threshold for release of additional predators to augment the natural population increased to five TSSM per leaf.

Tarnished plant bug. TPB damage (Fig. 4) can reach levels of 60 to 70% of a strawberry crop (43). Apple IPM programs have used a sticky visual trap (15 × 20 cm white rectangle) to monitor plant bug adults (40). The same trap placed 10 to 15 cm above the canopy or around the borders of strawberry fields captures adult TPB, but trap captures have not correlated well with fruit damage. This is primarily due to the confounding factor of berry injury caused by the nymphs, which are not caught on traps since they do not fly. Instead, TPB nymphs may be monitored by shaking flower trusses over a flat, white surface (Fig. 5) and counting those that fall out.

In different parts of the Northeast, either adults, nymphs, or a combination of both may cause significant berry damage. In Massachusetts, both can be a problem, and we used a hybrid approach for TPB. White TPB traps were placed at approximately 30-m intervals around the edges of the field at canopy height and checked weekly to indicate when adults were active and moving into the field. For fields with a history of TPB damage, a prebloom spray was recommended to suppress egg laying if trap captures exceeded two adult TPB per trap. Nymph monitoring began when the flower trusses were elongated enough to shake. An action threshold of 0.25 TPB nymphs per truss has been established for strawberries before 10% bloom (33,34). In New York, only nymphs were monitored and were used as the basis for making TPB treatment decisions. When an insecticide was needed, we attempted to time applications to also have an effect against SBW, and we selected materials that would be least harmful to *A. fallacis* (e.g., endosulfan at 0.56 kg a.i./ha before 10% bloom).

Fig. 5. A scout shaking fruit trusses and collecting insects on a white surface to estimate the population of tarnished plant bug nymphs (*Lygus lineolaris*).

The strawberry bud weevil. SBW, or "clipper," is the third key arthropod pest of concern in these strawberry IPM programs. SBW occurs somewhat less frequently than TPB in strawberry in the region, but when present it often causes economic injury by severing the peduncle prior to bloom, leaving detached flower buds on the ground. Naturally, the clipped buds will not develop into berries.

An action threshold of one female per 12 m of linear row or one cut bud per 0.6 m has been suggested (34). Because finding and identifying SBW in the field can be problematic, we used an action threshold for SBW damage of two clipped buds per meter of row (29). We further adjusted this threshold to accommodate our scheduled weekly field visits. If allowed to go unchecked, significant SBW damage can occur in 1 or 2 days, so the action threshold effective for a week must be relatively low. In fields where significant SBW injury was observed in previous years, any sighting of SBW warranted action once the flower trusses were visible in the crowns. In these fields, weekly scouting was not always frequent enough to detect migration into the field before economic losses occurred, although the qualitative threshold and grower scouting between visits helped limit SBW injury. In fields without a history of SBW damage, weekly scouting using the two-clipped-buds-per-meter action threshold provided adequate commercial control.

SBW treatment consisted of applying a recommended material when the threshold was reached. If after 7 to 10 days, plants had not yet reached 10% bloom, the application was repeated. We avoided using chlorpyriphos against SBW, as it may interfere with mite biocontrol.

Program Delivery

Strawberry growers generally have been eager to cooperate with our programs or to hire scouting and consultant services, particularly when the costs for such services have been subsidized. In Massachusetts, the university-based strawberry IPM program incorporated the use of weekly scouting visits to each cooperating grower location, alerting the grower to the current pest status in the field and making recommendations for treatment when needed. In 1989, a private pest management consultant began to scout strawberries, working in consultation with the university program. Since then, the size of the university program has progressively decreased, while the hectares of strawberries served by private consultants has increased (Fig. 6). At present, two private consultants in Massachusetts scout several crops, including strawberries, making travel more efficient, at least to those farms where several crops may be under contract to a single consultant. It is worth noting that much of the time spent in strawberry IPM scouting and consulting was spent traveling to sites (60% in New York, 40% in Massachusetts); hence, doing several crops on a farm or having a geographically concentrated group of clients increases a consultant's efficiency.

Private consulting has not fared as well in New York. The New York IPM program

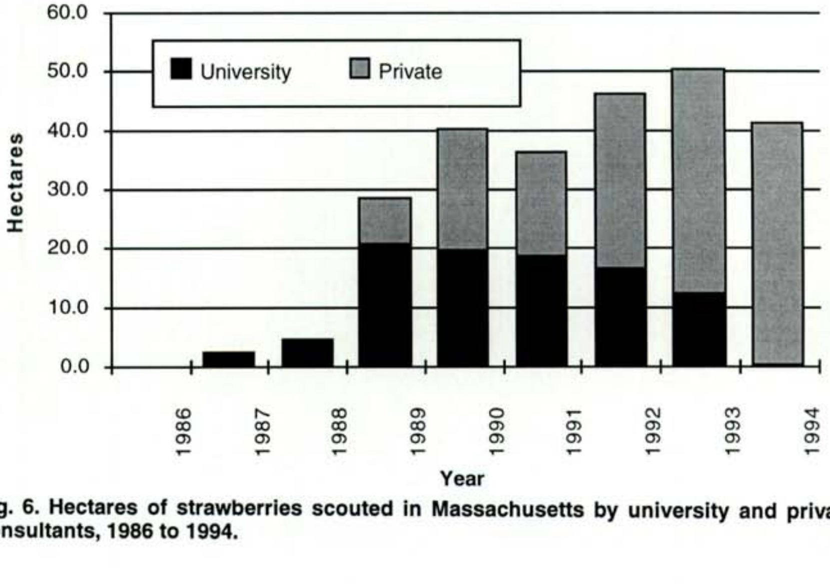

Fig. 6. Hectares of strawberries scouted in Massachusetts by university and private consultants, 1986 to 1994.

initially funded the strawberry scouting pilot project for 3 years, anticipating that growers would value this information to the extent that they subsequently would pay for a private consultant to continue scouting. However, it became clear that strawberry scouting alone could not provide an adequate income for consultants, and that additional crops would have to be scouted. When the strawberry program ended after the 1989 season, three scouts trained by the program offered IPM consulting services to growers of a variety of crops, and most growers from the pilot project did hire a scout for their strawberry acreage. However, none of these individuals is in the consulting business today. In addition, over the last 5 years, seven to eight well-trained individuals have tried to develop strawberry consulting businesses in New York, usually in combination with field crops, vegetables, tree fruit, or greenhouse scouting. All have failed because travel and administration costs were too high and profit margins were too low.

Strawberry growers in Massachusetts have paid higher IPM consulting fees than New York growers. Presently, neither university contracts strawberry IPM services with growers, but Massachusetts last charged \$75/ha for bearing beds and \$25/ha for new plantings on a total of 21 ha. By comparison, Cornell charged an average of \$38/ha on 146 ha. Thus, although costs for scouting, hourly wages, and travel during the scouting season (May through August) were approximately \$4,500 in Massachusetts and \$11,400 in New York, the fees covered only 35 and 49% of these direct costs, respectively. Furthermore, these costs did not include significant contributions by full-time IPM specialists and associated faculty, insurance, benefits, or administrative expenses. Hence, the universities have subsidized strawberry IPM programs significantly in both states.

Other public agencies outside the land grant universities have subsidized IPM, successfully encouraging growers to hire private consultants. Since 1990, growers in some parts of Massachusetts were paid up to \$34.58/ha by an Agricultural Stabilization and Conservation Service (now Consolidated Farm Services Association) program to increase participation in IPM programs. However, unless public subsidies continue, or growers begin to pay the full expense, strawberry IPM programs will not be able to survive in states like New York and Massachusetts.

In Massachusetts, the scouting data have been used to generate 10 to 14 written communications per season (one per week from April through mid-July) sent to approximately 200 subscribing growers. In addition to data indicating which pests were active, messages included time-sensitive information such as crop phenology, general weather and pest observations, and brief descriptions of IPM practices appropriate for the upcoming week. These messages have been distributed by surface and electronic mail to most commercial growers in Massachusetts since 1988.

We have also cooperated in the development of a regional strawberry IPM manual (9) and have met with growers, specialists, and researchers from other states to explain our programs (e.g., 8,16,27,45,46,50). For example, we cooperated in developing a strawberry IPM program in Minnesota, including production of a videotape on strawberry IPM (14). Cooperative efforts like this appear to us to be the best way to efficiently implement IPM.

Program Evaluation

Reporting the impact of IPM programs remains problematic for several reasons. When comparing costs or pesticide use for an IPM program versus a standard pest management program, each set of practices must be defined. Over time, these definitions lose relevance as useful IPM methods are adopted by most growers and become the new standard. Measuring the environmental impacts of pesticides, such as water contamination or reduction of nontarget species, is particularly difficult (24,28,30), and as a result so is quantifying the environmental impacts of an IPM program. Accomplishments in research and development are somewhat easier to quantify, but the relevance of such work may not be readily understood by the public. Ultimately, public trust in agricultural pest management proves whether IPM has had impact, although this is probably the most difficult assessment to make.

Most programs report results with an emphasis on the amount of pesticide used during the season. In Massachusetts' pro-

Table 3. Average dosage equivalents of types of pesticides used in Massachusetts by strawberry IPM cooperators and growers not involved in the IPM program. A dosage equivalent equals the rate of pesticide actually applied divided by the maximum rate of the pesticide recommended for that application. Dosage equivalents are summed for each program in each year

	Dosage equivalents by program and year									
	IPM program[x]						Standard program[x]			
Type of pesticide	88[y]	89[y]	90[z]	91[z]	92[z]	93[y]	87[y]	90[z]	91[z]	92[z]
Miticides	0.1*	0.1*	0.2	0.1	0.0*	0.0*	0.4	0.2	0.0	0.1
Fungicides	2.1*	2.5*	2.9	1.7*	1.8*	2.0*	4.1	3.5	2.6	2.9
Insecticides	1.0*	1.1*	1.5*	2.0	1.2*	1.3*	1.6	1.9	2.0	1.6
Herbicides	2.0	1.5*	1.2*	1.5*	2.5*	2.2*	2.5	2.5	2.9	3.0
Fumigants	0.3*	0.3*	0.3*	0.2	0.1*	0.1*	0.5	0.4	0.2	0.2
Total	5.5*	5.4*	6.0*	5.5*	5.5*	5.6*	9.1	8.6	7.7	7.8

[x] Pesticide use for growers in the program established via pre-IPM project survey data.

[y] Asterisks indicate significant differences in pesticide use by IPM cooperators in 1988, 1989, or 1993 compared to use by the same growers in 1987 ($P = 0.05$ by paired t tests).

[z] Asterisks indicate significant differences in pesticide use by IPM cooperators in 1990, 1991, or 1992 compared to use by a similar set of nonparticipating growers in each year ($P = 0.05$ by independent t tests).

Table 4. Relative difference in the dosage equivalents of different types of pesticides and total pesticides applied by Massachusetts IPM cooperators and nonparticipating growers

	Percent reduction in pesticide use[w]					
	Compared to pre-IPM use[x]			Compared to non-IPM use, same year[y]		
Pesticides	1988	1989	1993	1990	1991	1992
Miticides	–67%*	–81%*	–100.0%*	–32%*	100%*	–100%*
Fungicides	–49%*	–38%*	–51%*	–18%	–35%*	–39%*
Insecticides	–36%*	–31%*	–19%*	–24%*	1%	–29%*
Herbicides	–19%	–41%*	–12%	–53%*	–47%*	–14%
Fumigants	–49%*	–51%*	–80%*	–31%*	–9%	–63%*
Total[z]	–40%*	–41%*	–39%	–31%*	–28%*	–29%*

[w] Percentages marked with an asterisk (*) were significantly different from controls ($P = 0.05$ by independent t tests).

[x] Data from IPM cooperators in 1988, 1989, or 1993 compared to applications by the same growers in 1987 ($P = 0.05$ by paired t tests).

[y] Data from IPM cooperators in 1990, 1991, or 1992 compared to applications by a similar set of nonparticipating growers in each year ($P = 0.05$ by independent t tests).

[z] Percentages based on total dosage equivalents of all pesticides in a given year.

grams, pesticide savings are reported in terms of dosage equivalents (DE), where one DE equals the rate of pesticide actually applied in a given spray application divided by the maximum rate of the pesticide recommended for that application. DEs for each management system (IPM or standard) are summed for a season and compared.

Each year under IPM recommendations, cooperating growers in Massachusetts reduced pesticide applications by 2.2 to 3.6 DE (26 to 40%) compared to growers who were not in the program (Tables 3 and 4). Over 6 years, two types of comparisons were made. The first type, used in 1988, 1989, and 1993, compared pre- and post-program pesticide use data for a single set of growers. For 1990 through 1992, comparisons were made each year between IPM cooperators and a group of growers not enrolled in the program that year. For each of the 6 years, total DE of pesticide used were significantly lower for IPM cooperators than for non-IPM growers (independent *t* test at $P = 0.05$). When use was categorized by type of pesticide (i.e., miticide, fungicide, insecticide, herbicide, and fumigant), IPM cooperators used significantly less pesticide in all but five of the 30 comparisons made (Tables 3 and 4).

Even for those types of pesticides for which no IPM recommendations were given (i.e., the herbicides and fumigants), use by IPM cooperators was less than by the control groups in most cases. This suggests several possibilities, e.g., (i) growers that chose to participate in the IPM program were inherently predisposed towards implementing pesticide use reduction, notwithstanding a formalized program; (ii) on average, participating growers represented a more efficient segment of the industry than nonparticipants and were less likely to use pesticides unnecessarily; and/or (iii) positive results accruing from the implementation of IPM fungicide and insecticide recommendations and greater contact with University consultants convinced these growers that they could reduce their use of herbicides and fumigants as well.

In addition, pesticide use from 1987 to 1992 decreased for *all* Massachusetts strawberry growers, regardless of whether they claimed to practice IPM. This suggests that standard recommendations incorporated an IPM approach to at least some extent and that many growers were adopting these practices. For instance, in 1992 in a random sample of Massachusetts strawberry growers, 86% described themselves as practicing IPM. Despite this general grower acceptance of IPM principles and declining pesticide use, cooperators in Massachusetts have consistently used approximately 30% less pesticide than growers outside direct contact with the program.

Table 5. Comparisons of fruit quality from Massachusetts IPM cooperators and growers not involved in the IPM program in a typical year (1990) as evaluated from early, mid-, and late-season harvests combined. Data are mean percentages of fruit in each damage category

Type of damage	IPM cooperators[z]	Controls[z]
None	69%	68%
Tarnished plant bug	11%	9%
Gray mold (*Botrytis cinerea*)	2%	3%
Non-pest-damaged culls	18%	20%

[z] Data from 10 IPM cooperators and 10 comparable nonparticipating growers in 1990. Differences were not significant (paired *t* tests at $P = 0.05$).

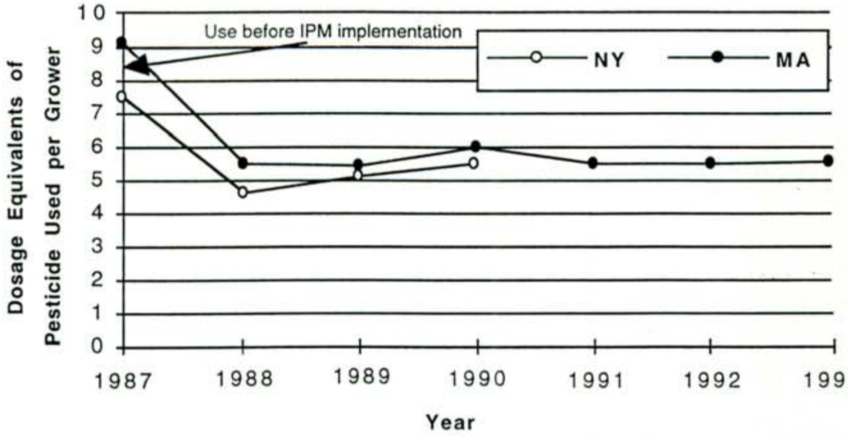

Fig. 7. Changes over time in total pesticide dosage equivalents used by strawberry growers involved in IPM programs in New York and Massachusetts, where a dosage equivalent equals the rate of pesticide actually applied divided by the maximum rate of the pesticide recommended for that application.

Miticide use on strawberries has been quite low for all Massachusetts growers, perhaps indicating a widespread adoption of the IPM approach to mite management. The program monitored TSSM, *A. fallacis* populations, and the effect of introducing *A. fallacis* for 5 years. Once a week, we monitored either 16 (1988 to 1989), 11 (1990 to 1991), or six sites (1992) by counting the number of TSSM and *A. fallacis* (resident and released) per leaf, and we collected spray records at the end of each season. Of these 60 cases, 41% had no TSSM outbreaks, 15% controlled TSSM with *A. fallacis* releases (one release per season), 22% had TSSM outbreaks that were brought under control with resident populations of *A. fallacis*, 6% controlled TSSM with miticides alone, 7% controlled them with a combination of miticide applications and predator releases, and 8% were unable to control TSSM outbreaks with either predators or miticides. Of the cases where no TSSM outbreaks occurred, resident populations of *A. fallacis* were found 30% of the time, suggesting that biological control was operating in these fields to keep TSSM at low levels (46). Maintaining a resident population of predators appeared to be the most effective way to prevent TSSM populations from reaching outbreak levels.

Harvest surveys in Massachusetts indicated that the quality of fruit grown by IPM cooperators was at least as good as that produced by other growers (Table 5). We evaluated fruit quality for each cooperating grower each year by selecting 10 random locations in a scouted field and picking all ripe fruit in 0.5 m of row at each location. Fruit were counted, weighed, and sorted for different types of damage (e.g., gray mold and TPB). From 1990 to 1993, we also evaluated commercial fields not cooperating with the IPM program, sampling from similar beds growing the same cultivars. When fruit quality parameters were compared using paired *t* tests ($P = 0.05$), there was no difference between IPM and conventional management.

In strawberries, cost savings alone probably would not motivate growers to adopt IPM. Saving one to three applications of most fungicides and insecticides would save approximately $20 to $360/ha per year. (Fumigation represents a far greater expense, from $1,000 to $2,500 per ha, but our programs did not have adequately proven alternatives to fumigation to recommend). Commercial strawberries in the Northeast gross approximately $12,000 to $50,000 per ha, making fungicide, insecticide, and miticide investments quite minor, and even low incidences of pest damage quite costly. However, many strawberry growers have an interest in using IPM as a marketing tool, and this interest may be a major factor influencing growers to adopt IPM.

To help strawberry growers in this effort while maintaining the integrity of the IPM designation, the Massachusetts Department of Food and Agriculture IPM Certification Program announced guidelines and provided support to those who wanted state IPM certification (23). These standards are a set of required and optional pest management practices, each of which provides points towards IPM certification. If a grower uses enough IPM practices and accumulates the associated points, certification is given and the grower gains access to logos and other IPM marketing materials. In contrast, efforts to establish a similar certification program in New York were abandoned, in large part due to opposition from various segments of the agricultural industry. A chief objection among opponents was the negative publicity that might befall nonparticipating growers, corresponding to the positive publicity anticipated by those seeking certification.

The Future of Strawberry IPM

Soon after the start of these two strawberry IPM programs, pesticide use dropped to a relatively constant level (Fig. 7). Data from both Massachusetts and New York show that in a given year, IPM growers have consistently used between five and six applications of all pesticides. Further reductions will require new IPM technology, such as nonpesticide alternatives. "Biointensive" approaches to IPM, emphasizing biological and cultural controls, may be the next phase in the evolution of many IPM programs (18,25). However, the challenge of developing biological and cultural controls in strawberries adequate to replace existing pesticides is just beginning to be met (e.g., 36).

The issue of soil fumigation illustrates this point. In Massachusetts in recent years, the annual quantity of soil fumigants used per ha of strawberries far exceeded that for all other types of pesticides combined (Table 6). Examining pesticide use in terms of dollars spent generated a similar pattern. Soil fumigation essentially sterilizes the soil and generally increases strawberry yield (54). Some plant pathologists have argued that biological control provided by the establishment of a rich soil microflora may accomplish the same objective (6). Yet the mechanisms involved in disease suppressiveness, biological control of plant pathogens, and plant growth promotion are complex. They include competition, antibiosis, predation/parasitism, symbiosis, and other factors (7). In addition, any alternative to fumigation probably will involve more than straightforward substitution of a biological control agent, but instead will combine several practices such as modification of physical and chemical soil characteristics with organic amendments, enhancement of host resistance, and implementation of crop rotations. A single fumigant application manages many problems, and it may take several biologically intensive alternatives to manage even one of them. Finding effective alternatives to soil fumigation is a complex and intimidating task.

In spite of the difficulties, this process has begun. Research on black root rot has provided a better understanding of the etiology of the disease complex (53), and alternative management techniques such as cover-cropping have been tested with limited success (44). New recommendations for alternative management of weeds also emphasize cover crops and mulches, suggesting that these cultural controls will play a more important role in future strawberry IPM programs (39).

Biointensive management options for gray mold are being developed. In Ontario, *Botrytis* biocontrol agents vectored by bees were as effective as fungicides (36,49). Research on row architecture and nitrogen fertilization in New York offers cultural control options for gray mold (52). Modeling of gray mold, leather rot, and anthracnose done in Ohio offers better methods for predicting and understanding these diseases (15).

Biointensive options for TPB may also exist. *Peristenus digoneutis* Loan, a braconid wasp parasite of TPB, was introduced from France into northern New Jersey in 1979 (12) and was introduced into Massachusetts and New York by our programs in 1990. Subsequent dissections and rearing from parasitized TPB in 1992 and 1993 indicated that *P. digoneutis* had become established in the Connecticut Valley of western Massachusetts. Differential resistance of strawberry cultivars to TPB has been demonstrated in Maine (22). The impact of either the parasite or cultivar resistance does not appear sufficient to control TPB, but combining these approaches may reduce the need for insecticide treatments.

Table 6. Quantities of pesticide used annually on strawberries in Massachusetts, by category for IPM program cooperators vs. a comparable set of nonparticipating growers

	IPM program[z]			Standard program[z]		
Type of pesticide	kg a.i./ha[z]	Percent total use	Percent use excluding fumigant	kg a.i./ha	Percent total use	Percent use excluding fumigant
Miticides	0.2*	0.4%	1.9%	0.5	0.5%	3.1%
Insecticides	2.1*	3.3%	20.2%	2.8	2.8%	17.7%
Fungicides	3.0*	4.7%	28.8%	4.5	4.5%	28.5%
Herbicides	5.1*	7.9%	49.0%	8.0	7.8%	49.4%
Fumigants	54.4*	83.9%	…	86.1	84.5%	…
Total	64.84*			101.86		

[z] Data from 1990 to 1992, obtained from records of growers participating in the strawberry IPM program and a comparable group of nonparticipating growers (n = 10 in 1990, 10 in 1991, and 8 in 1992, for each group of growers). Asterisks indicate significant differences ($P = 0.05$ by independent t tests).

If the challenge of moving the basis of strawberry IPM from relatively simple and predictably effective chemicals to much more complex alternatives is to be met, it will require a public commitment. Our programs required public funds, from sources such as the New York State IPM program, Massachusetts IPM program, USDA IPM funds, state and federal extension and experiment stations, and the USDA Sustainable Research and Education program. Moreover, grower adoption of IPM in Massachusetts and New York appeared to depend as much on societal pressure as on cost-saving motives. How willing growers will be to completely cover the costs of scouting and research in IPM remains to be seen, but they probably will not. If society wants to reduce strawberry pesticide use significantly below the five to six applications now used in New York and Massachusetts, it must be willing to make significant investments in developing and implementing reliable alternatives.

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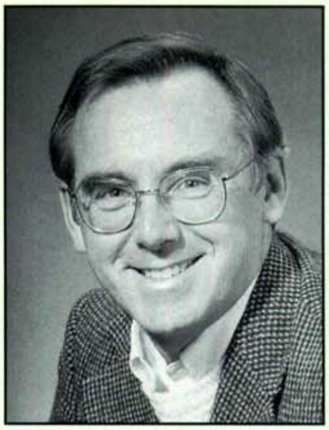

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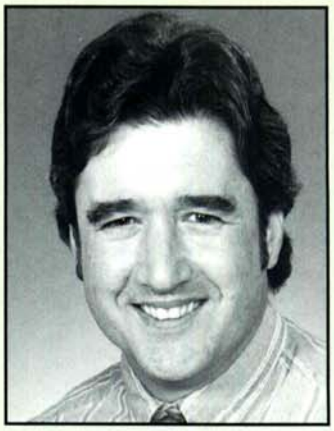

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