Azinphos-Methyl Information Request -- Pacific Northwest Response

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From: Jane M. Thomas
Sent: Wednesday, October 26, 2011 10:21 AM
To: Teung Chin; Tom Myers
Cc: Mike Willett; Bob McReynolds; Darrin Walenta; Diane Alston; Doug Walsh; E. Johansen; Peter Shearer; Richard Hilton; Rick Melnicoe; Jane M Thomas; Barry Jacobsen; Catherine Daniels; Ed Bechinski; Howard Deer; Janet Fults; Janice Chumley; Jeff Jenkins; Joe DeFrancesco; Paul Jepson; Phil Kaspari; Ronda Hirnyck
Subject: Azinphos Methyl Response

Teung and Tom: Attached is our response to your questions regarding the remaining uses of azinphos methyl.
~ Jane

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WASHINGTON STATE UNIVERSITY
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Teung F. Chin, Ph.D.
Office of Pest Management Policy
Agricultural Research Service
U.S. Department of Agriculture
4700 River Road, Unit 149
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Subject: Azinphos Methyl: Remaining Uses

The following information is provided to you from the Western Integrated Pest Management Center regarding your request for information on the remaining azinphos methyl uses in the Pacific Northwest. You had inquired about the use on apples, pears, sweet and tart cherries, blueberries, parsley, and alkali bee beds.

Apple, Pear, Sweet and Tart Cherry
The continued use of azinphos methyl is important to tree fruit growers in the Pacific Northwest. If EPA is seriously considering extending the phase out period for this chemical we would appreciate having the time to prepare a considered response. With the short turnaround time provided for this information request, many people were unable to provide comment within the time frame allowed. One important contact, Dr. Mike Willett, Vice President for Scientific Affairs of the Northwest Horticultural Council, specifically wished to respond but was unable to given the timeline. The responses to your azinphos methyl questionnaire that were received are attached to this letter. Should you want additional information, please let us know, and please provide at least three weeks for us to collect the required information and to prepare our response.

Parsely and Blueberry
No azinphos methyl use was reported for parsley or blueberry.

Alkali Bee Beds
Dr. Doug Walsh reported that alfalfa seed growers are now treating fields prebloom with chlorpyrifos, dimethoate, or pyrethroid insecticides to control blister beetles. He has conducted core sampling of alkali bee beds has found that this approach is effective for the control of this beetle.

I have attached a contact list should you have further questions.

Thank you for providing us this opportunity for input.

Sincerely,

Jane M. Thomas

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Utah responses to EPA's AZM questions:

Utah fruit growers still use AZM on apple, pear, and cherry (sweet and tart) to control key insect pests
Apple: codling moth and leafrollers
Cherry: western cherry fruit fly and leafrollers

Primary insecticide alternatives used:
Apple: Imidan, Altacor, Assail, Calypso, Delegate, Warrior, Danitol, Mustang
Cherry: Imidan, Delegate, Success, GF-120, Entrust, Warrior, Malathion, Sevin, Mustang

Efficacy of alternatives:
Good, but not as effective as AZM. For example, in 2011 there was an outbreak of fruittree leafroller in about 300 acres of tart cherries that didn't have AZM applied. The newer alternative products are more expensive than AZM. Because of the high cost of the newer insecticides, many growers have turned to Imidan as a replacement product. Utah has alkaline water, and Imidan is sensitive to breakdown in alkaline tank water. There have been problems with lack of efficacy of Imidan because of the alkalinity issue. Also, Imidan is not as long-lasting as AZM even when tank water is buffered. The other main alternative group of products Utah growers are using is synthetic pyrethroids. Mite flare-ups have become much more common in orchards treated with pyrethroids due to toxicity to predatory mites.

Yield loss:
In 2011, about 300 acres of tart cherry experienced 5-20% yield loss from an outbreak of the fruittree leafroller. The leafroller was a pest in orchards that had not been treated with AZM, but with alternatives that do not control as broad of a spectrum of insects as AZM. The growers used pyrethroids, Sevin, and Malathion to reduce the leafrollers. The outbreak was just before harvest, so they were limited to products with short PHIs. The Utah cherry growers are concerned about their ability to control the full spectrum of insect pests without AZM.

New and increasing pests:
Spotted wing drosophila
Leafrollers (Fruittree, Obliquebanded, Pandemis)
White apple leafhopper (in both apple and tart cherry)
Spider mites (in orchards where pyrethroid insecticides are used)
Woolly apple aphid
Rosy apple aphid
San Jose scale

Non-chemical controls used:
Mating disruption (pheromones) for codling moth – this technology is effective in reducing codling moth populations, but it is not a stand-alone control in most apple and pear orchards in Utah. Utah orchards interface with urban areas with unmanaged fruit trees, thus, pest pressure is always present. In 2009, 1,100 acres of apple were treated with codling moth mating disruption. In 2009, GF-120, which is not non-chemical but is a very low level of a microbial insecticide combined with a feeding bait, was applied to 1,200 acres of tart cherry. Following the 2011 fruittree leafroller scare, I expect that the acreage treated with GF-120 will decrease in 2012.
*2009 use data comes from a 2010 Utah tree fruit survey

AZM used as a tool against introduced pests:

Not to a great extent in Utah, but spotted wing drosophila has just been recently introduced to the state and currently isn't widespread.

Primary limitations for AZM alternatives:
Higher cost of newer, lower toxicity (caution signal word) alternatives
Lack of efficacy of Imidan in alkaline water
Mite flare-ups induced by applications of synthetic pyrethroids (which are less expensive than some of the newer products)
Narrower spectrum of many alternatives, thus the need to apply multiple products to address all the insect problems

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Azinphos methyl (AZM) use in southern Oregon pear production

The use of AZM has continued to decrease and, to the best of my knowledge, very little has been used over the past couple of years in our area. When AZM was used, the use was often aimed at eliminating old stocks of the material.

A number of newer materials are available which provide very effective control of codling moth, which is the primary target of AZM in pears. These newer materials include Delegate, Altacor and Belt along with continued use of the neonicotinoid insecticides, Assail and Calypso. Non-chemical approaches which are being used consist of mating disruption and the codling moth granulosis virus which is applied as a microbial pesticide. The current re-entry restrictions associated with AZM has made it difficult to use. Other OP insecticides, such as diazinon, which is occasionally used for control of San Jose scale and woolly apple aphid (on apples), and phosmet, which is still occasionally used for control of codling moth are still available for use if needed.

As far as needing AZM for new invasive pests, the material is not required for control of spotted wing drosophila in southern Oregon as a number of other materials are currently being used which are providing effective control in our local fruit crops. While the brown marmorated stink bug has not yet been found in the southern Oregon region, it is my understanding that AZM is not an effective control material for that invasive pest.

If you have any questions please feel free to contact me:

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Azinphosmethyl Use in Oregon Tree Fruit Production

Azinphosmethyl has a long history in the tree fruit industry in Oregon. It has successfully controlled numerous pests, including codling moth, leafrollers and apple maggot. In some cases, these pests have developed resistance to azinphosmethyl, but as a whole, azinphosmethyl was a relatively IPM friendly product when used appropriately. Several of our key natural enemies including predacious mites and green lacewings, have developed tolerance and some level of resistance to this material. This meant that growers could apply this product and not disrupt some secondary pests. This means that growers often did not have to spray other products to control secondary pest outbreaks.

There are new, effective products that control some of the same pests that azinphosmethyl did. In some cases, these new products were readily adopted because they worked better than azinphosmethyl, especially in cases where the pest developed resistance to azinphosmethyl such as leafrollers and codling moth. However, there are several drawbacks to a lot of these new products. In general, they are considerably more expensive and they are more likely to disrupt our IPMprograms because they are harmful to some of our key natural enemies. It unlikely that natural enemies will ever develop resistance to these new insecticides because of resistance management guidelines that limit their use during the growing season. The bottom line is that IPM programs that exclude azinphosmethyl and rely on newer insecticides are often more expensive and sometimes require additional applications of materials to control secondary pests.

There is a lot of data out there showing the weaknesses of new OP-replacement and OP alternative products for some pests and the increased costs of using them. It is unfortunate that the government has asked for input with such a short timeline. I have other pressing deadlines that were scheduled well before this request for information.

One reason to keep azinphosmethyl in cherries is because it is likely very effective against a new invasive pest, the spotted wing drosophila (*Drosophila suzukii*), and it would be beneficial to have a different class of insecticide to rotate to for resistance management purposes and in case we have a troublesome outbreak.

If you or the EPA/USDA require additional information, just ask. However, I would need more time to put together a comprehensive response because of existing time commitments.

Please keep me informed to this process.

Regards,
Peter

PS I have attached a relatively recent article from some of my work done back east.
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RESEARCH

Reduced-Risk Pest Management Programs for Eastern U.S. Apple and Peach Orchards: A 4-Year Regional Project

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Abstract: Studies were conducted from 2002 to 2005 to determine the effectiveness of reduced-risk (RR) tactics for managing key pests in 50 commercial apple orchards (114 ha) in Michigan, North Carolina, New York, Pennsylvania, Virginia, and West Virginia; and 20 peach orchards (190 ha) in Michigan, New Jersey, Pennsylvania, and West Virginia. At each apple site, a block of up to 5 ha received a seasonal program of selective RR and organophosphate-replacement insecticides, with or without pheromones for mating disruption of key lepidopteran pests of apple (codling moth, oriental fruit moth, and obliquebanded leafroller) and peach (oriental fruit moth, lesser peachtree borer, and peachtree borer). A comparison block at each site with the same varieties and tree training was managed using each grower's standard program of conventional insecticides (STD). Pheromone traps for lepidopteran species were hung in all plots and monitored weekly. Foliar samples were taken during the season to estimate phytophagous and predator mite densities. Red sphere traps baited with fruit volatiles were used to monitor apple maggot adults in apple orchards. Fruits were inspected for insect damage at harvest, and graded according to USDA standards. Partial budget analysis was used to assess the net profitability of RR programs to produce apples and peaches for their intended market in each state. Fruit damage at harvest caused by direct fruit pests was generally low across all blocks and treatments. There were no statistically significant differences in fruit damage or mite populations between the RR blocks, with or without pheromones, and the growers' standards. Insecticide use patterns in the RR plots represented up to 88 and 78% reduction in the amount of active ingredient applied per hectare, and an 85 and 77% decrease in their Environmental Impact Quotient for apples and peaches, respectively. However, RR programs were more expensive and generally less profitable compared with growers' standard programs. Regression analysis estimated that RR apple programs with and without mating disruption were on average \$465 and \$144/ha more expensive, and \$544 and \$159/ha less profitable, respectively, compared with standard programs. RR+MD programs for peaches cost an average \$314/ha more and returned about \$284/ha less than STD peach programs.

The management of arthropods in apple and peach orchards in the eastern United States is a complex and difficult task (Madsen and Morgan 1970, Chapman and Lienk 1971, Howitt 1993, Hogmire 1995). IPM programs for these crops are perhaps the most complex of all cropping systems, particularly in the eastern United States, where the diversity of tree fruit pests is much greater than in other parts of North America.

For eastern orchardists, 10 to 13 direct pests require management annually, and this pest complex is represented by members of the Lepidoptera (Tortricidae), Coleoptera (Curculionidae, Scarabaeidae), Diptera (Tephritidae), and Hemiptera (Aphididae, Miridae, Pentatomidae). Diverse indirect pests that can also affect fruit quality and yield include aphids (Hemiptera: Aphididae and Pemphigidae), leafhoppers (Hemiptera: Cicadellidae) and leafminers (Lepidoptera: Gracillariidae). The most common and potentially damaging mite pest is the European red mite, *Panonychus ulmi* Koch. If managed properly, however, a complex of predatory phytoseiid mites, including *Typhlodromus pyri* Scheuten and *Neoseiulus fallacis* (Garman), can maintain phytophagous mites below economically damaging levels. Hence, the preservation of predatory mite populations is a central theme in tree fruit pest management, particularly for apples.

The Food Quality Protection Act (FQPA) of 1996 required the U.S. Environmental Protection Agency to develop more stringent tolerances that place greater emphasis on the safety of infants and children. Organophosphate (OP) insecticides were the first group of pesticides reviewed under the FQPA guidelines because of chronic worker safety issues and concerns related to residues in food. These insecticides have been the cornerstone of apple and peach arthropod management programs for >40 yr and have provided excellent control of most direct insect pests. Despite their relatively broad-

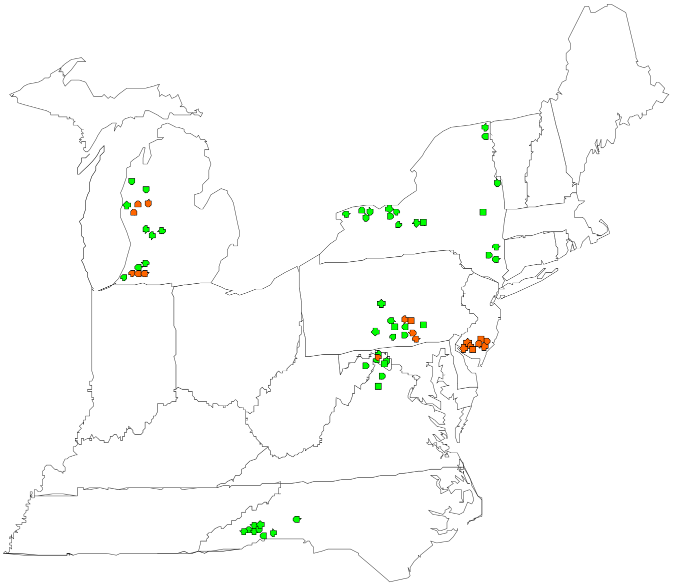

Fig. 1. Study sites at which comparison of reduced-risk (RR) and standard (STD) pest management practices were compared on apples (green) and peaches (orange) in the eastern United States. Total hectares of apples managed using RR practices: Michigan, 45; New York, 63; Pennsylvania, 17; Virginia, 4; West Virginia, 25; North Carolina, 36. Total hectares of peaches managed using RR practices: Michigan, 17; New Jersey, 28; Pennsylvania, 16; West Virginia, 4.

spectrum activity, OPs are of relatively low toxicity to many important natural enemies, particularly mite predators (Croft and Bode 1983). Although several registered pyrethroid and carbamate insecticides control many key pests, their high toxicity to beneficial mite and insect predators (Croft 1990, Hull et al. 1997) contributes to high mite populations and increased acaricide use. Consequently, reliance on this latter group of insecticides is not considered a sustainable approach to arthropod management on either apple or peach.

Several new insecticides classified as reduced-risk and OP-replacement materials, many of which are relatively safe to predatory phytoseiid mites (Villanueva and Walgenbach 2005), are effective against key apple and peach insects in the eastern United States (Sun et al. 2000, Reissig 2003, Borchert et al. 2004, Pelz et al. 2005, Villanueva and Walgenbach 2007). Advances in the use of pheromone-mediated mating disruption for management of oriental fruit moth, *Grapholita molesta* (Busck), (Il'ichev et al. 2002, Kovanci et al. 2005, De Lame and Gut 2006) and codling moth, *Cydia pomonella* (L.), (Epstein et al. 2007, Hull et al. 2007, 2008) in the eastern United States also have provided additional management tools for this pest complex. However, the relatively high cost, greater specificity, and incomplete knowledge of how to use these products in a management system has slowed their adoption by the grower community.

To aid in the development of alternative IPM programs for eastern apple and peach producers, a regional project was started in 2002 to evaluate pest management systems based on reduced-risk tactics that are considered to be effective, sustainable, economically viable, and would lead to enhanced biological control. Reported here are the results of this 4-yr project conducted in Michigan, New Jersey, New York, North Carolina, Pennsylvania, Virginia, and West Virginia.

Materials and Methods

General Procedures. Using a uniform protocol for each crop across all states, we made side-by-side comparisons of RR, consisting

Table 1. List of reduced-risk and OP-replacement insecticides and pheromones used in reduced-risk treatments on apple and peach.

Class	Chemical[a]	Target pests[b]	States used
Botanicals	Azadirachtin (P)	GPA, TPB/SB, PC	MI, WV
Insect growth regulators	Buprofezin (P)	SJS	NJ
	Methoxyfenozide (A,P)	CM, OFM, OBLR, TABM, VLR	MI, NC, NJ, NY, PA, VA, WV
	Novaluron (A)	CM, OFM, OBLR, TABM, VLR	MI, NC, PA, WV
	Pyriproxyfen (A,P)	SJS, RAA, CM	MI, NC, NJ, NY, PA, VA, WV
	Tebufenozide (A)	OBLR	NY
Microbials	*Bacillus thuringiensis (A, P)*	CM, OFM, OBLR, TABM	MI, NY, PA
	C. pomonella granulovirus (A)	CM	MI, WV
	Spinosad (A, P)	OBLR, TABM, VLR, AM, WFT	MI, NC, , NY, PA, VA, WV
Neonicotinoids	Acetamiprid (A)	RAA, TPB, PC, OFM, CM, AM, GAA, CIC, CMB	MI, NC, NJ, NY, PA, VA, WV
	Imidacloprid (A, P)	RAA, GAA, , GPA, TPB/SB, JB, RC, AM, LH, LM	MI, NC, , NJ, NY, PA, VA, WV
	Thiacloprid (A)	RAA, TPB, PC, OFM, CM, GAA, AM, CIC	MI, NC, PA, VA, WV
	Thiamethoxam (A, P)	RAA, GPA, TPB, PC, OFM, CM, GAA LH, LM	MI, NC, NY, PA, VA, WV
Oxadiazines	Indoxacarb (A, P)	RAA, TPB/SB, PC, OFM, CM, AM	MI, NC, NJ, NY, PA, VA, WV
Pheromones	Isomate-C Plus (A)	CM	MI, NC, NY, WV
	Isomate-C TT (A)	CM	MI, NC, NY, PA, WV
	Isomate CM/OFM TT (A)	CM, OFM	NC, NY, PA, WV
	Isomate LPTB (P)	LPTB, PTB	MI, NJ, PA, WV
	Isomate-M 100 (A, P)	OFM	MI, NC, NJ, NY, WV
	Isomate-M Rosso (A, P)	OFM	MI, NC, NJ, PA, WV
	Isomate PTB (P)	PTB	NJ
	Sprayable (A)	OFM, LPTB, PTB	MI, NC, NJ, PA, VA, WV

[a] A and P designate use on apples and peaches, respectively.

[b] Insect abbreviations: AM, apple maggot; CIC, periodical cicada; CM, codling moth; CMB, Comstock mealybug; GAA, apple aphid/spirea aphid complex; GPA, green peach aphid; ERM, European red mite; JB, Japanese beetle; LH, leafhoppers; LM, spotted tentiform leafminer; LPTB, lesser peachtree borer; OBLR, obliquebanded leafroller; OFM

of reduced-risk and OP-replacement materials, and conventionally managed orchards at 65 locations across six states from 2002 to 2005 (Fig. 1). Individual growers or their consultants determined pesticide programs in conventional blocks and relied extensively on OP insecticides. The project investigators in each state made pest management decisions in RR blocks and relied on reduced-risk and OP-replacement insecticides and pheromone-mediated mating disruption. The management tactics and decisions used in specific orchards were based on site-specific pest monitoring data, local pest complexes, and market destination of the crop. Reduced-risk management programs were tested in plots ranging in size from about 2 to 8 ha. Conventional management programs were applied to adjacent or nearby blocks (denoted as Standard, STD) with similar tree training systems, cultivars, ages of trees, and plant spacing. Data were collected to compare seasonal pest and beneficial arthropod populations, fruit damage, and the economics of reduced-risk and conventional management programs. In this article, we focus on results as they pertain to direct pests and mite populations.

Management Tactics. The selection of specific insecticide products and timing of applications in RR blocks varied among states, and in some instances among orchards within states, to reflect the relative importance of various pests and the registration of new products during the 4-yr project (Table 1). Insecticide applications were based on the knowledge of the importance of pests in specific orchards and relied on pest phenology models (e.g., Riedl et al. 1976, Borchert et al. 2004) and threshold population levels recommended by the Cooperative Extension Service in each state. Management tactics were targeted primarily against 10 apple (Fig. 2) and 13 peach pests (Fig. 3). With the exception of carbaryl applications for fruit thinning, broad-spectrum organophosphate, carbamate, and pyrethroid insecticides were avoided unless no other option existed for a critical pest, and in a few instances where organophosphates were used accidently by cooperating growers.

Pheromone-mediated mating disruption was used for several lepidopteran pests in RR orchards in apples and peaches, but not in every RR orchard. In apple orchards, mating disruption was used for codling moth and oriental fruit moth in ~50 and 60% of RR test blocks, respectively; only Michigan used mating disruption for obliquebanded leafroller (66% of RR blocks). In peach orchards, mating disruption was used in >90% of RR test blocks for oriental fruit moth and lesser peachtree borer, *Synanthedon pictipes* (Grote and Robinson), and in ~60% of RR test blocks for peachtree borer, *S. exitiosa* (Say). Except for oriental fruit moth, hand applied dispensers were used for mating disruption, while both hand-applied and sprayable pheromone was used for oriental fruit moth (Table 1). The only instance in which mating disruption was used in STD blocks was in Pennsylvania peaches for lesser peachtree borer in 56% of STD test blocks.

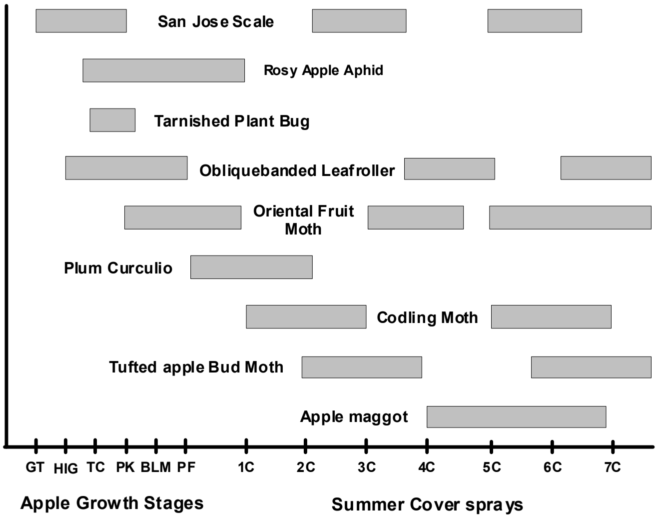

Fig. 2. Timing of management of direct apple insect pests in relation to apple tree phenology in the eastern United States (Apple Growth Stages: GT, green tip; HIG, half-inch green; TC, tight cluster; PK, pink bud; BLM, bloom; PF, petal fall; 1C, 1st cover, etc.).

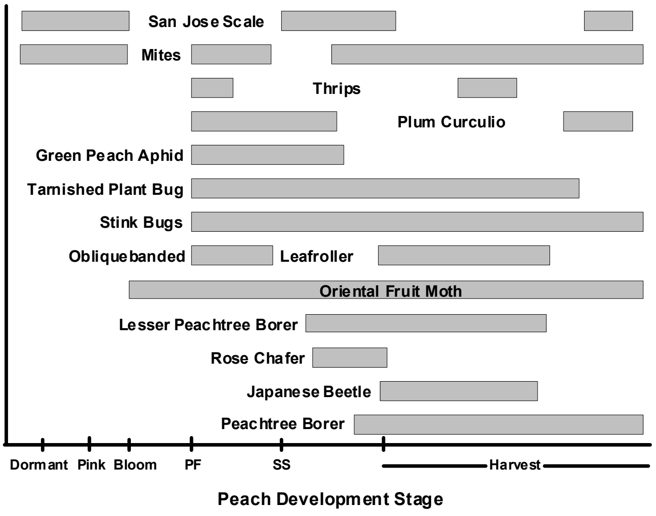

Fig. 3. Timing of management of direct peach insect pests in relation to peach tree phenology in the eastern United States (Peach Growth Stages: Dormant; pink; loom; PF, petal fall; SS, Shuck Split; Harvest).

Most of the insecticides consisted of broad-spectrum organophosphate, carbamate, and pyrethroid insecticides, although some reduced-risk insecticides were used against pests that had developed resistance to organophosphate insecticides, such as obliquebanded leafroller, *Choristoneura rosaceana* (Harris) (Waldstein and Reissig 2000), and tufted apple bud moth, *Platynota idaeusalis* (Walker) (Knight et al. 1990).

Data Collection. Predetermined and standardized sampling methods were used to monitor arthropod populations in RR and STD blocks. Wing- or delta-style pheromone traps were used to monitor codling moth, oriental fruit moth, obliquebanded leafroller, and tufted apple bud moth. For each species, two to three traps were placed in each RR and STD block and monitored weekly for the number of insects captured. Moth capture data were used to set biofix for phenological models (Onstad et al. 1985, Schmaedick and Nyrop 1995, Reissig et al. 1998, Penn. State Univ. 2008) and to measure the intensity of populations for supplemental insecticide applications. Apple maggot, *Rhagoletis pomonella* (Walsh), was monitored using adhesive-coated red plastic spheres baited with an apple essence lure (Zhang et al. 1999). Three spheres were deployed on the periphery of each apple orchard, and capture data were used to determine the need for insecticide sprays for apple maggot.

Direct sampling of phytophagous mites, including European red mite and twospotted spider mite (*Tetranychus urticae* Koch), and predatory phytoseiid mites, was done at periodic intervals to determine the effect of management programs on mite densities and the need for supplemental miticide applications. Mite populations were sampled at ~2-wk intervals by directly observing leaves with a visor lens, and on a less frequent basis by transporting leaves to the laboratory, placing them through a mite-brushing machine, and counting mites under a stereomicroscope.

To assess fruit insect damage, 30 to 50 fruit were removed from 20 trees per treatment block at the normal harvest date for the variety being evaluated. Fruit were inspected for insect damage and graded according to USDA grading standards (USDA 2002, 2004). All fruit that showed symptoms of infestation by internal larvae were then cut with a knife, and the number infested with lepidopteran or apple maggot larvae was recorded.

Environmental Impact Quotient (EIQ) Analysis. To estimate the relative environmental impact of reduced-risk and conventional management programs, pesticide records from each orchard were used to calculate seasonal cumulative EIQ field ratings (Kovach et al. 1992). EIQ values for each insecticide were obtained from the New York State IPM Program list of EIQ values (http://nysipm.cornell.edu/publications/eiq/files/EIQ_values04.pdf). Cumulative EIQ field ratings were calculated by

$$\text{EIQ Field Rating} = \sum(\text{EIQ}_i{*}\text{RT}_i{*}\text{AP}_i)$$

where EIQ_i = EIQ value of pesticide i; RT_i = rate of pesticide i; and AP_i = number of applications of pesticide i.

Applications of petroleum oil and carbaryl were not included in cumulative EIQ values in either treatment. Carbaryl was omitted because it was used for apple thinning and not as a pest management tool. Petroleum oil was omitted because its extremely high field EIQ rating masked treatment effects. Although petroleum oil is recognized as a relatively safe, non-hazardous IPM practice, its EIQ field rating of 220 far exceeds that of any insecticide. Furthermore, in instances where oil was used, it was applied to RR and STD treatments.

Statistical Analysis. Analysis of variance (ANOVA) was used to compare EIQ values and fruit damage for orchards managed using RR vs STD pest management practices. For the EIQ analysis, ANOVA was conducted on cumulative EIQ field ratings of all pesticides applied to RR and STD treatments within states by year, and across states by year. For fruit damage, ANOVA was conducted for each type of insect damage and for total damage in RR and STD treatments within years by state. Because of the proximity and similarity of Virginia and West Virginia study sites, and because only two sites were used in Virginia, apple data sets for these two states were combined and analyzed as a single state. Likewise, the one West Virginia peach site was combined with the Pennsylvania sites for analyses.

Data on European red mite and phytoseiid predators on apples were analyzed by first determining the average density in plots for each sample date and then subjecting the highest mite density at each location to ANOVA to compare treatment effects within states and across states. The number of instances in which European red mite densities exceeded threshold levels recommended by the state's Cooperative Extension Service were also calculated and compared between RR and STD treatments.

Economic Analysis. Partial budgeting analysis was used to evaluate the economic impact resulting from the use of RR vs STD insect management programs. The analysis involved comparing the costs of conventional spray programs with reduced-risk programs (cost of inputs) and evaluating the value of the fruit from each system (value of output). Cooperating growers provided pesticide records from each block, and pesticide costs from 2002-2005 were obtained from one regional pesticide distributor and applied to all data sets. Costs of RR treatments that used hand-applied dispensers for mating disruption (referred to as RR+MD) included the cost of pheromone dispensers and application costs and were analyzed separately from other RR plots. The value of fruit from each block was estimated based on grading data combined with annual fresh market prices (adjusted for location) or processing prices, depending on the destination of the crop. Yields were held constant at 5-yr averages (1998–2002) for the individual states, so only quality issues and costs related to insect management were captured in the analysis. Paired *t*-tests were used to compare pest management costs and net income for each paired comparison (STD vs RR, and STD vs RR+MD) for each state and across all states by year.

To understand the overall impact that different production factors (location, insect management, cultivar, and year) had on cost, fruit quality, and profitability, the ANOVA and analysis of covariance were regarded as regression models with qualitative binary explanatory variables, also known as dummy or indicator variables (Kmenta 1971, Mendenhall et al. 1990). This regression model approach was used to test the hypothesis that any of the estimated coefficients was individually equal to zero (Kmenta 1971). The analysis of data from this multiyear, multistate project was best suited to analysis using binary qualitative variables because of differences in location, climate, cultivar, and number of observations. Qualitative differences were characterized as individual binary variables, where the variable was set to 1 if it was characteristic of the observation and 0 if not. The three models and the binary explanatory variable classifications were:

Fruit Quality = f(state, treatment, cultivar, year)

Insect Management Cost= f(state, treatment, either apple cultivar

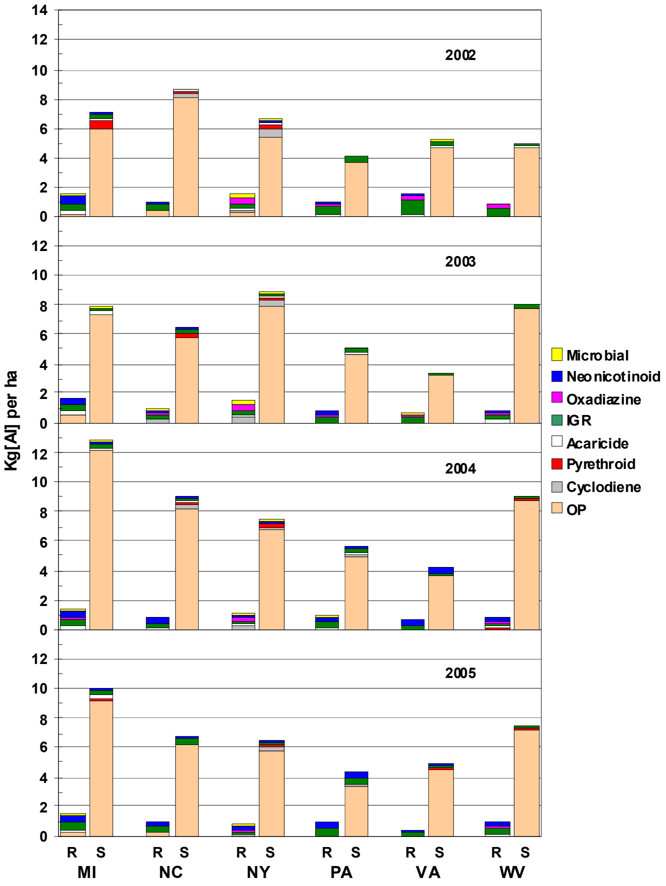

Fig. 4. Mean amount of specified insecticide classes applied to apples managed with reduced-risk (R) vs standard (S) pest management practices.

or cultivar maturity for peach, year)

Income = f(state, treatment, either apple cultivar or cultivar maturity for peach, year)

where f is the binary explanatory classification. To estimate these models, one state, treatment, cultivar, and year variable were dropped from the model to avoid least squares normal equations that were not independent. The binary variables dropped for apple data were Virginia/West Virginia, STD, other cultivar, and 2002; for peaches, the binary variables dropped were Pennsylvania/West Virginia, STD, late cultivar, and 2002.

Results

Pesticide Use

Replacement of organophosphate, pyrethroid and carbamate insecticides in favor of newer reduced-risk and OP- replacement insecticides resulted in a drastic reduction in active ingredients applied to RR vs STD treatments in both apples (Fig. 4) and peaches (Fig. 5). Averaged across all states, the reduction in insecticide active ingredients applied in RR vs STD apple treatments ranged from 4.9 (2002) to 7.1 kg/ha (2004). This is equivalent to a reduction of 79.7% (2002) to 88.2% (2004). Organophosphates, principally azinphosmethyl, accounted for ~90% of the total active ingredient in STD apple treatments.

The next most common active ingredients applied to STD treatments were insect growth regulators (principally tebufenozide and methoxyfenozide), which accounted for ~3.3% of total active ingredient across all states in all years. In RR apple blocks, insect growth regulators (again, principally tebufenozide and methoxyfenozide) accounted for the major component of total active ingredients, ranging from a low of 30.6% in 2003 to a high of 46% in 2002. The registration of several new neonicotinoids during the course of the study resulted in an increase in use of this group of insecticides in RR treatments on apple; averaged across all states, neonicotinoid use increased from 11.4% of total active ingredient in 2002 to 31.1% in 2005. In a few instances organophosphates were applied to RR treatments, either for control of apple maggot (in 2002) or because of mistaken applications by grower cooperators; these single applications by one or two growers were limited to Michigan (2002, 2003, and 2005) and North Carolina (2002 and 2005).

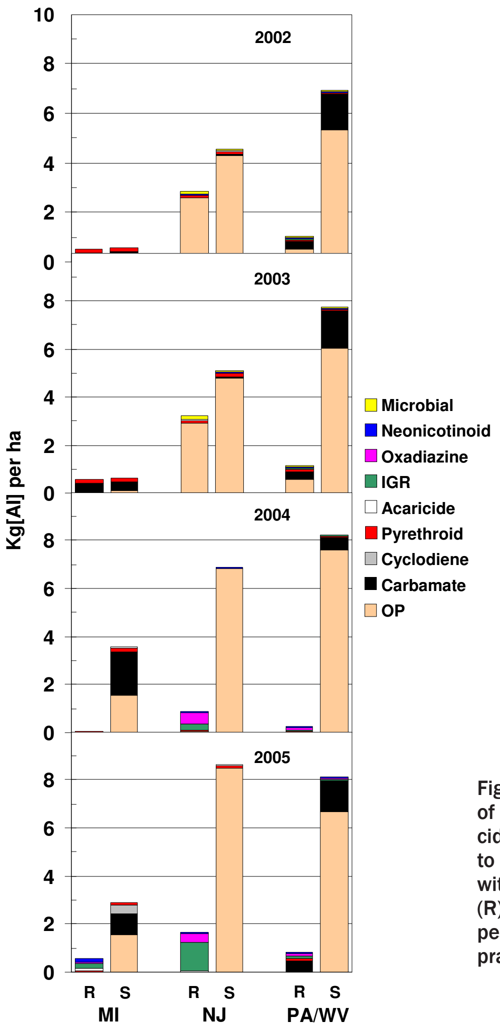

Fig. 5. Mean amount of specified insecticide classes applied to peaches managed with reduced-risk (R) vs standard (S) pest management practices.

As with apples, the amount of insecticide active ingredient applied to RR peaches was considerably less than STD peaches (Fig. 5). Averaged across all states, the difference between the two programs increased from 3.9 to 4.7 kg a.i./ha between 2002 and 2005, respectively, which equated 59.1 to 78.9% less active ingredient in RR blocks over the 4-yr study. Because of the lack of alternative insecticides registered for plum curculio on peaches early in the project, organophosphates (azinphosmethyl and phosmet) use was prevalent in RR and STD blocks in 2002 and 2003. As a percentage of total active ingredient applied to STD peaches, organophosphates increased from 62% in 2002 to 73.1% in 2005; in the RR, it declined from 48.3% in 2002 to 0% in 2005. Carbamates (carbaryl) accounted for 19.6 and 21.1% of total active ingredients used in RR and STD blocks, respectively, when averaged across states and years. Carbaryl was used in RR blocks in Michigan and Pennsylvania against Japanese beetle and rose chafer, respectively. As a percentage of total active ingredient applied to RR blocks from 2002 to 2005, IGR (principally methoxyfenozide) use increased from 0 to 38.9%, and oxadiazine (indoxacarb) use increased from 0 to 13.5%. Indoxacarb was used under an experimental use permit in 2003 and 2004 and was critical in replacing organophosphates for plum curculio in RR blocks. Neither IGRs nor indoxacarb was applied to STD blocks.

Environmental Impact Quotient (EIQ).

The EIQ rating system was developed as a tool to assess the relative impact of various pesticides on the environment and farm worker safety (Kovach et al. 1992). The reduced-risk insecticides used in this study resulted in a major reduction in EIQ ratings in RR compared with STD treatments at virtually every apple (Fig. 6) and peach (Fig. 7) study site. Cumulative EIQ ratings were significantly lower in RR compared with STD treatments in all years for both crops (**Apple:** 2002, $F = 116.28$, df = 1, 90, $P < 0.001$; 2003, $F = 237.33$, df = 1, 94, $P < 0.001$; 2004, $F = 234.80$ df = 1, 96, $P = 0.001$; 2005, $F = 197.03$, df = 1,94, $P < 0.001$. **Peach:** 2002, $F = 10.57$, df = 1, 27, $P = 0.0002$; 2003, $F = 155.17$, df = 1, 33, $P < 0.0001$; 2004, $F = 59.06$, df = 1, 33, $P < 0.0001$; 2005, $F = 22.42$, df = 1, 31, $P < 0.0001$). There were significant interactions for the peach ANOVA in 2002 and 2003, but these were caused by the extent of differences in EIQ ratings between RR and STD programs between states (2002, $F = 3.47$, df = 1, 2, $P = 0.046$; 2003, $F = 6.29$, df = 1, 2, $P = 0.005$). These interactions were excluded from the analyses.

When averaged across all states, apple EIQ ratings in RR blocks varied from a high of 38.9±4.2 in 2002 to a low of 25.7±2.3 in 2005. In STD blocks, ratings ranged from a high of 237.3±13.9 in 2003 to a low of 197.0±14.5 in 2005. Averaged across all sites in all years, cumula-

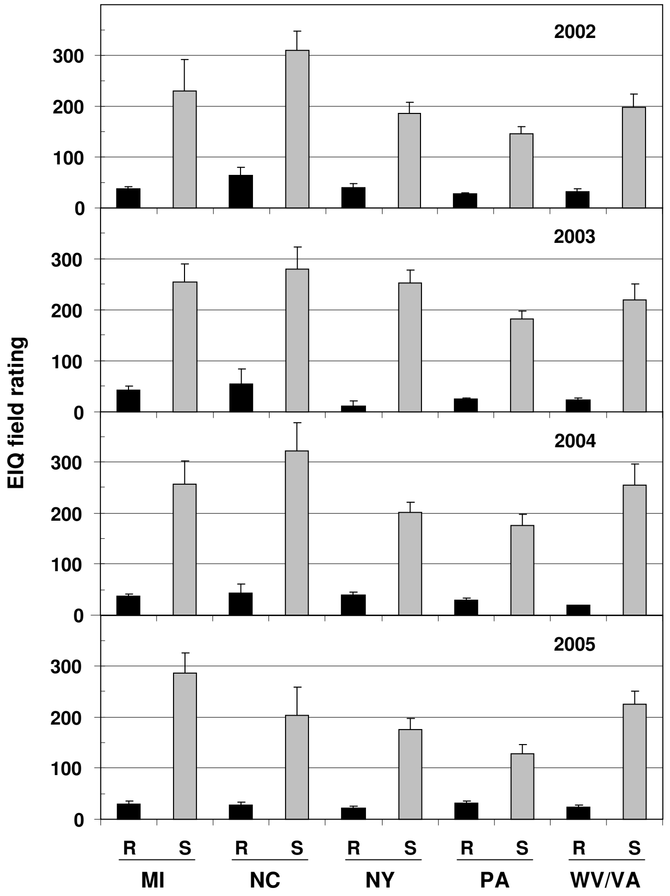

Fig. 6. Mean (± SEM) Environmental Impact Quotient (EIQ) field ratings of insecticides applied to apples managed with reduced-risk (R) vs standard (S) pest management practices.

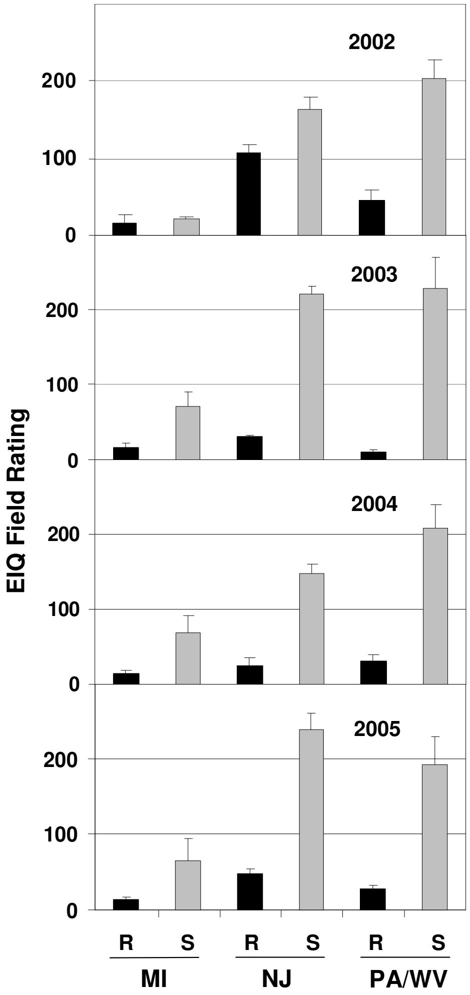

Fig. 7. Mean (± SEM) Environmental Impact Quotient (EIQ) field ratings of insecticides applied to peaches managed with reduced-risk (R) vs standard (S) pest management practices.

tive EIQ ratings in RR blocks were reduced by 85.1% compared with STD blocks (32.3 vs 217.0). Organophosphates accounted for 85.4% of total EIQ values in the STD treatments; and insect growth regulators (34.4%), neonicotinoids (24.4%), and the oxadiazine indoxacarb (22.5%) accounted for the most EIQ ratings in RR treatments.

Average EIQ ratings across all states in RR peach blocks averaged varied from 69.7 ± 26.9 in 2002 to 20.9 ± 7.0 in 2003; in STD blocks, they ranged from a low of 139.0 ± 42.0 in 2004 to a high of 167.8 ± 58.3 in 2005. Similar to apples, cumulative EIQ ratings in peach RR blocks were 77% less compared with values from STD blocks when averaged across all sites for all years (36.3 vs 157.8).

It is noteworthy that if petroleum oil were included in total EIQ calculations, cumulative EIQ field rates would have increased by 880 to 1220 in those locations where it was used.

Pest Management Efficacy

Fruit Damage. Fruit damage at harvest caused by direct insect pests was generally at acceptably low levels in all states during the project, with no statistically significant differences between the RR pesticide blocks, with or without pheromones, and the grower standards for either apples (Fig. 8) or peaches (Fig. 9). However, fruit damage caused by individual insects did occur at relatively high levels in some instances, but in no instance did damage levels significantly differ by management strategy.

Michigan: ***Apple.*** Average percentage of clean fruit among the nine apple study sites ranged from 95.7 to 98.9% in RR blocks, and 93.9 to 96.8% in STD blocks during the 4-yr period. Codling moth and leafrollers (obliquebanded leafroller) were the leading cause of damage in RR and STD treatments. Damage caused by all other insects was quite low in all years (<0.5%); plum curculio was highest in treatments in 2002 and 2004, and San Jose scale, *Quadraspidiotus perniciosus* (Comstock), in RR blocks in 2005.

Peach. Percentage of clean fruit in RR peach blocks ranged from a high of 99.7% in 2002 to 93.0% in 2004; in STD blocks, it ranged from 99.7% in 2002 to 93.9% in 2005. Catfacing damage (caused by various stink bugs [Pentatomidae] and mirids) was an important cause of damage in RR and STD blocks in most years. Among the insects responsible for damage classified as "Other" in RR blocks was the San Jose scale (2005), rose chafer (2003 and 2004), and leafrollers (2004). In STD blocks, rose chafer damage was prevalent in 2003 and 2005.

New Jersey: ***Peach***. Percentage of clean fruit ranged from 92.3 to 97.8% in RR peach blocks and 92.7 to 97.2 in STD blocks. Catfacing damage approached or exceeded 1% in both treatments every year. In RR blocks, plum curculio and Japanese beetle damage exceeded 0.5% in 2002 and 2004, whereas San Jose scale was prevalent in several RR blocks in 2004.

New York: ***Apple***. Averaged across the 17 study sites, percent clean fruit in RR blocks ranged from 90.4-95.6%, and in STD blocks from 92.9-96.0% over the course of the study. Leafrollers (obliquebanded lefroller) and tarnished plant bug were the leading cause of damage in both treatments. The leading contributors to damage in the "Other" category were European apple sawfly, *Hoplocampa testudinea* (Klug) (2002), San Jose scale (2002 and 2005), and rosy apple

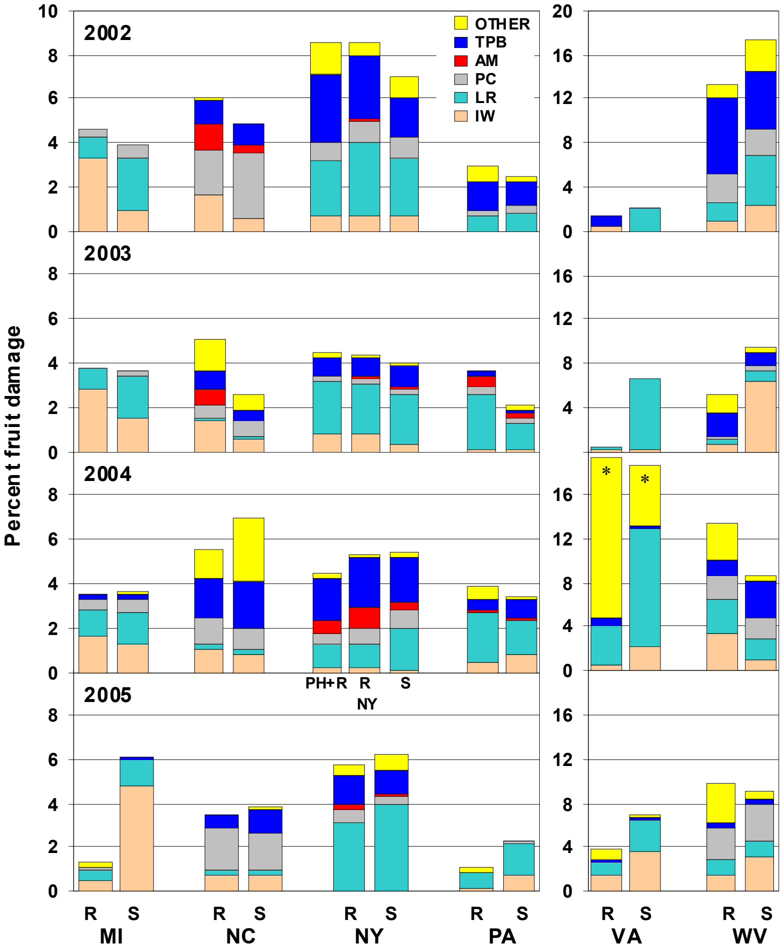

Fig. 8. Mean percentage of fruit damaged by various insects in apples managed with reduced-risk (R) vs standard (S) pest management practices [PH+R (New York only), reduced-risk split plots additionally receiving pheromones, vs. reduced-risk plots without pheromones (R)]: TPB, tarnished plant bug; AM, apple maggot; PC, plum curculio; LR, leafrollers; IW, internal-feeding lepidopteran larvae (predominantly codling moth and oriental fruit moth). * denotes that in 2004, damage in the R treatment of Virginia was 23.8%, of which 19.8% was caused by stink bugs.

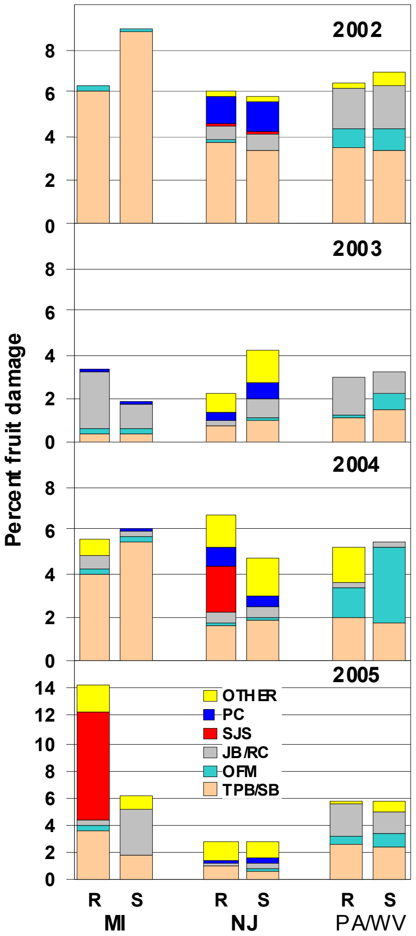

Fig. 9. Mean percentage of fruit damaged by various insects in peaches managed with reduced-risk (R) vs standard (S) pest management practices: TPB/SB, tarnished plant bug and stink bugs; OFM, oriental fruit moth; JB/RC, Japanese beetle and rose chafer; SJS, San Jose scale; PC, plum curculio; Other including feeding damage from leafrollers, thrips, white peach scale.

aphid (2005). Location within the treatment blocks influenced the proportion of fruit damaged by certain pests, such as plum curculio, tarnished plant bug, and obliquebanded leafroller, in that the highest incidence of damage occurred within the first three rows from block edges. The number of farms exhibiting damage from internal Lepidoptera in the RR plots decreased each year, from eight in 2002 to one in 2005, paralleling the decrease seen in the STD plots (from 10 farms to 1).

North Carolina: ***Apple.*** Average percentage of clean fruit among the nine locations ranged from 93.3 to 96.4% in RR blocks, and 93.1 to 97.6% in STD blocks over the course of the project. Codling moth and oriental fruit moth damage exhibited opposite trends during the four years, declining from a mean of 3.3 to 0.6% in RR blocks and increasing from 0.9 to 4.6% in STD blocks. Damage from tufted apple bud moth was slightly lower in RR than in STD blocks. Plum curculio and tarnished plant bug were consistent pests in RR and STD blocks during the 4–yr period, each causing damage that ranged from about 0.5 to 3.0%. Isolated instances of problems from apple maggot occurred in RR blocks in 2002 (1.7%) and 2003 (0.7%), and Comstock mealybug, *Pseudococcus comstocki* (Kuwana), in both treatments in 2003 and 2004.

Pennsylvania: ***Apple.*** Average percentage of clean fruit among the nine locations in the RR apple blocks ranged from 96.1 to 98.9%, and in the STD blocks from 95.1 to 97.9%. Leafrollers posed the greatest problems during the entire project, with damage ranging from ~1.0 to 2.5% in RR and STD blocks. Similar levels of tarnished plant bug damage occurred in both treatments and ranged from <1.0% in 2005 to a high of about 1.3% in both treatments in 2002. Apple maggot damage declined during the course of the study, with 0.7 and 1.2% fruit infested in RR and STD blocks in 2002, and no damage in either treatment by 2005. Sporadic and low levels of damage by European apple sawfly were observed in 2002 (0.6% in RR and 0.2% in STD), and stink bugs in 2004 (0.4% in RR).

Pennsylvania and West Virginia: ***Peach.*** The average percentage of clean fruit in RR peach blocks ranged from 93.5 to 96.9% and 93.1 to 96.4 in STD blocks. Catfacing damage was prevalent in both treatments throughout the study, and Japanese beetle in three of four years. Oriental fruit moth damage exceeded 0.5% in RR blocks three of four years and for all years in STD blocks. Leafroller damage was sporadic in both treatments.

Virginia and West Virginia: ***Apple.*** Average percentage of clean fruit among seven apple locations ranged from 89.8 to 97.5% in

Table 2. Summary of European red mite (ERM) management results and predatory phytoseiid mite population levels in Reduced-Risk (RR) and Standard (STD) apple orchards, 2002–2005.

		Sites where ERM exceeded treatment threshold		Maximum phytoseiid density (motiles/leaf)	
State	n	RR	STD	RR	STD
2002					
Michigan	9	1	2	1.33	0.13
North Carolina	9	3	4	0.72	0.20
New York	17	3	2	0.48	0.46
Pennsylvania	5	0	1	0.62	0.32
Virginia	2	2	2	0.02	0.12
West Virginia	5	1	2	0.63	0.81
Total	47	10	13		
Mean		21.2%	27.7%	0.63	0.34
2003					
Michigan	9	2	1	0.99	2.31
North Carolina	8	1	1	0.06	0.25
New York	17	2	3	0.39	0.38
Pennsylvania	5	1	1	0.27	0.47
Virginia	2	0	0	0	0.04
West Virginia	5	1	1	0.54	0.51
Total	46	7	7		
Mean		15.2%	15.2%	0.38	0.66
2004					
Michigan	9	2	1	1.50	1.20
North Carolina	9	0	3	2.51	0.88
New York	17	3	0	0.43	0.38
Pennsylvania	5	1	1	0.24	0.42
Virginia	2	0	1	0.55	0.75
West Virginia	5	2	1	0.31	0.33
Total	47	8	7		
Mean		17.0%	14.9%	0.92	0.66
2005					
Michigan	9	1	1	0.25	0.75
North Carolina	8	1	1	4.28	1.74
New York	17	1	2	0.96	0.96
Pennsylvania	5	0	0	0.73	0.69
Virginia	2	0	2	0.94	0.41
West Virginia	5	0	0	0.68	0.28
Total	46	3	6		
Mean		6.5%	13.0%	1.31	0.81

RR blocks and 87.1 to 92.3% in STD blocks. Leafrollers (primarily tufted apple bud moth), codling moth, and oriental fruit moth were important causes of damage in both states; leafroller damage was generally higher in STD than in RR blocks, although these differences were not significant. Damage levels caused by these two groups of direct pests varied considerably from year to year, but over the 4-yr project, total leafroller plus internal worm damage averaged 2.6 and 5.6% in RR and STD blocks, respectively. Plum curculio was an important pest in West Virginia, particularly in 2004 and 2005, when damage exceeded 2.0 and 4.0% in both treatments. The most important cause of "Other" damage included late-season stink bug damage (West Virginia in 2002 and Virginia in 2004) and San Jose scale (West Virginia in 2005).

Mite Populations. There were no statistical differences in maximum densities of either European red mite or phytoseiid predatory mites between the RR and STD apple treatments within or among states during any year. The percentage of sites where pest mites exceeded a threshold during the season and required an acaricide application, decreased from 21.2% (RR) and 27.7% (STD) in 2002, to 6.5% (RR) and 13.0% (STD) in 2005 (Table 2). Similarly, the maximum density of phytoseiid mites observed during the season in the RR and STD blocks increased from 0.63 (RR) and 0.34 (STD) motiles per leaf in 2002, to 1.31 (RR) and 0.81 (STD) in 2005. At sites where *T. pyri* was the predominant phytoseiid mite, the percentage of sites where European red mites surpassed treatment thresholds ranged from 11.4 to 13.6% (RR blocks) and 6.8 to 15.9% (STD blocks). In comparison, where *N. fallacis* was predominant, European red mites surpassed thresholds in 9.7–25.8% (RR blocks) and 25.8–32.3% (STD blocks), possibly indicating the greater predatory efficiency of the former species over that of the latter. During the course of this study, the first occurrence (2003) and eventual establishment of *T. pyri* as a widely distributed mite predator was documented in Pennsylvania.

Economic Analysis

Management Costs. In almost every comparison, insect management costs were higher in RR and RR+MD compared with those of the STD treatment for apple (Table 3). In fact, apple insect management costs were significantly higher in RR compared with STD treatments in 7 of the 16 state comparisons over the 4-yr project, and in 14 of 20 RR+MD vs STD comparisons. During the course of the project,

Table 3. Mean insect management costs ($/ha) in paired blocks of apples managed with reduced-risk (RR) vs standard (STD) insecticides, or with reduced-risk insecticides plus hand-applied mating disruption pheromone dispensers (RR+MD) vs standard insecticides.

	RR vs Standard			RR+MD vs Standard		
State	n[a]	RR	STD	n[a]	RR+MD	STD
2002						
Michigan	0	–	–	6	1,077*	366
North Carolina	5	761*	422	4	857*	415
New York	17	538*	368	17	973*	368
Pennsylvania	5	494	400	2	862	235
Virginia/West Virginia	4	753*	333	5	788*	259
All States	32[b]	595*	373	34	944*	351
2003						
Michigan	0	–	–	9	1,020*	487
North Carolina	5	489	427	3	882*	459
New York	17	622*	482	17	1,015*	482
Pennsylvania	5	482	380	2	771	341
Virginia	7	440*	316	2	677*	284
All States	34	546*	425	33	968*	462
2004						
Michigan	0	–	–	9	1,008*	459
North Carolina	6	536	472	3	743*	452
New York	17	593*	378	17	618*	378
Pennsylvania	5	506	393	2	600	316
Virginia/West Virginia	7	457	353	2	600*	316
All States	35	543*	390	33	741*	408
2005						
Michigan	0	–	–	9	981*	563
North Carolina	6	556	412	2	986	618
New York	16	388	353	2	830	408
Pennsylvania	5	521	477	2	877*	487
Virginia/West Virginia	7	492*	373	2	706	343
All States	34	459*	385	17	919*	516

Means followed by * indicate that average insect management costs of RR vs STD or RR+MD vs STD were significantly different by paired *t*-test ($P = 0.05$).

[a] Number of paired orchard blocks.

[b] The RR vs STD comparison for all states in 2002 includes one observation from New Jersey.

Table 4. Mean insect management costs ($/ha) in paired blocks of peaches managed with reduced-risk (RR) vs standard (STD insecticides), or with reduced-risk insecticides plus mating disruption (RR+MD) vs standard insecticides or reduced-risk insecticides plus mating disruption (RR+MD) vs standard insecticides plus mating disruption.

		RR vs Standard			RR + MD vs Standard			RR + MD vs Standard + MD		
Year	State	n[a]	RR	STD	n[a]	RR	STD	n[a]	RR	STD
2002	Michigan	–	–	–	3	445*	77	-	-	-
	New Jersey	–	–	–	8	551*	222	–	–	–
	Pennsylvania/West Virginia	–	–	–	3	494	284	3	425	376
	All States	–	–	–	14	531*	203	–	–	–
2003	Michigan	–	–	–	6	455*	138	–	–	–
	New Jersey	–	–	–	8	714*	255	–	–	–
	Pennsylvania/West Virginia	–	–	–	5	447*	245	1	x	x
	All States	–	–	–	19	561*	215	–	–	–
2004	Michigan	–	–	–	6	489*	99	–	–	–
	New Jersey	3	427*	203	5	484*	208	–	–	–
	Pennsylvania/West Virginia	–	–	–	2	316	334	5	252	297
	All States	–	–	–	13	460*	175	–	–	–
2005	Michigan	–	–	–	6	440*	121	–	–	–
	New Jersey	2	620	292	5	556*	237	–	–	–
	Pennsylvania/West Virginia	–	–	–	2	373	334	4	469*	334
	All States	–	–	–	13	474*	198	–	–	–

Means followed by * indicate that average insect management costs of RR vs STD or RR+MD vs STD or RR+MD vs STD + MD were significantly different by paired *t*-test ($P = 0.05$).

[a] Number of paired orchard blocks.

Table 5. Mean net income ($/ha) in paired blocks of apples managed with reduced-risk (RR) vs standard (STD) insecticides, or with reduced-risk insecticides plus hand-applied mating disruption pheromone dispensers (RR+MD) vs standard insecticides.

		RR vs Standard			RR+MD vs Standard		
Year	State	n[a]	RR	STD	n[a]	RR+MD	STD
2002	Michigan	0	–	–	6	6,800*	7,610
	North Carolina	5	7,734*	8,203	4	8,447	9,072
	New York	17	12,750	13,696	17	12,750*	13,696
	Pennsylvania	5	7,109	7,207	2	7,704	7,995
	Virginia/West Virginia	4	3,922*	4,248	5	3,801	4,236
	All States	32[b]	10,050*	10,438	34	9,581*	10,352
2003	Michigan	0	–	–	9	5,523*	6,128
	North Carolina	5	8,104	8,173	3	6,936*	7,546
	New York	17	8,060	8,195	17	7,788*	8,195
	Pennsylvania	5	5,753	5,923	2	5,644*	7,504
	Virginia/West Virginia	7	3,754	4,073	2	3,819	3,804
	All States	34	6,839*	7,010	33	6,812*	7,262
2004	Michigan	0	–	–	9	6,429*	6,958
	North Carolina	6	8,321	8,650	3	7,773	8,134
	New York	17	10,517*	10,668	17	10,604	10,668
	Pennsylvania	5	6,713*	6,834	2	7,704	8,037
	Virginia/West Virginia	7	3,816	3,977	2	3,596	4,604
	All States	35	8,257*	8,435	33	8,608*	8,899
2005	Michigan	0	–	–	9	6,602	6,689
	North Carolina	6	8,121	8,270	2	7,613	7,973
	New York	16	10,283	10,441	2	10,154	10,520
	Pennsylvania	5	7,099	7,148	2	5,819	6,056
	Virginia/West Virginia	7	3,658	3,648	2	3,846	3,609
	All States	34	8,069	8,176	17	6,723	6,854

Means followed by * indicate that average differences in net income between RR and STD or RRMD and STD were significantly different by paired *t*-test ($P = 0.05$).

[a] Number of paired orchard blocks.

[b] The RR vs STD comparison for all states in 2002 includes one observation from New Jersey.

Table 6. Mean net income ($/ha) in paired blocks of peaches managed with reduced-risk (RR) vs standard (STD insecticides), or with reduced-risk insecticides plus mating disruption (RR+MD) vs standard insecticides or reduced-risk insecticides plus mating disruption (RR+MD) vs standard insecticides plus mating disruption.

		RR vs Standard			RR + MD vs Standard			RR + MD vs Standard + MD		
Year	State	n[a]	RR	STD	n[a]	RR	STD	n[a]	RR	STD
2002	Michigan	–	–	–	3	4,050	4,043	–	–	–
	New Jersey	–	–	–	8	6,202*	6,565	–	–	–
	Pennsylvania/West Virginia	–	–	–	3	6,689	6,879	3	8,634	8,572
	All States	–	–	–	14	5,844	6,093	–	–	–
2003	Michigan	–	–	–	6	3,763	4,003	–	–	–
	New Jersey	–	–	–	8	6,531*	6,845	–	–	–
	Pennsylvania/West Virginia	–	–	–	5	8,184	8,429	1	x	x
	All States	–	–	–	19	6,091*	6,365	–	–	–
2004	Michigan	–	–	–	6	3,175	3,610	–	–	–
	New Jersey	3	6,909*	7,158	5	6,032	6,541	–	–	–
	Pennsylvania/West Virginia	–	–	–	2	6,079	6,390	5	9,286	9,059
	All States	–	–	–	13	4,722	5,164	–	–	–
2005	Michigan	–	–	–	6	5,510	5,604	–	–	–
	New Jersey	2	9,896	10,185	5	9,501*	9,802	–	–	–
	Pennsylvania/West Virginia	–	–	–	2	9,548	9,716	4	13,615	13,761
	All States	–	–	–	13	7,668	7,853	–	–	–

Means followed by * indicate that average insect management costs of RR vs STD or RR+MD vs STD or RR+MD vs STD + MD were significantly different by paired *t*-test ($P = 0.05$).

[a]Number of paired orchard blocks.

however, pest management costs in the STD treatment increased from an average of $362/ha in 2002 to $429/ha in 2005, an increase of ~18.5%. This is in contrast to the cost of RR programs, which declined from an average of $595/ha in 2002 to $459/ha in 2005, a decrease of ~23%. Averaged across all states, the cost of RR+MD ranged from $762/ha in 2004 to $968/ha in 2003.

Insect management costs for peaches also were considerably more expensive for RR vs STD blocks (Table 4). In peaches, insect management costs were evaluated for 59 paired standard (STD) and reduced-risk blocks with hand-applied pheromone dispensers (RR+MD) from 2002 to 2005 (another 18 blocks using various combinations of RR or MD techniques also were evaluated). Average insect management costs in STD blocks varied from a low of $432/ha in 2004 to a high of $531/ha in 2003. Average costs for the RR+MD blocks varied from a low of $1,137/ha in 2004 to a high of $1,384/ha in 2003. Over the 4-yr study, management costs were statistically higher in 20 of 22 state comparisons regardless of whether MD was used or not.

Net Income. There was considerable among-state variation in net income for apple, which was due to differences in crop destination (i.e., fresh vs processing markets) and cultivar. Over the entire study period, RR had higher incomes than STD treatments in 46 of 135 comparisons (34%), but in only 18 of 117 comparisons (15%) for RR+MD vs STD. However, for individual state comparisons, these differences were significant in only 4 of 16 comparisons of RR vs STD, and 7 of 20 instances for RR+MD vs STD (Table 5). Overall, the mean difference in income between STD and RR treatments narrowed from a high of $388/ha in 2002 to only $107/ha in 2005. The difference between STD and RR+MD treatments narrowed from a

Table 7. Results of analysis of variance and analysis of covariance for three binary explanatory dependent variables (fruit quality, insect management costs and net income) for apple.

	Quality	Costs	Net income
Adjusted R^2	0.13	0.60	0.82
F	5.51*	46.18*	136.31*
n	444	444	444
		Coefficients	
Intercept[a]	0.874*	278*	9,374*
States			
Michigan	0.073*	184*	1,063*
North Carolina	0.072*	139*	3,167*
New York	0.045*	76	4,143*
Pennsylvania	0.089*	54	2,819*
Treatments			
RR	–0.001	144*	–159
RR+MD	–0.002	465*	–544*
Cultivar			
'Delicious'	–0.008	116*	–3,372*
'Empire'	0.015	60	–749*
'GoldenDelicious'	–0.002	41	–2,651*
'York'	–0.004	105	–5,293*
'RomeBeauty'	0.000	12	–3,954*
'Macintosh'	0.014	–5	355
Year			
2003	0.024*	17	–2,875*
2004	0.021*	–60*	–1,379*
2005	0.028*	–32	–1,712

Values followed by * are significant at $P = 0.05$.

[a]Coefficients for fruit quality are expressed as proportion of insect-injured fruit, and $/ha for management costs and net income.

Table 8. Results of analysis of variance and analysis of covariance for three binary explanatory dependent variables (fruit quality, insect management costs and net income) for peach.

	Quality	Cost	Net income
Adjusted R^2	0.011	0.618	0.527
F-value	1.168	24.75*	17.35*
n	148	148	148
		Coefficients	
Intercept[a]	0.941*	161*	7544*
States			
Michigan	–0.002	–88*	–4516*
New Jersey	0.006	61*	–1806*
Treatments			
STD+MD	–0.024	169*	1018
RR	0.018	260*	1576
RR+MD	–0.004	292*	–133
Cultivars			
Early	0.006	7	830*
Mid	0.007	34	67
Years			
2003	0.010	19	1493*
2004	–0.007	32	1463*
2005	0.002	59*	673

Values followed by * are significant at $P = 0.05$.

[a] Coefficients for fruit quality are expressed as proportion of insect-injured fruit, and $/ha for management costs and net income.

high of $771/ha in 2002 to only $131/ha in 2005.

As with apple, net income for peach was generally lower for RR programs compared with STD programs. A total of 59 net income comparisons were made between blocks with STD programs and RR+MD programs (Table 6). Over the entire study period, only 11of the RR+MD comparisons (19%) had higher incomes than their STD comparisons. Overall, the mean difference in income between STD and RR+MD treatments averaged $284/ha. Another 13 comparisons of the cost and net income from a STD+MD vs RR+MD treatment were conducted in Pennsylvania from 2002 to 2005. There were no statistically significant differences between the costs or net incomes of these treatments over the four years.

Production Factor Effect on Economics. Regression results for the three models using binary explanatory variables showed that there were significant differences in apple fruit quality, production costs and net income among states, for certain years and cultivars, depending on the model (Table 7). Although all variables were important in helping to explain variation in each model, the coefficients of most interest were those relating to the RR and RR+MD treatment. In the apple quality model, there was no statistically significant quality difference among the STD, RR, and RR+MD treatments, confirming that all three treatments resulted in high-quality fruit. For insect management expenses, there was a significant increase in cost, estimated at $144/ha for RR and $465/ha for RR+MD over the STD treatment. There was a negative, but statistically insignificant, impact on net income estimated for the RR treatment (–$159/ha), and a significant impact of –$544/ha for RR+MD over the STD treatment. As expected, state, cultivar, and year variables had significant impacts on apple net income.

The coefficients of most interest in the peach models also were those relating to the variables that included RR and MD. The peach quality model revealed no statistically significant quality difference among the STD, STD+MD, RR, and RR+MD treatments (Table 8); all four treatments resulted in high-quality fruit. There was a significant increase in cost: $167/ha for STD+MD, $261/ha for RR, and $292/ha for RR+MD over the STD treatment. The binary variable analysis indicated that there was no statistically significant difference in net income among the management programs, in contrast with the conclusions from the paired *t*-tests (Table 5). The statistical significance of the early cultivar maturity variable may account for variability in the data that could not be evaluated by simple paired comparisons. This suggests that a combination of market differences and yields were able to overcome the significantly higher insect management costs for STD+MD, RR, and RR+MD. Similar to the apple analysis, state and year variables also had significant impacts on peach net income.

Discussion

A goal of this project was to help eastern U.S. apple and peach growers make the transition from organophosphate-based insect management programs to those that rely on reduced-risk and organophosphate-alternative insecticides and mating disruption. The geographic area included in these studies extended from the northernmost eastern production regions in Michigan and New York to the southernmost in North Carolina. The diversity of arthropod pests in eastern North American is as complex as anywhere in the world; in these studies, fruit damage was recorded from a minimum of 12 insect species on apple and 10 on peach. The pest complex attacking apples was similar throughout the region; the principal difference was that obliquebanded leafroller was most important in more northern areas (Michigan and New York), whereas tufted apple bud moth was the key leafroller species in Mid-Atlantic states. The primary difference in the peach pest complex was the species of Scarabaeidae that damaged fruit; the rose chafer was important in Michigan, and the Japanese beetle was important in New Jersey, Pennsylvania, and West Virginia. The similar pest complexes among a diversity of locations, combined with the use of relatively large plots (2–8 ha) in commercial orchards, provided for a robust experimental evaluation of new pest management tactics.

Our RR pest management strategies were largely successful in that they greatly reduced the environmental impact of apple and peach production and resulted in fruit quality equivalent to standard organophosphate programs. The large reduction in insecticide active ingredients (a.i.) applied to RR blocks was primarily due to the low use rates of new insecticides because there were few differences in the total number of insecticide applications in RR vs STD orchards in most study sites, particularly in the first two to three years. By the final year of the study, RR blocks received on average 86% less a.i. than the STD blocks for apple (or 5.7 kg a.i./ha less insecticide) and 79% (4.7 kg a.i./ha less) for peach. Given that about 75,000 ha of apples and 30,200 ha of peaches are produced in the eastern United States (USDA–NASS 2004), the implementation of RR programs could potentially eliminate ~570,000 kg a.i./ha of insecticides annually from these two crops, of which ~90% are organophosphates. Such a reduction in pesticide load would surely have a positive impact on environmental quality. In fact, EIQ field ratings in the RR treatments averaged 85 and 77% lower than STD treatments for apples and peaches, respectively.

Although the level of insect damage did vary among states and years, the fact that there were no significant differences between RR and STD programs indicated that RR programs were at least as effective as STD programs. In those instances where relatively high levels of damage were observed at specific locations or states, damage was usually high in RR and STD blocks. For leafrollers, this was probably because in most instances, the same insecticides were applied to RR and STD blocks. Development of OP-resistant populations of obliquebanded leafroller (Waldstein and Reissig 2000, Ahmad et al. 2002) in New York and Michigan, and tufted apple bud moth in North Carolina, Pennsylvania and Virginia/West Virginia (Knight et al. 1990, Bush et al. 1993) by the 1990s, accelerated the early adoption of IGRs and microbial insecticides for control of these two pests. In other instances, however, relatively high levels of damage occurred in treatments where RR and STD insecticides were applied. For example, tarnished plant bug and stink bug damage exceeded 3% in both treatments on several occasions (Figs. 8 and 9); and in most instances, neonicotinoids were used in RR blocks and organophosphates or pyrethroids in STD blocks. This would suggest that none of the insecticides was particularly effective against plant bugs, or alternatively that ground cover management played a more important role than insecticides in managing plant bug populations. The presence of flowering broadleaf weeds early in the growing season attracts plant bugs and leads to higher damage compared with more intensively managed orchard floors (Killian and Meyer 1984, Atanassov et al. 2002). Finally, in several instances, relatively high levels of damage were inflicted by sporadic pests that are not typically included in scouting programs; e.g., Comstock mealybug in North Carolina apples in 2003 and 2004, and San Jose scale in New Jersey (2004) and Michigan (2005). In these latter instances, damage was the result of the absence of control programs for these specific pests because of their unexpected occurrence.

Despite the increased importance of the codling moth and oriental fruit moth in eastern U.S. orchards during recent years (Bergh 2002, Hull et al. 2003, Reissig 2003, Mota-Sanchez et al. 2008), damage by these species was relatively low in this study, except in Michigan, where damage peaked at ~5% in STD blocks in 2005. Michigan was the only state where codling moth mating disruption was used in all RR blocks, and its continuous use likely contributed to reducing damage from an average of 3.3% in 2002 to 0.5% in 2005. Codling moth and oriental fruit moth also were leading causes of damage in several apple orchards in Virginia and West Virginia, particularly in STD apple blocks in 2003 (West Virginia) and 2005 (Virginia and West Virginia). Oriental fruit moth was the leading cause of damage at these sites, and OP-resistant populations are known to occur in this region (Usmani and Shearer 2001). Oriental fruit moth was adequately managed in peach orchards, except for a few instances in Pennsylvania (2002 and 2004).

Recently registered insecticide chemistries are generally applied at lower use rates and have greater selectivity compared with older broad-spectrum insecticides, such as organophosphates. However, we did not observe increased levels of biological control by either predatory mites or generalist predators in our RR compared with STD treatments. Despite the greater selectivity of RR insecticides, they exhibit varying levels of toxicity to key natural enemies. For instance, several neonicotinoid insecticides classified as reduced-risk (i.e., acetamiprid and thiacloprid) are highly toxic to coccinellids, which can be important biological agents of aphids. Acetamiprid also has been shown to prevent the predatory mite, *Galendromus occidentalis* (Nesbitt), from responding normally to increasing populations of European red mite (Beers et al. 2005). Nonetheless, the fact that peak populations of phytophagous and predatory mites did not differ between our RR and STD blocks demonstrates that RR programs did not negatively impact mite biological control programs compared with STD programs.

While our RR pest management programs were highly successful in providing commercially acceptable levels of pest suppression without upsetting mite biological control programs, they were generally more expensive and less profitable than STD programs. Reduced profitability was the result of the higher cost of new-chemistry pesticides relative to the older chemical products, along with the additional expense of pheromone dispensers in RR+MD treatments. It is noteworthy, however, that the profitability gap between RR and STD apple treatments declined from $388/ha to $107/ha in 2002 and 2005, respectively. Unfortunately, only a few peach blocks received only RR insecticides; thus, a trend in profitability could not be made. The improved economic performance of RR apple treatments over time, however, was due to several factors, including

- Our enhanced understanding of the attributes of new-chemistry insecticides over time, which allowed us to use these products more efficiently as the project progressed. For example, the average amount of insecticide active ingredients applied to RR plots decreased from 1.24 kg a.i./ha in 2002 to 0.95 kg a.i./ha in 2004, whereas it increased in the STD from 6.11 kg a.i./ha in 2002 to 6.69 kg a.i./ha in 2005.
- By the end of the 4-yr project, growers had incorporated numerous RR insecticides into their STD programs, most notably neonicotinoids. Average neonicotinoid use in STD programs increased from 0.02 kg a.i./ha in 2002 to 0.13 kg a.i./ha in 2005.
- Although not significant, there was less insect damage in RR vs STD treatments later in the project compared with earlier, and this increased quality difference increased income in RR blocks. Average total insect damage in RR treatments declined from 6.2% in 2002 to 4.2% in 2006, whereas damage in STD blocks only declined from 6.3% in 2002 to 5.8% in 2005.

The generally poor economic performance of our RR+MD treatments (which never were statistically more profitable than STD treatments) was due to the additional cost of mating disruption and because there was little, if any, reduction in insecticide use where mating disruption was used. Codling moth mating disruption has been most successful when used in large contiguous areas (Witzgall et al. 2008), and our use in relatively small plots adjacent to untreated areas was not the best strategy for this technology. The increasing incidence of pesticide-resistant codling moth populations throughout the eastern United States, however, is expected to create incentives for use of areawide or whole-farm mating disruption (Hull et al. 2007, 2008), which will likely lead to improved control, reduced insecticide use, and greater profitability. Similarly, mating disruption was effective for managing oriental fruit moth in blocks of peach, and, although MD use increased costs by $292/ha compared with STD treatments, yearly averages of net income across states revealed statistical differences in only one of four years.

This project successfully demonstrated the feasibility of using a RR approach to manage arthropod pests on apples in the eastern United States. Although RR programs were slightly less profitable than STD programs because of the higher cost of new technology, the profitability gap was reduced as we learned to use these new products more efficiently. This profitability gap will be further reduced, if not eliminated, in the near future when patents on new insecticides have expired and less expensive generics become available. Another factor that is expected to improve the economics of RR programs is the increasing incidence of organophosphate-resistant codling moth populations (Mota-Sanchez et al. 2008) and the increased damage associated with these populations (Hull et al. 2003, Reissig 2003). A result is that growers can expect better returns by reducing damage through the use of new insecticides against this pest.

Whereas our approach was to eliminate older chemistry insecticides from RR plots in an abruptly manner, growers will make the transition to RR programs by gradually incorporating those new tools that fit their systems most effectively. In fact, our cooperating growers adopted components of our RR programs into their STD programs during the course of this study, and additional components have been adopted since this project ended. The fruit industry has lost several organophosphate insecticides in recent years because of FQPA-related regulatory actions, and additional losses will occur in the future (e.g., azinphosmethyl on apple in 2012). This project has helped to demonstrate to the eastern U.S. orchard fruit industry that there is indeed life after organophosphates!

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