Research Updates

Comparing Integrated Pest Management and Protectant Strategies for Control of Apple Scab and Codling Moth in an Iowa Apple Orchard

M.L. Gleason[1], M.K. Ali[2], P.A. Domoto[2], D.R. Lewis[3], and M.D. Duffy[4]

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Iowa State University, Ames, IA 50011.

[1]*Dept. of Plant Pathology.*

[2]*Dept. of Horticulture.*

[3]*Dept. of Entomology.*

[4]*Dept. of Economics.*

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Summary. Integrated peat management (IPM) strategies for control of apple scab and codling moth (*Cydia pomonolla)* were compared with a traditional protestant spray program in an Iowa apple orchard over a 3-year period. IPM tactics for scab included a postinfection spray program and an integrated, reduced-spray program based on the use of demethylation inhibitor fungicides. Codling moth spray timing was determined by pheromone-trap captures and degree-day models. The IPM tactics resulted in an average of three fewer fungicide sprays and two fewer insecticide sprays than the protestant program. Neither yield, incidence of fruit scab, nor incidence of codling moth injury on fruit was significantly different among the two IPM treatments and the protestant treatment. A no-fungicide treatment had significantly lower yield and greater scab incidence than the other treatments. A partial budget analysis indicated that the treatment using the postinfection strategy was more costly per acre than the protectant program for orchards <20 acres, about equivalent in cost for 20 acres, but leas costly for 40 acres. A treatment incorporating the integrated, reduced-spray strategy was less costly than either postinfection or protestant strategies at orchard sizes from 5 to 40 acres. Return (total revenue – cost for control of primary scab and codling moth) per acre for the IPM strategies was somewhat lower than for the protestant program.

Most commercial apple growers in Iowa and other midwestern states of the United States apply fungicide and insecticide sprays at certain stages of crop development and according to calendar date (Gleason et al., 1989). They do not account systematically for the influence of weather on pest activity or ascertain whether the target pests are present. As a result, pesticides sometimes are applied when they are either ineffective or unnecessary. Techniques of integrated pest management (IPM) are gaining favor as a way to reduce pesticide use while maintaining acceptable control of pests. These methods are based on weather-driven models and and on monitoring of pest populations to assess the risk of crop damage.

Mills (1944) summarized how temperature and duration of wetness periods affect infection of apple leaves by ascospores of the apple scab fungus (*Venturia inaequalis).* Various modifications (Jones et al., 1980, MacHardy and Gadoury, 1989) of the "Mills Table" (Mills and LaPlante, 1951) have been used in recent IPM programs in which infection periods are monitored and sprays of demethylation inhibitor (DMI) fungicides are applied on a postinfection basis (Ellis et al., 1985). An alternative IPM tactic for scab control, the integrated reduced spray (IRS) program (Wilcox et al., 1992), relies on four prescheduled sprays of DMI fungicides in combination with contact fungicides, at the tight cluster, pink, petal fall, and first cover stages of flower bud and fruit development. Atypical protectant program for scab (Gleason et al., 1989) specifies two sprays prior to tight cluster and another spray during bloom, in addition to the four sprays of the IRS program. In comparison to postinfection programs, the IRS program is attractive because it dispenses with weather monitoring and allows orchardists more flexibility in combining fungicide and insecticide sprays, thereby saving trips through the orchard (Gadoury et al., 1989).

The effect of temperature on hatching of codling moth larvae has been summarized in reference tables (e.g., Beers et al., 1990; Brunner et al., 1982;) that predict the timing of each stage of the insect's life cycle based on the accumulation of degree-days. Degree-day models have been used in conjunction with population monitoring by means of pheromone traps, so that insecticide sprays are applied only when potentially damaging numbers of a damaging life-cycle stage are present (Beers et al., 1990).

Apple growers in certain areas have made extensive use of IPM

(Kovach and Tette, 1988), but the small-scale, widely scattered growers inmost Midwestern states of the United States have barely begun to try it. Few efforts to integrate IPM tactics for multiple types of pests (Prokopy et al., 1991) or to assess apple IPM strategies in economic terms (Funt et al., 1990) have been reported. Our study compared several IPM tactics for control of apple scab and codling moth to a protestant program with regard to number of pesticide sprays, efficacy of pest control, cost, and return.

Materials and methods

Experimental design. The 3-year (1989–91) study was located in a rootstock trial block of 'StarkSpur Supreme' Delicious apple *(Malus domestica* Borkh.) trees (5 years old in 1989), spaced 12 × 18 feet, at the Horticulture Research Farm of Iowa State Univ. near Gilbert. The experimental design was a randomized complete block with four treatments replicated four times. To minimize heterogeneity, rootstock were distributed randomly within treatments, and yield and pest data were taken from a subset of five trees in each replication that were selected in May 1989 on the basis of uniformity of tree size and fruit set.

Treatments. Treatments consisted of four strategies for timing fungicide and insecticide sprays to control codling moth and the primary infection phase of apple scab (Table 1). One treatment, designated POST, timed postinfection sprays for primary scab according to a modified Mills table (Zuck, 1986) and insecticide sprays according to degree-day models and threshold criteria for captures of male codling moths in pheromone traps (Great Lakes IPM, Vestaburg, Mich.) (Beers et al., 1990; Brunner et al., 1982). Weather data (air temperature, relative humidity, and duration of wetness period) were monitored with a Leaf Wetness Meter (Belfort Instruments, Inc., Baltimore, Md.). A second treatment, designated IRS, used the IRS strategy for scheduling scab sprays (Wilcox et al., 1992) and the same tactics for codling moth sprays as in the POST treatment, except that a max–min thermometer was used to record temperature. A third treatment, NOFN, received no fungicide sprays, but codling moth sprays were timed as in the IRS treatment. The fourth treatment, a protestant program (PROT), applied scab sprays at specified stages of blossom and fruit development, and codling moth sprays at regular time intervals during late spring and summer, as specified in the annual Iowa State Univ. Tree Fruit Spray Guide (Gleason et al., 1989).

Pesticides. Pesticides were applied to runoff at recommended rates (Gleason et al., 1989) with a hydraulic sprayer equipped with an adjustable spray gun and operated at 350 psi. Products and rates used for each treatment are given in Fig. 1. The fungicide myclobutanil (Nova 40 WP) was used in IPM treatments for scab because of its eradicant capabilities; it was tank-mixed with mancozeb (Dithane M45) in 1989, but used alone in 1990 and 1991. The protestant treatment (PROT) used a tank mix of benomyl (Benlate 50 WP) and mancozeb in 1989, and myclobutanil plus captan (Captan 50 WP) in 1990 and 1991. The insecticide phosmet (Imidan 50 WP) was used for codling moth control in all treatments.

In all treatments, endosulfan (Thiodan 50 WP) was applied at the pink growth stage and phosmet at petal fall to control tarnished plant bug *(Lygus lineolaris),* plum curculio *(Conotrachelus nenuphar),* and other insects that can cause deformation of fruit. In all treatments except the no-fungicide control (NOFN), captan was applied every 10 to 14 days from third cover until 2 weeks before harvest to control secondary apple scab, sooty blotch *(Gloeodes pomigena),* and fly-speck *(Zygophiala jamaicensis).* Dormant oil (Superior oil, 70 s viscosity) was applied to the PROT, POST, and NOFN treatments at green tip, and to the IRS treatment at tight cluster, to control European red mite *(Panonychus ulmi)* and San Jose scale *(Quadraspidiotus perniciosus).*

Codling moth IPM. About 1 May, pheromone traps (Pest Management Supply, Hadley, Mass.) for codling moth were placed at eye level in an apple tree in the center of the study block and at two locations in a neighboring block of bearing apples, ≈ 1000 ft from the test block. The pheromone lure was replaced in each trap every 4 to 6 weeks until harvest. The number of codling moths per trap was counted every other day until the first capture was recorded, then weekly during the remainder of the growing season. During 1989, the IPM strategy summed degree-days from 1 Mar. using a base temperature of 50F (10C) (Brunner et al., 1982), and Imidan was applied at 550 and 1550 degree-days only if an average of two or more codling moths per trap per week were captured at those times. In 1990 and 1991, the IPM strategy was changed to a more biologically rational strategy (Beers et al., 1990), which began to accumulate degree-days on the date, termed the biofix, when the first co-

Table 1. ***Description of treatments for control of primary apple scab and codling moth.***

Treatment	Primary apple scab: Pesticide timing and strategy	Primary apple scab: Monitoring equipment	Codling moth: Pesticide timing and strategy	Codling moth: Monitoring equipment
POST	Postinfection [z]	Leaf Wetness Recorder[y]	Population monitoring and degree-day model'	Leaf Wetness Recorder, pheromone traps
IRS	IRS strategy"	None	Population monitoring and degree-day model	Max–rein thermometer, pheromone traps
NOFN	No fungicides	None	Population monitoring and degree-day model	Max–rein thermometer, pheromone traps
PROT	Protestant schdule[v]	None	Protestant schedule"	None

[z]*Zuck (1986).*
[y]*Belfort Instrument Co., Baltimore, Md.*
[x]*Brunner et al. (1982), in 1989; Beers et* al *(1990) in 1990 and 1991.*
[w]*Wilcox et al. (1992).*
[v]*Gleason et al. (1989).*

Timing (developmental stage)	Treatment[z]						
	POST[y]		IRS[x]		NOFN[w]	PROT[v]	
	Fungicide	Insecticide	Fungicide	Insecticide	Insecticide	Fungicide	Insecticide
Green Tip	Post-infection[u]	Superior oil 1/4 gal (89)[t] 1/2 gal (90-91)[sr]	none	none	Superior oil 1/4 gal (89) 1/2 gal (90-91)	Benlate 0.5 oz.+Dithane 3 oz. (89) Benlate 0.75 oz.+Captan 4 oz. (90) Nova 0.5 oz (91)	Superior oil 1/4 gal (89) 1/2 gal (90-91)
Tight Cluster		none	Nova 0.5 oz (89) Nova 0.62 oz (90-91)	Superior oil 1/4 gal (89) 1/2 gal (90-91)	none	Same as Green tip	none
Pink		Thiodan 4 oz.	Nova 0.31 oz + Dithane 0.4 qt (89) Nova 0.62 oz (90-91)	Thiodan 4 oz.	Thiodan 4 oz.	Benlate 0.5 oz.+ Dithane 3 oz.(89) Benlate 0.75 oz.+Nova 0.5 oz.(90) Nova 0.5 oz. (91)	Thiodan 4 oz.
Bloom		none	none	none	none	Same as Pink	none
Petal Fall		Imidan 4 oz.	Nova 0.31 oz. (89) Nova 0.62 oz. (90-91)	Imidan 4 oz.	Imidan 4 oz.	Same as Pink	Imidan 4 oz.
First cover		DD + trap[q]	Nova 0.31 oz.+Dithane 0.2 qt (89) Nova 0.62 oz.(90)+Captan 8 oz. (91)	none (89) DD + trap (90-91)	DD + trap	Dikar 8 oz. (89) Captan 6 oz. (90) Nova 0.5 oz (91)	Imidan 4 oz.
Second cover (7-10 days after first cover)			Dikar 8 oz. (89) Captan 6 oz. (90-91)	DD + trap		Dikar 8 oz. (89) Captan 6 oz. (90) 8 oz. (91)	Imidan 4 oz.
Third cover thru harvest (10-14 day interval)	Dikar 6 oz. (89) Captan 6 oz. (90-91)		Dikar 6 oz. (89) Captan 6 oz. (90-91)			Dikar 6 oz. (89) Captan 6 oz. (90-91)	Imidan 4 oz.
Three weeks before harvest until harvest (10-14 day interval)	Captan 4 oz. (89) Captan 6 oz. (90-91)		Captan 4 oz. (89) Captan 6 oz. + Benlate 0.75 oz.(90) Captan 6 oz. (91)			Captan 4 oz. (89) 6 oz (91) Captan 6 oz.+ Benlate 0.75 (90)	Imidan 4 oz. (until 1 wk pre-harvest) (89,91) DD + trap (90)

[z]Formulations of products: Benlate 50WP, Captan 50 WP, Dikar 50, Nova 40 W, Dithane F 45, Imidan 50 WP, Thiodan 50 WP.
[y]POST Post-infection spray timing for scab
[x]IRS: Integrated reduced spray strategy (Wilcox ex al., 1992)
[w]NOFN: No fungicide sprays
[v]PROT: Protectant spray timing for scab
[u]1989 All post-infection fungicide sprays were as follows: Nova 0.5 oz + Dithane F45 0.2 qt/25 gallons dilute spray.
1990 All post-infection fungicide sprays were as follows Nova 0.5 oz + Captan 8 oz. (per 25 gallons) dilute spray.
1991 All post-infection fungicide sprays were as follows: Nova 0.5 oz/25 gal dilute spray.
[tsr]89, 90, 91= 1989, 1990, 1991
[q]Degree day criteria & pheromone trap captures

Fig. 1. Plan for spray timing and pesticide used, field experiment, 1989–91. All rates are per 95 liters (25 gallons) diluted spray, unless otherwise noted. Treatment was used. for all 3 years unless designated otherwise. The treatment of every developmental stage in the fungicide section of the NOEN study was no fungicide spray.

dling moths were captured. Phosmet was applied at 250 and 1260 degree-days after biofix, and also at 2 and 4 weeks after these dates if an average of more than two codling moths per trap were caught in each of the 2 preceding weeks.

Scab inoculation. Because of severe drought in 1988 and 1989, scab-infected leaves were almost absent from central Iowa in Fall 1989. To provide overwintering inoculum, several hundred pounds of scab-infected apple leaves obtained from orchards in Illinois, Michigan, and Missouri were distributed evenly throughout the orchard in Dec. 1989.

Harvest. Apples from each tree were harvested separately, graded, and sorted by fruit diameter using commercial grading equipment. Weight of fruits in each standard size range were recorded, and the fruits were classified into marketable or cull grades. The probable causes of injury to each cull apple (e.g., apple scab, codling moth, mechanical injury) were identified. In addition, apples that had dropped from the tree within several weeks before harvest were weighed and probable causes of injury determined.

Economic analysis. A partial budget technique (Calkins and DiPietre, 1983) was used to compare data from all treatments. The analysis encompassed all direct costs of pesticide application and pest monitoring for codling moth and primary apple scab. Labor rates for monitoring and spraying were estimated at $6.00/h (Duffy, 1992), and the time required to spray with an airblast sprayer was estimated at 20 rein/acre. The fixed cost per acre for a 40-hp tractor and airblast sprayer was estimated to be $3.15 per spray(Duffy, 1992). An amortization rate of 15% and a lifetime of 10 years was estimated for the Leaf Wetness Recorder. Retail prices of pesticides in 1989–1991 were obtained from two Iowa agrichemical dealers and averaged.

To calculate return, cost of control of codling moth and primary scab was subtracted from revenue [(marketable yield × price per unit size) + (cull yield × price per unit weight)]. Wholesale prices per pound used to calculate revenue were based on 1987 averages for Iowa apples (K. Khojasteh, Iowa Dept. of Agriculture and Land Stewardship, personal communication) because these data were more representative of long-term averages than 1988 or 1989 prices. Prices per lb were $0.386 for apples >3.20 in diameter, $0.391 for apples between 2.70 and 2.96 inches, $0.382 for apples <2.70 inches, and $0.146 for culls (juice apples).

An economic engineering approach (Calkins and DiPietre, 1983) was used to project the estimated differences among treatments over orchard sizes of 5, 10, 20, and 40 acres. A single unit of weather-monitoring equipment was assumed to provide adequate information for an orchard of up to 40 acres in size (Funt et al., 1990). Additional assumptions and calculations used in the economic analysis are detailed in Ali (1991).

Table 2. ***Monthly rainfall at the Iowa State Univ. Horticulture Research Farm during the study.***

Month	Rainfall (inches) 1989	1990	1991	30-year mean[z]
April	2.56	2.40	8.90	3.38
May	2.87	9.61	7.72	4.27
June	2.71	9.96	3.43	5.25
July	2.40	7.95	1.46	3.74
August	1.89	5.23	2.40	3.93
September	3.38	1.10	3.15	3.48

[z]*Measured at Ames, Iowa, airport, 1961–1991.*

Table 3. ***Number of fungicide sprays applied for control of primary apple scab and number of insecticide sprays applied for control of codling moth.***

	Fungicide sprays				Insecticide sprays			
Treatment	1989	1990	1991	3-year mean	1989	1990	1991	3-year mean
POST	3	3	4	3.3	4	7	6	5.7
IRS	4	3	4	3.7	5	7	6	6.0
NOFN	0	0	0	0.0	5	7	6	6.0
PROT	7	7	5	6.3	9	9	6	8.0

Results

Rainfall. **From** April through June, the period of maximum risk for primary scab infection, weather was unusually dry in 1989 and unusually wet in 1990 and 1991 (Table 2).

Pesticide sprays. IPM treatments (POST and IRS) saved an average of three fungicide sprays and two insecticide sprays, in comparison with a protestant schedule (PROT) (Table 3).

Yield. Differences in marketable and cull yields in the IPM treatments and the protestant treatment were not statistically significant (Table 4). The no-fungicide treatment had significantly lower marketable yield than the other treatments in 1991 and in 3-year averages.

Apple scab. Mean incidence of scab symptoms on harvested fruit in the IPM treatments was not significantly different than in the protestant program, but the no-fungicide treatment had significantly more scab than the other treatments (Table 5).

Codling moth. Codling moth injury occurred only in 1989 (Table 6). The incidence of damage was higher in dropped than in harvested fruit (data not shown); however, the overall incidence of codling moth injury in 1989 was <1.4% in all treatments, and differences among the treatments were not significant.

***Economic* analysis.** The estimated per-acre cost of treatments relative to each other varied with orchard size (Table 7). The POST treatment was more expensive than the protestant treatment for orchard sizes of 5 and 10 acres, nearly equivalent at 20 acres, and less expensive at 40 acres. The IRS treatment was less expensive than either the PROT or POST treatments, and the no-fungicide treatment had the lowest costs of all treatments. For all orchard sizes, return per acre per treatment was in the following order: PROT > POST > IRS> NOFN (Table 7).

Table 4. ***Mean yield of marketable and cull fruit.***[z]

	Marketable yield (lb/acre)[y]				Cull yield (lb/acre)[x]				Ratio of
Treatment	1989	1990	1991	3-year mean	1989	1990	1991	3-year mean	marketable/cull
POST	2608 a	4416 ab	5287 a	4104 a	2880 a	4704 ab	1959 a	3181 ab	1.30 a
IRS	2088 a	4217 ab	3899 a	3402 a	2048 a	4954 ab	1836 a	2946 ab	1.16a
NOFN	2164 a	2284 b	1629 b	2026 b	2555 a	3632 b	2041 a	2743 b	0.74 b
PROT	2992 a	4240 ab	5411 a	4214 a	3012 a	5851 ab	1925 a	3596 a	1.17 a

[z]*Means in the same column followed by the same letter are not significantly different (Duncan's multiple range test,* P *= 0.05, n = 4).*
[y]*Grade U.S. No. 1.*
[x]*More than 90% of culled fruit in each year resulted from non-pest injury, primarily mechanical injury (Ali, 1991).*

Discussion

We have shown that two alternative IPM strategies can control codling moth and primary apple scab in Iowa as effectively as a protestant program and with substantially fewer pesticide sprays.

The average reduction in fungicide sprays in comparison to protestant programs, three per season, is in the range of previous studies of postinfection (Funt et al., 1990; Shaffer, 1986, 1992) and IRS programs (Wilcox et al., 1992). IPM treatments controlled scab as well as a protestant program, and much better than an unsprayed treatment. In 1991, however, scab incidence in the sprayed treatments exceeded 7% in all treatments. This poor control was attributed to fewer protestant fungicide sprays (five in 1991 vs. seven in both 1989 and 1990), large amounts of overwintered inocu-

Table 5. *Mean incidence (%) of apple scab symptoms on harvested fruit.*[z]

Treatment	1989	1990	1991	3-year mean
POST	0.0 a	0.2 a	7.3 b	2.5 b
IRS	0.0 a	0.0 a	12.2 b	4.1 b
NOFN	0.0 a	1.8 a	39.8 a	13.9 a
PROT	0.0 a	0.0 a	7.6 b	2.5 b

[z]*Means in the same column followed by the same letter are not significantly different (Duncan's multiple range test,* P *= 0.05, n = 4).*

Table 6. *Mean incidence (%) of codling moth injury on harvested fruit.*

Treatment	1989	1990	1991	3-year mean[z]
POST	0.42 a[y]	0.00 a	0.00 a	0.14
IRS	0.39 a	0.00 a	0.00 a	0.13
NOFN	1.37 a	0.00 a	0.00 a	0.46
PROT	0.25 a	0.00 a	0.00 a	0.08

[z]*Three-year means were not analyzed statistically because protocol was changed for 1990 for POST, IRS, and NOFN treatments.*
[y]*Means in the same column followed by the same letter are not significantly different (Duncan's multiple range test,* P *= 0.05, n = 4).*

Table 7. *Estimated annual cost per acre for control of codling moth and primary scab, and annual return[z] per acre.*

Treatment	Cost per acre per year ($)				Return per acre per year ($)			
	5 acres	10 acres	20 acres	40 acres	5 acres	10 acres	20 acres	40 acres
POST	311.24	238.35	202.57	184.68	1570.33	1643.50	1679.28	1697.17
IRS	178.46	176.24	175.80	175.57	1447.90	1450.12	1450.57	1450.79
NOFN	100.96	98.74	98.29	98.07	1001.99	1004.21	1004.65	1004.87
PROT	202.36	202.37	202.37	202.28	1799.72	1799.72	1799.72	1799.81

[z]*Return = revenue – cost of control of codling moth and primary scab.*

lum, particularly in the no-fungicide control, and very wet weather in April and May 1991 (Table 2). Wilcox et al. (1992) cautioned against using the IRS program for scab control if incidence of fruit scab the previous season was above 1% to 2% because this implies a much higher incidence of scab in overwintering leaves. In fact, when fruit scab incidence in the no-fungicide treatment was 1.8% in 1990, incidence of scab on overwintering leaves in this treatment was 22% (Gleason, unpublished data). This level of inoculum may have been sufficient to trigger an epidemic in 1991. Similarly, postinfection spray programs such as our POST treatment may not provide acceptable control when the amount of overwintering inoculum is large (J. Hartman, Univ. of Kentucky, personal communication). The failure of the protestant treatment to provide acceptable scab control in 1991, however, suggests that intervals between fungicide sprays were too long, given the extremely wet conditions that prevailed that spring and the presence of abundant overwintered inoculum.

As with primary scab, the IPM tactics controlled codling moth as well as a protestant program. The absence of any fruit injury in 1990 and 1991 despite substantially greater codling moth captures than in 1989 (Gleason, unpublished data) suggests that criteria for the IPM program in 1990 and 1991 were too stringent. Other IPM programs have used biofix thresholds of two to five moths per trap per week (J. Johnson, Dept. of Entomology, Michigan State Univ., personal communication) and action thresholds of five (Travis, 1992) or 10 (Lucas, 1991) codling moths captured per trap per week.

The cost of the Leaf Wetness Recorder (about $1700 in 1989) was the primary reason that the postinfection treatment was more expensive than the protestant program for orchard sizes of 20 acres or less. Because a single recorder was assumed to be sufficient for orchards up to 40 acres in size (Funt et al., 1990), per-acre costs fell as orchard size increased. Similarly, a postinfection strategy for scab control that used an electronic disease-monitor called a Predictor (Reuter–Stokes, Inc., Twinsburg, Ohio) had an increased cost advantage compared with a protestant schedule when orchard size increased from 20 to 40 acres (Funt at al, 1990).

The IRS strategy, which used no weather instruments for monitoring wetness duration and only a max–min thermometer for degree-day monitoring, was less expensive than the protestant program for all orchard sizes tested. The analysis suggests that the IRS program may be more cost-effective than IPM strategies that rely on relatively expensive wetness-monitoring devices, particularly for orchards of 20 acres or less. It is critical to remember, however, that the IRS program should be used only for situations in which fruit scab incidence was minimal the previous year.

Although the protestant treatment had a higher return per acre than the IPM treatments for all orchard sizes, this result should be interpreted with caution, because yield differences among these treatments were not statistically significant. Additional field-testing is needed to clarify the relative effects of the IPM and protestant treatments on yield and return.

In sum, our findings suggest that two different IPM programs can control scab and codling moth in Iowa as efficiently as a traditional protestant program, but they require substantially fewer pesticide sprays. POST, an IPM program that monitored wetness duration, was more expensive than the protestant program for orchards of 5 and 10 acres, equivalent for 20 acres, and less expensive for 40 acres. IRS, the other IPM program, did not monitor wetness duration and was less expensive than the protestant program for orchard sizes from 5 to 40 acres. Return (total revenue minus the cost of scab and codling moth control) was somewhat higher for the protestant program than for the IPM programs.

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