Development and Evaluation of a More Efficient Monitoring System for Apple Maggot (Diptera: Tephritidae)

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ABSTRACT A series of tests done in commercial and research apple (*Malus domestica* Borkh.) orchards during 1986–1988 evaluated different trap designs and treatment thresholds for apple maggot, *Rhagoletis pomonella* (Walsh). No difference in catch efficiency in unsprayed trees was observed among Ladd yellow-panel-plus-red-hemisphere traps, red wooden-sphere traps, and Olson sphere traps covered with standard, brushable, or diluted adhesive mixtures. Of 10 trap designs that we tested in 20 commercial orchards, all sphere traps baited with synthetic apple volatiles were more effective at catching apple maggot adults than were unbaited sphere traps, which caught more adults than did yellow-panel traps. In a test using the baited traps to time control sprays in commercial orchards, we achieved acceptable levels of control with a catch action threshold of eight adults per trap. With this threshold, 70% fewer sprays (2.8 fewer applications) were applied than in a calendar-based program. Trials in 16 blocks scouted by growers with baited traps and a threshold of five adults per trap for timing sprays resulted in 0.6 fewer applications and no difference in fruit infestation levels, compared with blocks sprayed according to the growers' conventional schedules. Despite the use of a threshold of five adults per trap, which was chosen to be more conservative than that in the research trials, growers did not always follow the recommended treatment guidelines. The use of this trapping system has been incorporated into current commercial pesticide recommendations for New York apple growers.

KEY WORDS Insecta, *Rhagoletis pomonella*, apple volatiles, trapping

MORE INSECTICIDE SPRAYS are currently recommended for control of the apple maggot, *Rhagoletis pomonella* (Walsh), in New York apple (*Malus domestica* Borkh.) orchards than for any other insect pest (Agnello 1988). Growers usually apply an average of three to four sprays on a 10–14-d schedule during July and August when adults are active. During the past 10 yr, formal research studies (Prokopy & Hauschild 1979, Reissig & Tette 1979) and informal observations by university extension and integrated pest management (IPM) personnel have shown that control sprays for apple maggot can be reduced by 40–60% by the use of monitoring systems. Despite the proven effectiveness of the current New York monitoring recommendations for apple maggot, which rely on red sticky spheres and a catch action threshold of one adult per trap, most New York apple growers are not using apple maggot traps because they are concerned about the risk of crop loss in monitored orchards, and because the most commonly used traps are difficult to prepare, deploy, and maintain.

Much research has been done on trap designs and monitoring systems for apple maggot in North America (Kring 1970; Reissig 1975a,b; Prokopy & Hauschild 1979; Neilson et al. 1981; Reissig et al. 1982, 1985; AliNiazee et al. 1987; Stanley et al. 1987). Two basic traps, yellow panels and red spheres, have been investigated under various conditions and in combination with apple volatile lures to determine their relative effectiveness in catching apple maggot adults. A yellow panel with red hemispheres is the most effective unbaited trap design even at low population levels of apple maggot (Kring 1970, AliNiazee et al. 1987). A synthetic apple volatile lure can increase the effectiveness of standard red sticky spheres in commercial apple orchards by 2–4 times (Reissig et al. 1985, AliNiazee et al. 1987). Field tests in which one volatile-baited sphere (VBS) was hung in the canopy of unsprayed trees of various sizes showed that the traps were very sensitive in detecting adults, and that in no case was damage observed without adults being captured (Stanley et al. 1987). Field tests to define a catch action threshold to begin control sprays in monitoring systems using VBS traps have indicated that use of the same threshold (one adult on any trap) currently recommended for the standard traps is not practical because the more sensitive VBS traps catch so many apple maggot adults that spray schedules based on these guidelines are no different from those of a standard protective schedule. However, Stanley et al. (1987) showed that by using higher catch action thresholds (2–5 adults per trap) for VBS monitoring systems in commercial orchards, the number of treatments could be reduced substantially compared with those in a standard protective schedule. A threshold of 10 adults per trap resulted in fruit injury by apple maggot that was commercially unacceptable.

Standard red wooden-sphere traps must be dipped in melted adhesive and allowed to dry before placed in the trees in the orchard. However, a variety of commercial products are now available that would simplify monitoring procedures, provided they are as effective as the original (research) versions. Relatively inexpensive, disposable, plastic spheres that assemble in the field and adhesives that can be applied with a brush or by dipping the traps at ambient temperature would make the traps easier to handle and more attractive to growers. Similarly, synthetic chemical lures capable of detecting low populations of apple maggot would increase the reliability of these monitoring systems in commercial plantings. Field bioassays of different volatile blends and components showed that traps baited with a single component, butyl hexanoate, caught just as many adults as traps baited with any other blend or combination of compounds (Averill et al. 1988).

Here we report the results of four field evaluations done in western New York over a 3-yr period to integrate all available monitoring components into an apple maggot trapping system with an appropriately defined catch action threshold. Our purpose was to provide a basis for recommending its use by growers who do not participate in formal IPM programs.

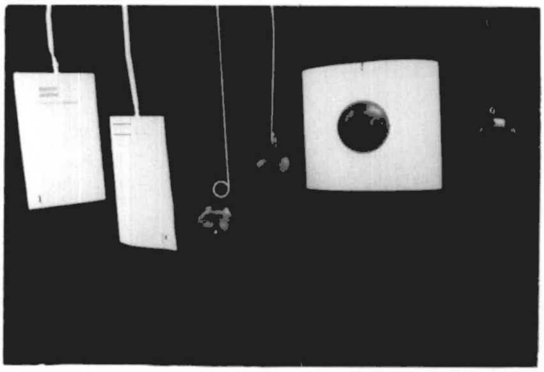

Fig. 1. Different trap designs tested for apple maggot attraction. L to R: Pherocon panel, Scentry panel, Pest Management Supply sphere, Olson sphere, Ladd yellow panel with red hemispheres, red wooden sphere.

Materials and Methods

1986 Trap–Adhesive Test. A test of commercial spheres (Fig. 1) and adhesives was done in a mixed-variety planting of semidwarf (MM106 rootstock) 'McIntosh,' 'Red Rome,' 'Cortland,' 'Monroe,' 'Golden Delicious,' and 'Rhode Island Greening' trees in a research orchard at the New York State Agricultural Experiment Station, Geneva. This orchard had not been treated with insecticides for several years and consequently supported a moderate population of apple maggot adults. Eight trap designs were evaluated in 1986: Olson red sphere (Olson Products, Medina, Ohio) coated with standard adhesive (Bird Tanglefoot; The Tanglefoot Company, Grand Rapids, Mich.) (OSS); Olson red sphere coated with brushable adhesive (Olson Products) (OSB); Olson red sphere coated with diluted adhesive (600 ml Bird Tanglefoot and 700 ml mineral spirits made by stirring at room temperature) (OSD); Great Lakes sphere (Great Lakes IPM, Vestaburg, Mich.) coated with standard adhesive (GSS); Great Lakes sphere coated with diluted adhesive (GSD); Ladd yellow panel with red hemispheres (Ladd Research Industries, Burlington, Vt.) coated with standard adhesive (LYP); 8.5-cm-diameter dark red wooden sphere (Pest Management Supply Company, Amherst, Mass.) coated with standard adhesive (RWS); and Pherocon AM (Zoecon Corporation, Palo Alto, Calif.) prebaited, pre-coated yellow panel (PYP).

The orchard was divided into two blocks to account for the historical differences in apple maggot numbers between the two ends of the orchard. Each block consisted of 48 trees; the eight trap treatments were replicated three times within (i.e., choosing 24 random trees) each block. One of each of the eight traps was hung in a tree in a randomized complete block design. Trees containing traps were separated by one to three trees without traps so that different traps were at least 10 m apart to minimize possible competition or interference. No insecticides were applied to the orchard. Traps were hung in the tree at a height of approximately 2 m, and their placement in relation to the foliage was consistent with the recommendations of Drummond et al. (1984). All traps were checked and rerandomized weekly within the blocks; fresh adhesive was applied as needed. Apple maggot adults that we captured were removed, counted, and their sexes were determined in the laboratory. The traps were set out 15 July and removed 26 August.

1987 Trap–Lure Test. The effectiveness of 10 trap designs (Fig. 1 and 2) was investigated in 20 commercial apple orchards in Wayne County, N.Y. These were PYP trap; Scentry (Scentry, Buckeye, Ariz.) prebaited, glued yellow panel (SYP); RWS trap; Pest Management Supply glued, 10-cm-diameter, red plastic sphere (Pest Management Supply Company) (PMS); OSB trap; RWS baited with 0.75 ml of a modified blend of apple volatiles (Fein et al. 1982, Reissig et al. 1982) in a 7.4-ml vial attached with a paper clip and rubber band to the top of the sphere (FBS); a sphere plus vial identical to the FBS trap except that the vial contained only butyl hexanoate, one component of the Fein blend (BHS); LYP trap baited with the Fein blend of synthetic apple volatiles released from a rubber septum (Ladd Research Industries) attached with a paper clip to the top of the trap (LSL); RWS baited with a 1.4-cm-diameter, sustained-release plastic membrane impregnated with butyl hexanoate (Consep Membranes, Bend, Oreg.) attached with a paper clip to the top of the sphere (CMS); and RWS baited with a Ladd rubber septum identical to that used in the LSL trap (LSS).

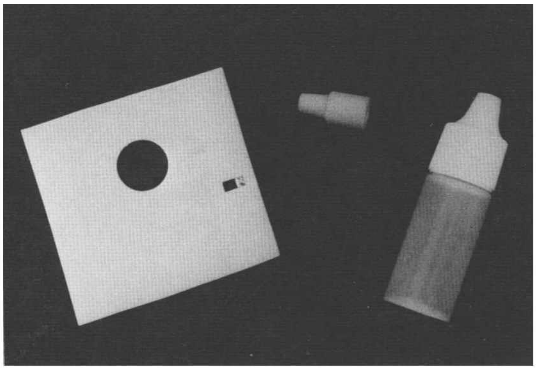

Fig. 2. Different release systems for synthetic apple volatiles. L to R: Consep membrane, Ladd septum, 7.4-ml polyethylene vial.

The 20 test orchards were chosen to represent the variability occurring among commercial blocks of apples in western New York. These orchards contained different cultivars, various ages planted at different densities on seedling, and several size-controlling rootstocks. In addition, the test blocks had been exposed to various levels of indigenous and immigrating apple maggot populations in previous years. One of each of the 10 traps was hung in trees in the outer row of each orchard. Trees containing traps were separated by one to three trees without traps so that different traps were at least 10 m apart to minimize possible competition or interference. To reduce position effects, traps were rerandomized among the 10 test trees within each orchard each week. The traps were hung along the outside edge of the tree canopy, approximately 2 m above the ground, with as much fruit and foliage as possible surrounding them at a distance of 15 to 20 cm. The traps were examined and cleaned weekly, and replaced with fresh traps when necessary. The Ladd septa were replaced once. Except for the PMS trap, which was set out on 2 July, the traps were set out on 23 June before the apple maggot emerged, and all traps were removed on 27 August. Numbers of adults caught by the different traps were not used in any decisions regarding the timing or number of insecticide sprays applied by the growers during the summer.

1987 Threshold Test. FBS traps were used to investigate various catch action thresholds based on catches of apple maggot adults in small plots replicated in sections of six commercial orchards located in Wayne County, N.Y. Four treatment schedules were compared to determine whether timing control sprays on the basis of catches on baited sphere traps could provide protection equal to that obtained with a calendar schedule. The treatments were a constant 14-d spray schedule and catch action thresholds of two, five, or eight adults per trap on FBS traps.

The orchard sections, each of which was a separate block, ranged from 0.5 to 1.8 ha and consisted of mature trees maintained for the processing market. The cultivars present were primarily 'Northern Spy,' 'Rome,' 'McIntosh,' 'Cortland,' '20-Ounce,' 'Wealthy,' and 'Rhode Island Greening' on standard (nondwarfing) rootstocks. One quarter of each section was assigned to each of the four treatments. Treatment plots within an orchard section were approximately equal in size (range, 12–30 trees) and were arranged linearly within the section. Treatments were assigned randomly to the plots within a section. The six orchards comprised two each that historically had low, moderate, and high levels of apple maggot damage. On 25 June, two FBS traps were hung in each of the threshold plots and placed in the trees at the edges of the blocks nearest to the potential sources of apple maggot immigrants in a manner consistent with the method of Drummond et al. (1984). The traps were checked and cleaned twice weekly from 30 June until 20 August. To establish a correlation between adult catch and oviposition potential, all apple maggots captured were collected, placed in 70% ethanol, and brought to the laboratory, where their sex was determined, and females were dissected to obtain egg counts. Traps were not hung in the calendar spray schedule plots. Azinphosmethyl (Guthion 50% wettable powder [WP]; Mobay Chemical Corporation, Kansas City, Mo.) at 113 g (AI)/379 liters was applied with an airblast sprayer if the appropriate catch action threshold was exceeded and the block had not been treated in the past 10 d. The 10-d treatment interval was used because azinphosmethyl at the above rate is estimated (Wilcox et al. 1987) to provide 12 d of protection from damage, and 1–2-d were allowed to apply the treatment. The first spray in the calendar schedule plots was applied 10 d after the first recorded adult catch in the region (30 June), in accordance with the average 9–10 d period before oviposition of apple maggot in New York (Dean & Chapman 1973). All of the sprays in the threshold plots were applied within 1 d of reaching the designated threshold, except that in one of the plots with a threshold of two adults per trap, 6 d elapsed between when the threshold was reached and the spray was applied. Catches of apple maggot during the 10 d after an application were not included in the cumulative catch values used to make treatment decisions. Chemical sprays were not applied after 18 August. Damage levels were assessed just before normal harvest (10–16 September) by counting the number of fruit with tunnels in 100 fruits picked and up to 25 dropped fruits collected from each of five trees in each treatment. The two trap trees were among those sampled in each of the treatments containing traps.

1988 Trials Scouted by Growers. OSB traps baited with Consep membrane lures (Fig. 3) were used in a simplified scouting program (Agnello et al. 1989) administered by Cornell Cooperative Extension personnel in 16 commercial orchard blocks located in Niagara, Orleans, Monroe, Wayne, and

Ontario counties. The blocks ranged from approximately 2 to 4 ha and consisted primarily of 'McIntosh,' 'Red Delicious,' 'Ida Red,' 'Rome,' 'Paula Red,' and 'Cortland' cultivars on several size-controlling rootstocks (dwarf and semidwarf) and of different ages, producing fruit primarily for the fresh market. On or about 15 July, two traps were set out in each block. The traps were checked and cleaned twice weekly by the grower until 19 August. An insecticide effective against apple maggot, usually azinphosmethyl (35% WP) at 113 g (AI)/379 liters, was recommended to be applied with an airblast sprayer by the grower when an average of five adults per trap were caught, and the block had not been treated in the past 10–14 d. Despite indications from the 1987 threshold test that a higher treatment threshold could be used with some confidence (see Results section), we chose to use the more conservative threshold of five adults per trap in these trials to guard against the remote possibility of unacceptable fruit damage from unexpectedly high population levels of apple maggot. Records of trap catches and sprays applied were evaluated to ascertain compliance with the recommended procedures, and injury was assessed in each block immediately before the normal harvest. A total of 1,000 fruits, including at least 750 picked and up to 250 dropped fruits collected from five trees, were inspected in each block. Where possible, information about sprays and fruit damage was recorded also for a generally comparable orchard maintained by the same grower but in which spray decisions were not based on trap catches.

Statistical Analyses. All catch data were transformed by $\log_{10}(x + 1)$ before analysis. Spray numbers in the 1987 threshold test and 1988 trials that were scouted by growers were transformed by square root $(x + 0.5)$ before analysis. Catches in the 1986 trap–adhesive test, and catch, days until first spray, days per spray, and number of sprays in the 1987 threshold test were all compared with an analysis of variance and mean separation using the least significant difference test (Proc ANOVA, SAS Institute 1985, 113–137). Days per spray was calculated as the days between sprays, from the date of first adult catch to first spray, or from the last spray to date of harvest in the respective threshold plots. Fruit damage proportions in the 1988 trials that were scouted by growers were subjected to an arcsine square-root transformation before analysis using the least significant difference test. Catches in the 1987 trap–lure test were compared among the different types of traps with an analysis of variance and least-squares means separation (Proc GLM, SAS Institute 1985, 433–506) to account for the unbalanced nature of these data.

Results

1986 Trap–Adhesive Test. A total of 6,228 adults were trapped during the season, including 3,662 males and 2,566 females. The performance of the

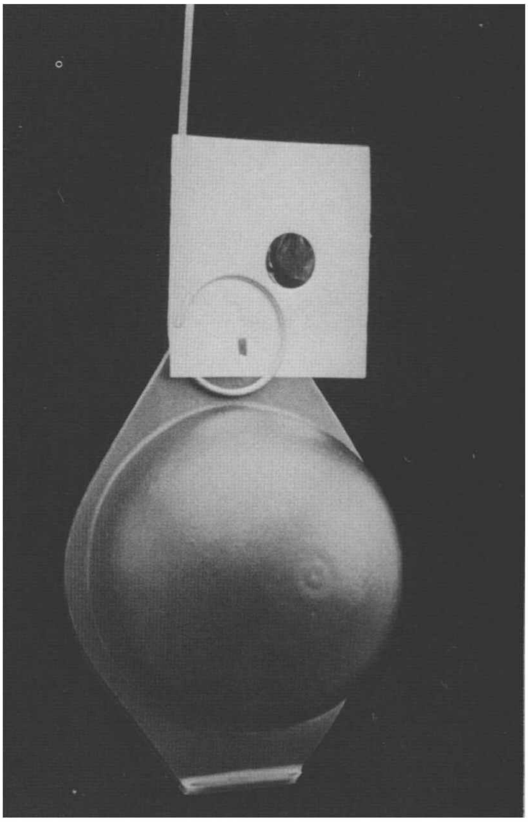

Fig. 3. Olson sphere baited with Consep membrane lure.

different traps is summarized in Table 1. With the generally higher levels of apple maggots in these trees than are normally found in a commercial orchard, catch efficiency did not differ (t = 1.97, df = 280, $P < 0.05$) among the LYP, the RWS, and the OSS, OSB, or OSD traps. The LYP trap caught more adults than did the PYP or the GSD, and GSS traps, but among all the sphere traps, the GSD and GSS traps performed as well as all except the OSS trap. Weekly catches of adults peaked in late July, after which numbers dropped sharply before tapering off at the end of August. The OSB trap did not catch as many adults during this peak period as did any of the other traps, which accounts for its relatively low per week value of apple maggots (19.2, compared with 28.5–54.8 for all the other trap types). However, its catches remained relatively constant for the remainder of the season, so that it ranks much higher overall when the transformed values are compared.

1987 Trap–Lure Test. In the 20 commercial orchards where the traps were tested, a total of 4,788 adults, including 1,789 males and 2,999 females, were trapped. Although some of these orchards had a history of high apple maggot populations, the catch levels in this test were much lower than those obtained in the unsprayed orchard in the trap–adhesive test (Table 2). Catch efficiency

Table 1. Mean (SEM) apple maggot catch with various traps and adhesives in an unsprayed orchard of mixed apple cultivars, 1986

Trap	Apple maggot/trap[a,b]	
Ladd yellow panel with red hemispheres (LYP)	32.0a	(5.8)
Olson sphere + standard adhesive (OSS)	24.5ab	(3.4)
Red wooden sphere + standard adhesive (RWS)	21.1abc	(3.7)
Olson sphere + brushable adhesive (OSB)	17.8abc	(2.2)
Olson sphere + diluted adhesive (OSD)	20.3abc	(3.8)
Pherocon yellow panel (PYP)	20.7bc	(3.8)
Great Lakes sphere + standard adhesive (GSS)	18.8c	(3.9)
Great Lakes sphere + diluted adhesive (GSD)	17.8c	(3.3)

Means followed by the same letter are not significantly different ($P = 0.05$; least significant difference test [SAS Institute 1985]).

[a] Average number of apple maggot adults per week. $\log_{10}(x + 1)$ transformation applied to catches before analysis.

Table 2. Mean (SEM) apple maggot catch with various traps and lures in commercial orchards, 1987

Trap	Apple maggot/trap[a,b]		Frequency of positive catch[b]
Butyl hexanoate + sphere (BHS)	5.39a	(0.73)	0.66
Consep membrane + sphere (CMS)	4.91ab	(0.61)	0.72
Ladd septum + Ladd (LSL)	4.99ab	(0.53)	0.68
Ladd septum + sphere (LSS)	4.55ab	(0.54)	0.67
Fein blend + sphere (FBS)	3.53b	(0.38)	0.73
Red wooden sphere (RWS)	1.39c	(0.19)	0.41
Olson sphere + brushable adhesive (OSB)	1.02cd	(0.15)	0.40
Pest management supply sphere (PMS)	0.66d	(0.12)	0.39
Scentry yellow panel (SYP)	0.13e	(0.03)	0.11
Pherocon yellow panel (PYP)	0.10e	(0.03)	0.09

Means followed by the same letter are not significantly different ($P = 0.05$; least-squares means test [SAS Institute 1985]).

[a] Average number of adults per trap. $\log_{10}(x + 1)$ transformation applied to catches before analysis.

[b] Proportion of time an apple maggot was caught over all trapping opportunities (20 orchards on each of nine dates).

differed very distinctly according to trap design type, with the baited sphere traps (BHS, CMS, LSL, LSS, and FBS) being the most efficient and exhibiting few significant differences as a group ($F = 26.46$, df = 28, $P < 0.05$), followed by the unbaited sphere traps (RWS, OSB, and PMS), which were likewise comparable as a group, and finally the panel traps (SYP and PYP). Despite some variability within the respective design types during the period of peak adult catch (24 July to 19 August), this pattern of trapping efficiency was seen also ($P < 0.05$) in each of the nine weekly catch totals, which were analyzed using the same method as that used for the season catches. The baited sphere traps caught a mean of 5.05 to 16.05 adults per trap per week during this peak period. In some periods, population levels of apple maggot were low enough that one or both of the panel traps had no catches during the week, even though the remaining traps were catching adults. During the second week of trapping (2–8 July), the SYP and PYP traps failed to catch any apple maggot adults, whereas the numbers in the other traps ranged from a mean of 0.05 to 1.75 adults per trap. In addition, the PYP traps caught no adults during the third (9–15 July), fourth (16–22 July), and ninth (20–26 August) weeks of trapping, whereas mean catches ranging from 0.10 to 1.75, 0.10 to 4.50, and 0.05 to 1.50 apple maggot adults per trap were recorded in the remaining traps during those same weeks. Table 2 also includes an index of how frequently each of the respective traps caught one or more adults among all replicates (20 orchards on each of nine sampling dates). These frequencies of a positive catch, which range from 0.09 to 0.73, also rank similarly according to trap design, although the order among the five baited sphere traps is different from the mean catch ranking.

1987 Threshold Test. A total of 1,027 apple maggot adults including, 588 males and 439 females, were captured in these trials. Results of the different catch action thresholds are summarized in Table 3. To verify that the same relative amount of apple maggot immigration occurred in the different plots, the mean apple maggot catch per trap per 3–4-d period was compared and found to be statistically the same ($t = 1.96$, df = 532, $P < 0.05$) among the timing schedules. Although the traps were still on the trees when the insecticide sprays were applied, catches were disregarded for 10 d after an application, after which time the pesticide residue on the traps was assumed to have a negligible influence on catch levels. As expected, days until first spray, counted from the first catch to the first chemical application in a given plot, increased significantly ($t = 2.13$, df = 15, $P < 0.05$) as the catch action threshold increased. The conventional 10-d waiting period from the first regional emergence of apple maggot until spraying in the calendar plots was not significantly different from the 5.0 d elapsed until the first spray in the two adults per trap plots. Days per spray increased ($t = 1.99$, df = 73, $P < 0.05$) as the catch action threshold increased; this number was obtained by averaging the intervals between sprays, the period from first apple maggot catch to the first spray, and the period from the last spray to harvest in the respective orchards. The number of sprays required decreased significantly ($t = 2.13$, df = 15, $P < 0.05$) as the catch action threshold increased. This amounted to 2.5 fewer sprays than the calendar schedule (a 62.5% reduction) in the treatments of five adults per trap, and 2.8 fewer sprays (a 70% reduction) in the treatments of eight adults per trap. Despite substantial numbers of adults, no fruit damage was detected in any of the plots. Maximum catches within individual orchards ranged from 18 to 69 adults per 3-d period, and mean numbers of adults caught among the test orchards exceeded five per trap in

Table 3. Mean (SEM) apple maggot catches and seasonal insecticide treatment patterns associated with treatment schedules, 1987

Treatment schedule	Apple maggot/trap[a,b]	First spray[c]	Days/spray[d]	Sprays[e]	% Fruit damage
Calendar	—	10.0a (0.0)	13.5a (1.3)	4.0a (0.0)	0.0
2 apple maggots/trap	1.75a (0.18)	5.0a (2.1)	18.9ab (2.5)	2.0b (0.0)	0.0
5 apple maggots/trap	1.72a (0.21)	13.5b (1.1)	23.9bc (3.1)	1.5c (0.2)	0.0
8 apple maggots/trap	2.25a (0.28)	25.2c (2.3)	30.0c (1.9)	1.2c (0.2)	0.0

Means in the same column followed by the same letter are not significantly different ($P = 0.05$; least significant difference test [SAS Institute 1985]).

[a] Average number of adults per trap per 3–4-d period.

[b] $\log_{10}(x + 1)$ transformation applied to catches before analysis.

[c] Days after first catch of apple maggot in respective threshold traps (or in general region for calendar plots).

[d] Days between sprays, from date of first apple maggot catch to first spray, or from last spray to harvest.

[e] Square-root $(x + 0.5)$ transformation applied to spray numbers before analysis.

early August (Fig. 4). Dissection of the females collected revealed substantial average numbers of mature eggs per fly during a majority of the collection periods (Fig. 5), so the absence of fruit damage would not seem to be attributable to insufficient numbers of either apple maggot in general or mated females in particular.

1988 Trials Scouted by Growers. Patterns of apple maggot infestations and pesticide sprays are summarized in Table 4. Dates of last treatments in the respective orchards ranged from 20 July to 26 August. A broad range of numbers of adults was noted in the different orchards, including three locations of low infestation where no sprays should have been applied during the trapping period, and at least three other locations where populations were so high that the effort of monitoring for apple maggot was no more practical than following a three-spray calendar schedule. On each occasion in each orchard when a spray was either applied or recommended by the catch action threshold guidelines, we assessed the grower's adherence to the guidelines based on a scale of 1 to 4, where a low value denotes a greater degree of compliance: 1, recommendations were followed; 2, spray was applied as recommended but not timely (i.e., within 2 d of the threshold being reached); 3, spray was not applied when recommended; and 4, spray was applied when not recommended. More than 50% of the growers felt the need to treat for apple maggot on a least one occasion when the monitoring guidelines recommended that no treatment was necessary; in contrast, only 25% failed to apply a spray when the need was indicated. A few growers sprayed as recommended, but acted too slowly (compliance rating of 2) by a conservative estimate to prevent the fruit from being susceptible to damage during their response period.

The number of chemical sprays applied in test blocks was significantly lower ($t = 2.04$, df = 30, $P < 0.05$) than in the comparison blocks on the same farms, in which management decisions were based on methods other than trap monitoring. However, overall fruit infestation levels did not differ significantly ($t = 2.06$, df = 25, $P < 0.05$) between the test blocks and these comparison blocks. Fruit damage by apple maggot was found in more of the blocks in which the monitoring-based spray schedule was used compared with blocks in which the growers' schedules were used. However, growers 14 and 16 each applied the same numbers of sprays in their respective test block and comparison block, so their poor compliance ratings suggest that the fruit damage in their test blocks is related to timing of the sprays. The high (2.6%) proportion

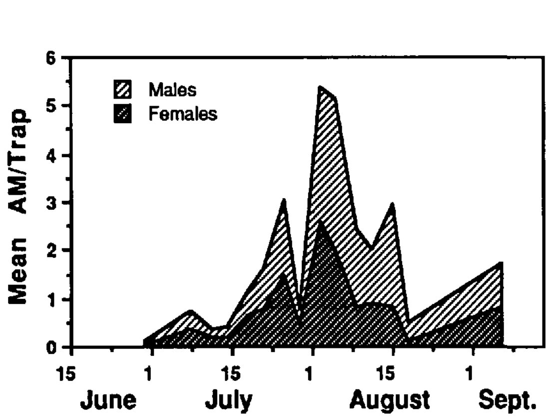

Fig. 4. Mean adults per trap caught during 1987 in treatment threshold plots with red wooden-sphere traps baited with a modified blend of apple volatiles.

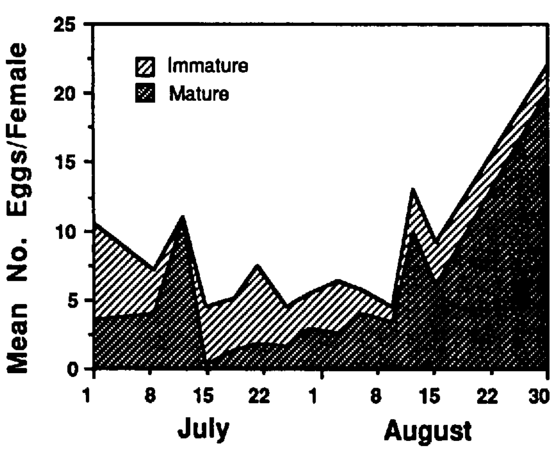

Fig. 5. Mean number of eggs per female caught during 1987 in treatment threshold plots.

Table 4. Apple maggot infestations and pesticide spray patterns in blocks that were scouted by growers with volatile-baited sphere traps and a treatment threshold of five adults per trap, 1988

Grower	Total apple maggots/trap[a]	Compliance codes[b] (mean)	No. of sprays[c]		% Fruit damage[e]	
			Test block	Comparable block[d]	Test block	Comparable block[d]
1	33.0	4, 1, 2 (2.3)	3	3	2.6	—
2	88.5	3 (3.0)	1	3	0.5	—
3	28.0	4, 1 (2.5)	2	2	0.0	0.0
4	71.0	1, 1, 4 (2.0)	3	3	0.0	0.0
5	16.0	3 (3.0)	1	2	0.0	0.0
6	154.0	2, 1, 4 (2.3)	3	3	0.0	0.1
7	24.0	1 (1.0)	1	3	0.1	—
8	49.5	4, 1 (2.5)	2	2	0.6	0.0
9	36.5	1, 1 (1.0)	2	2	0.0	0.0
10	67.3	2, 4 (3.0)	2	2	0.0	0.1
11	8.5	4 (4.0)	1	3	—	—
12	12.0	4, 4 (4.0)	2	3	0.0	0.0
13	39.0	3 (3.0)	1	2	0.0	0.0
14	4.5	4, 4 (4.0)	2	2	0.3	0.0
15	126.5	2 (2.0)	1	1	0.0	0.0
16	31.5	1, 4, 4 (3.0)	3	3	0.4	0.0
Mean	49.3	2.7	1.88a	2.44b	0.30a	0.02a
(SEM)	(41.3)	(0.9)	(0.20)	(0.16)	(0.17)	(0.01)

Means in the same column followed by the same letter are not significantly different ($P = 0.05$; least significant difference test [SAS Institute 1985]).

[a] From 15 July to 19 August.

[b] Codes assessed when sprays were applied or recommended: 1, followed recommendations; 2, treated as recommended, but not timely; 3, did not treat when recommended; 4, treated when not recommended.

[c] Square root ($x + 0.5$) transformation applied to spray numbers before analysis.

[d] Generally comparable block on the same farm in which spray decisions were not based on trap catches.

[e] Arcsine square-root transformation applied to the damage proportions before analysis.

of fruit damage in the case of grower 1 corresponds with an untimely third spray, which was applied well after the threshold catch was reached. Despite an attempt to select comparison blocks as similar as possible to the orchards being monitored, few were of sufficiently comparable age, cultivar, horticultural quality, or apple maggot susceptibility to constitute a truly valid comparison. Also, some growers tended to allow the trap catches in their test block to influence their spray decisions in the comparison block and on the remainder of the farm. Nevertheless, we consider the range of conditions under which this method was tested to be a fair representation of the different orchard management scenarios likely to be encountered in apple production systems in New York.

Discussion

The ultimate goal of this series of investigations was to determine the comparative efficacy of different apple maggot monitoring systems and to optimize the results to identify a procedure that is not only accurate and efficient, but also practical enough to warrant widespread commercial adoption. By determining the sex of the adults caught, we established that females, which actually cause the damage, were caught nearly as often as were males. Results of our 1986 trials indicated that most of the sphere trap and adhesive combinations that we tested performed adequately in detecting the presence of apple maggot in unsprayed trees, but some differences in efficiency did exist, and some designs were inherently easier to use and maintain over the monitoring period. For these reasons, we selected the LYP, RWS, OSB, and PYP traps for further evaluation in commercial orchards during 1987, adding a volatile lure component to the test design. As concluded by Reissig et al. (1985), the VBS traps were more sensitive in detecting low apple maggot populations than were the unbaited traps. This greater sensitivity made the VBS traps more effective in a wide range of commercial orchards differing in cultivar, age, size, and density of trees. The commercial availability of two of the sustained-release systems tested in 1987 adds to the convenience and economy of these trap designs. The choice of OSB traps baited with Consep membrane lures for the trials that were scouted by growers was based on catch efficacy and our subjective judgement of relative ease of handling and the economics of supplying a large-scale field trial; however, any of the alternative baited sphere traps would have been as suitable for the purpose of fulfilling the test objectives.

The appropriate catch action threshold to use with these VBS traps will, of course, need to be proven over a period of time and in many management situations before broad acceptance by growers can be expected. Stanley et al. (1987) suggested that a treatment threshold for VBS traps should be between two and five adults per trap on about three traps per block in commercial orchards. The results of our threshold test with five adults per trap agree with this assessment and even allow a margin of error of an additional three adults per trap without evidence of unacceptable fruit damage. A more important consideration is the likelihood of resistance by growers to any proposed change in the apple maggot management practices they commonly use. Our tests on commercial farms in 1988 showed that many New York apple growers find it difficult to alter their beliefs about the need for frequent pesticide sprays to prevent apple maggot damage, despite their willingness to participate in trials that promote modifications. Also, we recognize the tendency of growers to depart from recommended guidelines in response to schedule constraints in the farm operation. A grower who is monitoring apple maggot with a threshold of five adults per trap may feel justified in spraying before or after this level is reached if it is simply more convenient and economical to do so.

Nonetheless, we are confident that the overall results of these investigations, together with economic and social pressures for reducing pesticide use, constitute a reasonable argument for modifying current apple maggot monitoring procedures, particularly in those cases where apple maggot populations are unpredictable enough to warrant monitoring. To this end, the suggested use of a VBS trap with a treatment threshold of five adults per trap has been incorporated as an option into the commercial tree-fruit pesticide recommendations for New York (Agnello et al. in press). The use of this system should allow growers to reduce their control sprays while maintaining acceptable fruit quality.

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