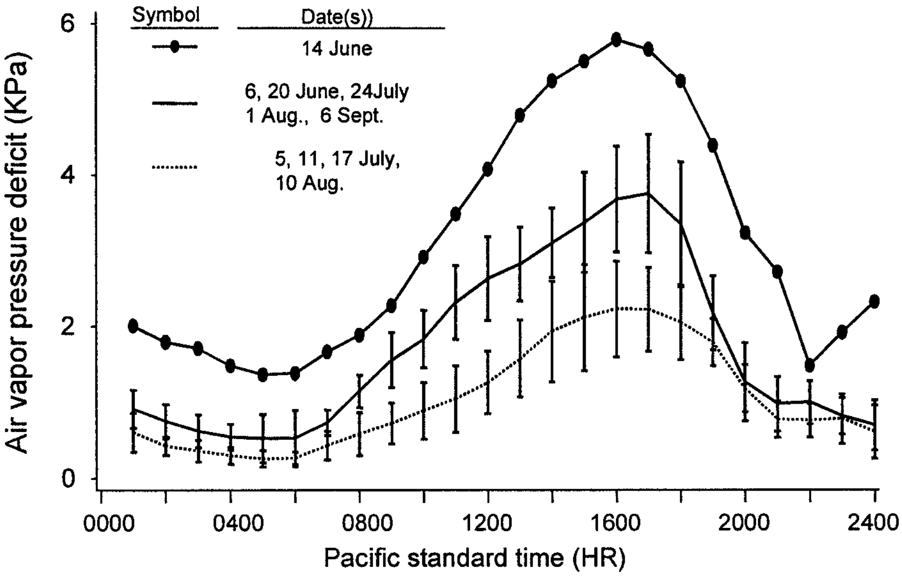

Fig. 5. Diurnal patterns in hourly average air vapor pressure deficit corresponding with midmorning and midday stem water potential measurements. Vertical bars represent ± 2 SE where multiple dates are pooled; 1.0 MPa = 10.0 bar.

can be a convenient and practical tool for irrigation management. There may also be opportunity to further adapt SWP measurement for on-farm irrigation management, if mid morning measurements can be accurately related to mid afternoon measurements of SWP but this will require additional experimentation.

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Effects of Microbial, Botanical, and Synthetic Insecticides on 'Red Delicious' Apple Arthropods in Arkansas

Tahir Rashid,[1]
Donn T. Johnson,[2]
Don C. Steinkraus,[3] and
Curt R. Rom[4]

ADDITIONAL INDEX WORDS. ***Cydia pomonella*, *Grapholita molesta*, spider mite, virus, predator, *Bacillus thuringiensis*, pest control**

SUMMARY. Insecticides were compared for control of codling moth (*Cydia pomonella*) and oriental fruit moth (*Grapholita molesta*), and effects on european red mites (*Panonychus ulmi*) and predatory mites (*Neoseiulus fallacis*) in 'Red Delicious' apple trees (*Malus* ×*domestica*). Ten days after treatment with azinphosmethyl, celery

Agricultural Building 321, Department of Entomology, University of Arkansas, Fayetteville, AR 72701.

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[1]Graduate student.

[2]Professor.

[3]Professor.

[4]Associate professor, Department of Horticulture.

looper (*Anagrapha falcifera*) nuclear polyhedrosis virus, rotenone–pyrethrin, or codling moth granulosis virus, fruit damage by larval codling moth and oriental fruit moth was significantly less than trees treated with *Bacillus thuringiensis* var. *kurstaki* or water (control). Trees treated with azinphosmethyl or celery looper nuclear polyhedrosis virus had fewer damaged fruit where larvae exited than did other treatments. By 21 days after the last treatment, all treatments had significantly more wormy or damaged fruit than did azinphosmethyl. At 10 days after treatment, the two viruses were more deleterious to codling moth than to oriental fruit moth causing a <1:3 ratio of these larvae compared to >3:1 ratio for the other treatments. On 16 June, 100 predatory mites were released onto the trunk of each tree. The minimum ratio of predatory mites to european red mites (>1:10) that favors biological control of european red mites occurred in all treatments by 14 July, except those treated with azinphosmethyl or rotenone–pyrethrin that had significantly more cumulative mite days of european red mites than the other treatments. The use of azinphosmethyl delayed biological control of the european red mites until 27 July whereas rotenone–pyrethrin treatment never attained biological control of the mites.

The codling moth and the oriental fruit moth are major pests of deciduous tree fruit in Arkansas (Johnson, 1988). Many insecticides such as DDT, organophosphates, carbamates and pyrethroids have been used to control these pests (Croft and Riedl, 1991). Frequent applications of these chemicals result in outbreaks of secondary pests such as european red mite by killing predatory mites (e.g., *Neoseiulus fallacis*) (Glen et al., 1984). In addition, resistance to chemicals may develop as happened after long exposure of codling moth to DDT during the mid-1950s (Barnes and Moffit, 1963). Azinphosmethyl is the most widely used insecticide against codling moth and oriental fruit moth (Rothschild and Vickers, 1991; Varela et al., 1993). However, Varela et al. (1993) found populations of codling moth tolerant to azinphosmethyl in California, Oregon, Utah, and Washington. In the USSR, populations of codling moth were reported to be resistant to several organophosphate compounds (Tolstova, 1979). Oriental fruit moth populations have also been reported to be resistant to organophosphates and carbamates with developing low levels of resistance to pyrethroids (Kanga et al., 1999). The potential for chemical insecticides to cause outbreaks of secondary pests and the need to conserve natural enemies makes microbial insecticides an attractive alternative for control of codling moth and oriental fruit moth.

Microbial insecticides have been tested against numerous lepidopterous pests. Codling moth granulosis virus (CMGV) is a baculovirus that was effective against codling moth in the United States (Falcon, 1981), Canada (Jaques, 1990) and Europe (Burgerjon, 1986). Also, CMGV does not cause population resurgence of arthropod pests as do certain pesticides (Hess and Falcon, 1987; Jaques, 1990). The celery looper nuclear polyhedrosis virus (AfNPV) may control several economically important lepidopterous larvae including codling moth (Hostetter and Puttler, 1991). The bacterium, *Bacillus thuringiensis* var. *kurstaki*, significantly reduced apple fruit damage by internal lepidopterous larvae, e.g., codling moth, oriental fruit moth and the lesser appleworm (*Grapholita prunivora*). This bacterium was significantly less effective than azinphosmethyl against internal lepidopterous larvae (Andermatt et al., 1988; Rothschild and Vickers, 1991).

Botanical insecticides have not been as effective as microbial insecticides in fruit tree orchards. One commercially available mixture of botanical insecticides is rotenone (a ground root of cube imported from Peru) and pyrethrin [seeds of chrysanthemum (*Chrysanthemum cinerariaefolium*) from Kenya]. In New York, a complex of internal fruit-feeding lepidoptera including codling moth, oriental fruit moth, and lesser appleworm, caused 28% and 1% apple fruit damage, respectively, when sprayed weekly with a mixture rotenone–pyrethrin or sprayed every 14 d with the synthetic insecticide azinphosmethyl (Kovach et al., 1989). In addition, rotenone–pyrethrin and a synthetic pyrethroid, esfenvalerate (Asana®) (Du Pont Agricultural Products, Wilmington, Del.) disrupted biological control of spider mites by killing 64% of the population of the predatory mite, *Typhlodromus pyri* (Kovach et al., 1989; Nyrop et al., 1990). Acaricides have long been used to control outbreaks of european red mite in commercial orchards. Registrations of acaricides such as cyhexatin, dicofol and chlordimeform have been canceled or subjected to toxicological reevaluation. In addition, resistance has developed to several acaricides (Royalty et al., 1991). Thus, conservation or augmentation of natural enemies must be integrated with a more selective pesticide program that may include use of microbial insecticides.

The utility of microbial insecticides or botanicals for control of codling moth and oriental fruit moth in apple has not been reported for any southern state in the United States. Our objective was to compare field efficacy of three microbials, one botanical and one synthetic insecticide against codling moth and oriental fruit moth in Arkansas. In addition, we noted the effects of each treatment on native populations of european red mite and augmented populations of predatory mites.

Materials and methods

The occurrence of egg hatch periods of codling moth and oriental fruit moth were estimated by recording pheromone trap counts three times each week until biofix (first trap catch) occurred then monitored weekly or more often from mid-May through Aug. 1993. Three Pherocon® 1CP or 1C pheromone traps (Trece Inc., Salinas, Calif.) were each baited with lures for codling moth or oriental fruit moth, respectively. Traps were placed in early April in apple trees at a height of 1.5 m (4.9 ft) in trees adjacent to the test block. Pheromone lures were replaced every 4 weeks and trap bottoms were replaced as needed. Daily temperature records were obtained from a NOAA weather station set 400 m (1312 ft) from the study block (National Oceanic and Atmospheric Administration, 1993, 1994). Degree-days were calculated by using the codling moth and oriental fruit moth stage development models (Johnson, 1988, 1989). Cumulative degree-days after first moth catch (biofix) were used to time treatment applications against hatching larvae of each generation of each species.

In 1979, three rows of apple trees were planted on Malling-Merton 106 rootstock at the University of Arkansas Agricultural Experiment Station in Fayetteville. These trees were spaced 2.5 m (8.2 ft) apart with 3 m (9.8 ft) between rows [≈1333 trees/ha (539 trees/acre)]. The two outer rows used in this study were sports of 'Red Delicious', i.e., 'Royal Red', 'Red Spur' and 'Nu Red'. The middle row of 'Golden Delicious' acted as a buffer. In 1993, each 'Red Delicious' tree averaged about 4 m (13.1 ft) in height.

Treatments were arranged in a randomized complete block design with six replications. Each block contained six trees. No fungicide nor bactericide applications were applied to this block of trees. An 11-L (2.9-gal) Hudson® hand pump (H. D. Hudson Manufacturing Co., Chicago, Ill.) and a 15-L (4.0-gal) Solo® lever pump sprayer (United Spray Systems, Inc., Le Sueur, Minn.) both held at 2.8 $kg \cdot cm^{-2}$ (39.8 $lb/inch^2$) were used to apply each spray treatment. Each treatment was mixed into a 0.18% water solution of Latron CS-7 (no-foam spreader-binder, Rohm and Haas Co., Philadelphia, Pa.). During spraying, adjacent apple trees were covered with a plastic tarp to reduce contamination by spray drift. The sprayer was agitated every minute to sustain each insecticide in suspension. According to the tree-row-volume formula (Sutton and Unrath, 1988), these trees were about 75% of tree standard size and required about 2.13 L (0.56 gal) of spray per tree to attain spray run off [about 2838 $L \cdot ha^{-1}$ (300 gal/acre)]. Treatments included 1) *Bacillus thuringiensis* (*Bt*) (Javelin® 6.4% Wettable Granule WG, Sandoz Agro Inc., Des Plains, Ill.) used at a rate of 78.4 g/100 L (10.5 oz/100 gal); 2) AfNPV used at a rate of 2.8×10^{12} polyhedral inclusion bodies/100 L (26.4 gal) (Biosys Inc., Palo Alto, Calif.); 3) CMGV used at a rate of 5.6×10^{12} granular inclusion bodies/100 L (obtained from L.A. Falcon, Univ. Calif.–Berkeley); and 4) Bonide® (Bonide Products, Inc., Yorkville, N.Y.), a mixture of plant-derived compounds including 1.1% rotenone, 2.2% other Cube extracts, and 0.8% pyrethrins (weight/weight) was used at a rate of 0.93 L/100 L (119 fl oz/100 gal). Treatments 1 through 4 were applied weekly during the egg hatch period on 27 May; 3 and 11 June; 16, 23 and 30 July; and 6 Aug. The AfNPV and CMGV treatment solutions had the addition of 1 kg skim milk powder/100 L (8.35 lb/100 gal) to increase persistence against ultraviolet radiation (Vail et al., 1991). Treatment 5, azinphosmethyl (Guthion 50 Wettable Powder) was applied every two weeks during the egg hatch period (27 May; 11 June; 16 and 30 July; and 6 Aug.) at the rate (a.i.) of 53.9 g/100 L (7.2 oz/100gal). Treatment 6 was an application of the 0.18% water solution of Latron CS-7, which served as a check. All trees were sprayed between 220 (396) and 390 (702) and between 700 (1260) and 950 (1710) degree-days [°C (°F)] of the biofix, respectively, to control the second and third generations of oriental fruit moth. These time periods equated to between 55 (99) and 222 (400) and between 500 (900) and 700 (1260) degree days [°C (°F)] after the biofix for the second and third generations of codling moth.

On 16 June, the endemic predatory mite population was augmented in the treatment trees. One 100-mL (3.38-fl oz) plastic cup filled with vermiculite and about 100 predatory mites (reared by Stanley Gardens, Belchertown, Mass.) was stapled to the north side of each tree trunk. From 2 June to 8 Sept., estimates were made every 2 weeks of the counts of european red mites and predatory mites per leaf. Twenty-five leaves were randomly collected from the canopy interior to the exterior on the east and west sides of each tree. A mite-brushing machine was used to brush mites from leaves onto a glass plate. Counts of mites per glass plate were made using a stereomicroscope. Cumulative mite days were calculated following the method developed by Hull and Beers (1990).

On 16 Aug., 10 d after the last treatment, 100 apples on each tree were randomly inspected to estimate the percentage damaged by larvae of codling moth or oriental fruit moth. Each damaged fruit was removed from the tree and dissected to determine the number of live larvae and how many fruit had feeding tunnels and frass only. The latter were referred to as percentage frass only the implication that larvae had survived and exited the fruit. From 24 to 27 Aug. 1993, all remaining fruit were harvested from trees and those that collected on the ground since 16 Aug. Each fruit was categorized according to the type of damage. For both sample dates, live larvae were removed from damaged fruit. Each larva was reared to an adult on artificial diet following the procedure described by Etzel and Falcon (1976) and identified to species.

Percentages were transformed by arcsine (X/100) and evaluated by analysis of variance. Treatment means

Table 1. Mean pheromone trap counts (N = 3) for codling moth (CM) and oriental fruit moth (OFM), cumulative degree-days[z] (DD) and spray application dates,[y,x] Fayetteville, Ark., 1993.

Date	CM/trap	OFM/trap	CM DD[w]	OFM DD[w]
14 Apr.	0	3.3	---	50
28 Apr.	0	9.3	---	123
14 May	2.3	6.7	68	289
27 May[x]	---	---	154	412
28 May	0.3	1	166	426
3 June[y]	---	---	224	501
11 June[x]	---	---	316	617
14 June	0.7	0.7	357	667
28 June	1	3	558	907
14 July	11.3	8.3	828	1222
16 July[x]	---	---	862	1261
23 July[y]	---	---	991	1410
28 July	7.3	18.7	1091	1525
30 July[x]	---	---	1128	1568
6 Aug.[x]	---	---	1243	1702
14 Aug.	3	13.3	1374	1856
28 Aug.	2	8.3	1647	2169

[z]A degree day is average daily temperature minus the lower developmental base temperature of a species; OFM DD = base 7.2 °C (45 °F); CM DD = base 10 °C (50 °F).
[y]Applied all above treatments except azinphosmethyl.
[x]Applied azinphosmethyl, celery looper nuclear polyhedrosis virus, codling moth granulosis virus, Bacillus thuringiensis var. kurstaki, and rotenone–pyrethrin.
[w]Multiply each value of degree day in °C by 1.8 to convert to degree days in °F.

were separated by least significant differences generated by the General Linear Model procedure (SAS Institute, 1987). The effects of species and species by treatment interaction were determined using least significant means (LSMEANS) at $P = 0.05$ (SAS Institute, 1987).

Results

Seasonal average counts from three pheromone traps each for codling moth and oriental fruit moth and respective cumulative degree days are noted in Table 1. The biofix for oriental fruit moth and codling moth was 7 Apr. and 5 May, respectively. The peak trap catches for generations one and two for oriental fruit moth were 7 and 12 moths per trap and for codling moth were 2.5 and 6 moths per trap, respectively.

The percentage fruit damaged by codling moth or oriental fruit moth larvae and the percentage of damaged fruit with frass only each differed significantly among treatments ($P < 0.01$ (Tables 2 and 3). Ten days after the last treatment (16 Aug.), trees treated with azinphosmethyl, AfNPV, rotenone–pyrethrin and CMGV had significantly less damaged fruit (<4.5%) than did the check (8.2%). Percentage fruit damaged in *Bt*-treated trees was not different from CMGV-treated trees (4.5%) and the check. The estimates of percentage damaged fruit with frass only were significantly more in the CMGV and *Bt*-treated trees and check trees (>1.6%) than in trees treated with azinphosmethyl or AfNPV (<0.5%). Trees treated with rotenone–pyrethrin (1.2%), CMGV and Bt had similar levels of fruit damage, but the latter two treatments were not different from the check. Twenty-one days after the last treatment (27 Aug.), the AfNPV, CMGV and *Bt*-treated trees all (<14.4%) had significantly less percentage damaged fruit than the check (24.3%) but fruit damage in the rotenone–pyrethrin treatment (20.4%) was similar to the check (Table 3). Fruit from azinphosmethyl-treated trees had significantly less damaged fruit (4.8%) and fruit with frass only (2.4%) than all other treatments.

Spray treatments, species and species x treatment interaction ($P < 0.01$, 0.01 and 0.001, respectively) significantly affected the number of moths that emerged from diet after transfer from treated fruit on both sample dates (Table 2). The count of moths emerging from trees sprayed with azinphosmethyl was at least 3- and 2-fold less than that from all other treatments on both 16 and 27 Aug., respectively. On 16 Aug., codling moth accounted for more than 75% of the moths emerging from fruit treated with azinphosmethyl, rotenone–pyrethrin and *Bt*, whereas trees treated with AfNPV and CMGV had a significantly lower percentage of total moths emerging as codling moth (<23%) compared to the other treatments. By 27 Aug., all treatments had significantly more of the moths emerge as codling moth (75%) than did CMGV-treated fruit (55.4%, $P < 0.05$) (Table 4).

The treatments had significantly different effects ($P<0.05$) on european red mite and predatory mite populations per leaf (Table 5). On 2 June, european red mite and predatory mite counts per leaf varied from 1.7 to 7.3 and 0 to 0.13, respectively (Table 5). Trees treated with azinphosmethyl or rotenone–pyrethrin had significantly more european red mite per leaf on 2 June (>6) and 14 July (>4) than did the check (1.7 and 0.9, respectively). This resulted in significantly more cumulative mite days (>120) by 14 Aug. than the other treatments (all <76).

Table 2. Analysis of variance of main effects and interactions on apple fruit damage and the emergence of codling moth and oriental fruit moth on two sampling dates, Fayetteville, Ark.

Source	df	16 Aug. 1993 MS	16 Aug. 1993 F	27 Aug. 1993 MS	27 Aug. 1993 F
Damaged fruit (%)					
Treatment	5	57.3	5.4*	263.1	5.5*
Damaged fruit (%), frass only[z]					
Treatment	5	9.8	4.4*	79.3	4.3*
Adult emergence (%)[y]					
Treatment	5	6,697.0	6.0*	1,208.0	5.5*
Species	1	7,044.0	6.7*	63,026.0	168.5**
Species × treatment	5	13,748.0	13.1**	2,416.0	6.5**

[z]Of the damaged fruit, the percentage with frass only (no larvae present).
[y]Percentage codling moth and oriental fruit moth larvae removed from damaged fruit that eclosed to adults after rearing on artificial diet.

Table 3. Percentage of apple fruit damaged by codling moth and oriental fruit moth in a block of 'Red Delicious' apple trees, Fayetteville, Ark. (*Bt* = *Bacillus thuringiensis*; AfNPV = celery looper nuclear polyhedrosis virus; CMGV = codling moth granulosis virus).

Treatment	16 Aug. 1993 (n > 600 fruit)[z] Damage (%)	16 Aug. 1993 (n > 600 fruit)[z] Frass only (%)[x]	27 Aug. 1993 (n > 1200 fruit)[y] Damage (%)	27 Aug. 1993 (n > 1200 fruit)[y] Frass only (%)
Bt	8.0 ab[w]	2.7 ab	14.4 b	8.7 a
AfNPV	3.4 cd	0.5 c	13.8 b	9.5 a
CMGV	4.5 bc	1.6 abc	14.3 b	9.7 a
Rotenone–pyrethrin	4.1 cd	1.2 bc	20.4 ab	10.7 a
Azinphosmethyl	0.7 d	0.1 c	4.8 c	2.4 b
Check	8.2 a	3.1 a	24.3 a	13.3 a
$LSD_{0.05}$	3.7	1.7	8.6	5.0

[z]Based on visual inspection of 100 apples per tree (six to seven trees per treatment).
[y]All remaining fruit were harvested from the tree and ground.
[x]Of the damaged fruit, the percentage with frass only (no larvae present).
[w]Means within a column followed by the same letters are not significantly different ($P > 0.05$) (SAS Institute 1987). Analysis was performed using arcsine (x/100) transformed percentage values only. Actual percentage values are used in the table.
*,**Significant difference at $P < 0.01$ and 0.001, respectively (PROC GLM, LSMEANS Option, SAS Institute 1987). Analysis was performed using arcsine (x/100) transformed percentage values only.

On 2 June, the endemic population of predatory mites per leaf was significantly higher in trees treated with rotenone–pyrethrin than all other treatments, except azinphosmethyl and the check. Johnson and Croft (1981) reported that it takes greater than one european red mite per leaf to sustain predatory mite feeding and reproduction in apple trees. By 10 June, all treatments had >1 european red mites per leaf and had similar counts of predatory mites per leaf. After 2 June, all trees had similar counts of predatory mites except on 26 June and 14 Aug. when AfNPV, CMGV and rotenone–pyrethrin had significantly lower counts than the other treatments. Cumulative mite days of predatory mites were significantly greater for trees sprayed with azinphosmethyl than for rotenone–pyrethrin and CMGV-treated trees but not for the other treatments or the check. The augmentation of endemic populations of predatory mites on 16 June followed by no insecticide applications until 16 July produced counts between 0.25 to 0.47 predatory mites per leaf and 0.9 to 4.5 european red mite per leaf in all treatments on 14 July.

All treatments achieved biological control of the european red mite

Table 4. Number of larvae removed from treated fruit on 16 and 27 Aug. 1993, reared on artificial diet and the percentage that emerge as either codling moth (CM) or oriental fruit moth (OFM), Fayetteville, Ark. (*Bt* = *Bacillus thuringiensis*; AfNPV = celery looper nuclear polyhedrosis virus; CMGV = codling moth granulosis virus).

Treatment	Apples (no.)	Larvae (no.)	Emergence: Moths (no.)	CM (%)[z]	OFM (%)[z]
Sampled 16 Aug. 1993					
Bt	74	40	24	75.0 a	25.0 b
AfNPV	86	25	13	8.3 b	91.7 a
CMGV	55	24	12	22.2 b	77.8 a
Rotenone–pyrethrin	32	16	11	90.0 a	10.0 b
Azinphosmethyl	11	4	3	100.0 a	0.0 b
Check	80	41	26	73.2 a	26.8 b
$LSD_{0.05}$				46.8	46.8
Sampled 27 Aug. 1993					
Bt	307	101	65	94.8 a	5.2 c
AfNPV	273	70	40	75.6 b	24.4 b
CMGV	304	73	39	55.4 c	44.6 a
Rotenone–pyrethrin	233	95	66	83.7 ab	16.3 bc
Azinphosmethyl	82	40	21	88.9 ab	11.1 bc
Check	393	163	109	89.2 ab	10.8 bc
$LSD_{0.05}$				18.8	18.8

[z]Sample date means within a column followed by the same letters are not significantly different ($P > 0.05$) (SAS Institute 1987). Analysis was performed using arcsine (x/100) transformed percentage values only. Actual percentage values are used in the table.

Table 5. Treatment effects on counts of european red mites and predatory mites (*Neoseiulus fallacis*) per 'Red Delicious' apple leaf and cumulative mite days for each in Fayetteville, Ark., 1993 (CMD = cumulative mite days; *Bt* = *Bacillus thuringiensis*; AfNPV = celery looper nuclear polyhedrosis virus; CMGV = codling moth granulosis virus).

Treatment	Month/day: 2 June	10 June	26 June	14 July	27 July	14 Aug.	CMD[z]
European red mite							
Bt	2.7bc[y]	4.4 b	1.0 ab	1.6 b	0.4 b	0.03 a	75.0 c
AfNPV	2.6 bc	2.4 b	0.4 b	1.7 b	1.0 ab	0.0 a	54.0 c
CMGV	1.8 c	4.6 b	0.7 b	1.1 b	0.6 ab	0.08 a	67.5 c
Rotenone–pyrethrin	7.3 a	5.9 ab	2.7 ab	4.5 a	2.4 a	0.0 a	120.8 b
Azinphosmethyl	6.0 ab	9.1 a	4.3 a	4.1 a	1.8 ab	0.2 a	193.0 a
Check	1.7c	3.4 b	1.7 ab	0.9 b	0.8 ab	0.05 a	68.0 c
$LSD_{0.05}$	3.6	4.4	3.5	2.3	1.8	0.2	37.8
Predatory mite[x]							
Bt	0.03 b	0.03 a	0.1 ab	0.45 a	0.2a	0.3 ab	9.9 ab
AfNPV	0.0 b	0.15 a	0.0 b	0.43 a	0.23 a	0.18 ab	8.4 ab
CMGV	0.0 b	0.05 a	0.23 ab	0.25 a	0.25 a	0.1 b	7.0 b
Rotenone–pyrethrin	0.13 a	0.2 a	0.2 ab	0.47 a	0.17 a	0.07 b	7.5 b
Azinphosmethyl	0.05 ab	0.05 a	0.27 a	0.33 a	0.25 a	0.58 a	11.0 a
Check	0.05 ab	0.0 a	0.13 ab	0.38 a	0.13 a	0.23 ab	9.3 ab
$LSD_{0.05}$	0.1	0.22	0.24	0.59	0.31	0.45	3.15

[z]Multiply each value of degree days in °C by 1.8 to convert to degree days in °F.
[y]Means for each mite species within a column followed by the same letter(s) are not significantly different ($P > 0.05$) (SAS Institute 1987). Analysis was performed using arcsine (x/100) transformed percentage values only. Actual percentage values are used in the table.
[x]100 predatory mites per cup were stapled to each tree on 16 June 1993.

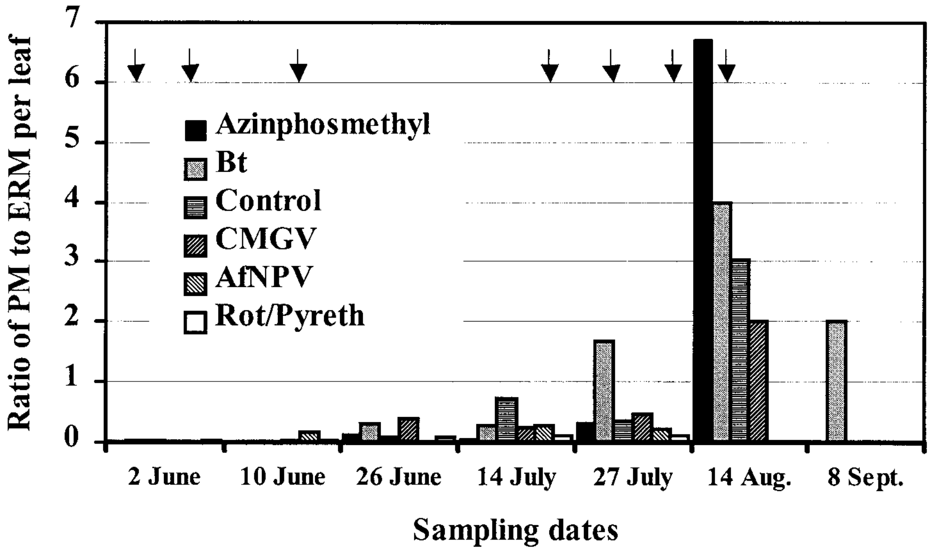

Fig. 1. Comparison of the effects of insecticide treatments (noted by arrows) and augmentation of 100 predatory mites (PM) (*Neoseiulus fallacis*) per tree on the ratio of populations of predatory mites to european red mites (ERM) in apple trees in Fayetteville, Ark., 1993. Biological control of mites is favored by ratios above 0.1. *Bt* = *Bacillus thuringiensis*; CMGV = codling moth granulosis virus; AfNPV = celery looper nuclear polyhedrosis virus; Rot/Pyreth = rotenone–pyrethrin.

population at different times during the sampling period (Fig. 1). This was noted by >0.1 ratio of predatory mites to prey (european red mite) (Croft, 1975). The check, *Bt* and CMGV treatments exceeded 0.1 ratio by 26 June, AfNPV and rotenone–pyrethrin by 14 July and azinphosmethyl by 27 July. On 14 Aug., the mean ratios of predator to prey mites for azinphosmethyl (6.7 ratio), Bt (4.0 ratio) and the control (3.0 ratio) were significantly greater than ratios <2.1 recorded on the other dates ($P < 0.05$; Student's *t* test). The rotenone–pyrethrin treatment for all dates remained at a ratio <0.13, whereas the other treatments exceeded a ratio of 0.2 sometime between 26 June and 14 July.

Discussion

Both CMGV and AfNPV have the potential to provide population reductions of some fruit-feeding lepidopterous larvae in apples. In California, Europe and Canada, CMGV was very effective against codling moth but allowed more unsuccessful shallow entries (stings) of fruit than deep tunnels (Falcon, 1981; Glen and Payne, 1984; Jaques, 1990). In our studies, lower percentage emergence of codling moth from the larvae collected from virus-treated fruit on 16 Aug. suggests that codling moth was more susceptible than oriental fruit moth to AfNPV and/or CMGV. This could be a problem in Arkansas where both species are pests in apple. Over a 2 year period in Germany, CMGV-treated trees suffered 0.6% and 0.7% fruit infested by codling moth compared with 0.7% and 1.8% for organophosphate-treated trees, and 4.4% and 6.6% in untreated trees, respectively (Huber and Dickler, 1977). In Canada, CMGV was inactivated by 50% on apple tree leaves within 2 d and by 80% within 10 d of application (Jaques, 1990). Other researchers noted that control of codling moth with *Bt* was unsatisfactory in field conditions (Andermatt et al., 1988). On 27 Aug., CMGV still had significantly lower percentage codling moth emergence and higher oriental fruit moth emergence than the other treatments (Table 4). This suggests less effectiveness of CMGV against oriental fruit moth compared to other materials.

The ineffectiveness of AfNPV and *Bt* against codling moth 20 d after application (27 Aug.) may be attributed to environmental effects such as inactivation of the virus and *Bt* by UV radiation. Selected brighteners such as stilbene (Phorwite, Ark.) and Tinopal LPW may reduce LC-50s for AfNPV against these moths as it did against gypsy moth, *Lymantria dispar*, and cotton bollworm, *Helicoverpa zea* (Webb et al., 1994; Shapiro and Vaughn, 1995). The behavior of the larvae should also be considered. Larvae of codling moth and oriental fruit moth are solitary and rarely encounter other individuals when entering and feeding in fruit. Hence, the chance of spreading virus or bacteria becomes minimal, thus requiring repeated applications of *Bt* and virus.

Chemical insecticides such as pyrethroids, carbamates and organophosphates (azinphosmethyl) have been known to kill beneficial phytoseiid predator species and cause outbreaks of european red mite and other phytophagous mite populations (Li and Harmsen, 1992). However, long exposure of both pest and predator mites to azinphosmethyl and other insecticides has resulted in the development of resistance to these compounds (Strickler and Croft, 1981). In our test block, before release of predatory mites on 16 June, endemic populations of predatory mites were higher in the rotenone–pyrethrin and azinphosmethyl plots than in other treatments but so were the counts of european red mite. This resulted in lower predator to prey ratios in the trees treated with rotenone–pyrethrin and azinphosmethyl than the other treatments (Fig. 1). Predatory mite populations released into our study orchard were reported to be resistant to azinphosmethyl (D. Stanley, personal communication) and also appeared to have some resistance to sprays of pyrethroids and rotenone.

Azinphosmethyl allowed the least fruit damage at harvest by codling moth and oriental fruit moth of any treatment (Table 3). Use of either virus is expected to cause a significant decline in populations of codling moth without disrupting biological control of european red mite. However, oriental fruit moth may remain a problem when apple is treated with either virus. These viruses allowed significantly more percent adult emergence of oriental fruit moth than codling moth from treated fruit (Table 4). The use of azinphosmethyl, *Bt* or either virus, is expected to maintain a population of predatory mites in the trees that maintains the european red mite population below the economic injury level of 750 (1350) cumulative mite days [°C (°F)] (Hull and Beers, 1990). However, the use of azinphosmethyl did delay biological control of the european red mite population. In contrast, the rotenone–pyrethrin treatment reduced the predatory mite population so that biological control of the european red mite populations was not attained.

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