Effects of Seasonal Mineral Oil Applications on the Pest and Natural Enemy Complexes of Apple

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ABSTRACT This 3-yr study examined the use of two different apple, *Malus domestica* Borkhausen, pest management programs based on horticultural mineral oil. Whereas oil provided some additional control of codling moth, *Cydia pomonella* (L.), when targeting eggs of both generations (Oil/Direct Pest program, typically six applications per season), the additional benefit was difficult to detect when densities were high. With moderate densities, oil reduced the number of fruit infestations, but not stings (unsuccessful entries). There also were some measurable benefits to leafroller, *Pandemis pyrusana* Kearfott control. Oil was most useful, however, in suppression of secondary pests. White apple leafhopper, *Typhlocyba pomaria* McAtee, was the primary target of oil applications in the Oil/Indirect Pest program (typically three applications per season). However, leafhopper suppression in the Oil/Direct Pest program was generally greater because of the higher number of applications. Phytophagous tetranychid and eriophyid mites also were suppressed by more oil applications. Predatory mite populations were lower in both oil programs than in the check, but it is difficult to determine whether direct toxicity or reduction of prey was responsible for lower predator populations. There also was some evidence that oil suppressed woolly apple aphid, *Eriosoma lanigerum* Hausman. The six-spray oil program largely prevented a woolly apple aphid outbreak that occurred in July and August 1998 in the check, although the three-spray program seemed to provide some suppression despite the nonspecific spray timing.

KEY WORDS horticultural mineral oil, pheromone mating disruption, IPM

The use of horticultural mineral oil for pest management has a long history (Agnello 2002). It has been used on a wide spectrum of pests and on a variety of crops over the years (Davidson et al. 1991), including many of the primary and secondary pests of apple (Spuler 1927, Chapman et al. 1952). The recorded effects of oil include ovicidal activity (Smith and Pearce 1948), oviposition deterrence (Zwick and Westigard 1978, Riedl et al. 1995, Fernandez et al. 2001), and acute toxicity, usually to soft-bodied insects (Willett and Westigard 1988, Davidson et al. 1991). It also has been widely used as an adjuvant for other insecticides (Davidson et al. 1991). The popularity of oils with growers has waxed and waned depending on qualities of the petroleum products, available alternatives, and perception of phytotoxicity risk, but they have been a component in pest management programs for at least 120 yr.

The history of oil use in apple, *Malus domestica* Borkhausen, is similarly long. In the early part of the 20th century, oils were used against a variety of orchard pests. Use of oil to supplement control of codling moth, *Cydia pomonella* (L.), dates back to the lead arsenate era (Spuler 1927), and use against overwintering eggs of leafrollers was explored in the early 1940s (Chapman et al. 1941). Efficacy of oil emulsions on European red mite (overwintering eggs and motile forms) was established early in the 20th century (Yothers 1922), and regularly reexamined over the years (Ginsburg 1940, Chapman and Lienk 1966). Use of oils postbloom has been reexamined with newer oils in the 1990s (Agnello et al. 1994). Efficacy against white apple leafhopper nymphs has been established recently (Beers et al. 1997). Data on aphids, leafminers, and other tree fruit pests are limited (Yothers and Griffin 1940). Concerns about phytotoxicity and yield reduction have largely restricted oil to the dormant and early prebloom period on apple (Spuler 1927, Willett and Westigard 1988).

Several trends have led to the reconsideration of oil for postbloom use in apple pest management. The first has been improvements in the distillation process that have provided oils with greater pesticidal efficacy and reduced risk of phytotoxicity (Jacques and Kuhlman 2002). Although some of these principles were established some time ago (Chapman et al. 1952), the ready availability of highly effective synthetic organic pesticides has limited the use of oils to the prebloom period, when risk of phytotoxicity is lowest.

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The second trend has been the decline in the number of new pesticides registered for use in apple and the cancellation of former uses of pesticides during the reregistration process begun in 1988. The Food Quality Protection Act (FQPA) of 1996 continued the increase in restrictions on pesticide use and registration by redefining acceptable risk (DiFonzo 1997). Organophosphate insecticides, the primary insecticide class used in tree fruit against key lepidopteran pests, were identified as the highest priority for reexamination or replacement (Brunner et al. 2001). Although insect growth regulators (IGRs) have been registered in Europe since the 1980s, the first compound in this class for U.S. apples was not available until the 2000 growing season. Furthermore, restrictions such as longer reentry and preharvest intervals have curtailed organophosphate insecticide use because of interference with orchard operations.

The third trend has been registration, development, and widespread implementation of pheromone mating disruption for codling moth, the key pest of apples in the western United States (Brunner et al. 2001). Before the introduction of mating disruption, control of this pest involved a program of two to six applications of an organophosphate insecticide (Brunner et al. 2003). This single-tactic approach led inevitably to secondary pest problems and resistance (Bush et al. 1993, Varela et al. 1993, Knight et al. 1994, Dunley and Welter 2000). Partial or complete replacement of the organophosphate program with codling moth mating disruption supplemented by nonorganophosphate insecticides has provided new opportunities for integrated control of apple pests.

These three trends have provided considerable impetus to restructure apple pest management programs in such a way as to preserve natural enemies and increase stability of the agroecosystem. Instead of relying on a single, highly effective insecticide, programs seek to implement multiple tactics or technologies, each of which alone typically provides inadequate control. Appropriate combinations of tactics can have the net effect of suppression of pest populations below the economic threshold. Petroleum oil has some interesting characteristics in that it has some level of activity against a variety of both direct (fruit-feeding) and indirect (wood-, root-, or foliage-feeding) pests, but it is rarely considered a stand-alone tactic for any given pest. In addition, no cases of resistance to oil have been reported (Willett and Westigard 1988), perhaps due in part to its modes of action (including hypoxia) or its relatively low selection pressure against pests.

The objective of this study was to assess the target and nontarget impact of seasonal postbloom oil programs when used in combination with other pest management tactics. One program had oil applications timed primarily for direct pests (codling moth and leafrollers), and one had applications timed primarily for indirect pests (leafhoppers, mites, aphids, and leafminers). In addition to efficacy against the various pests, our study examined effects on the natural enemy complex present in apple orchards.

Materials and Methods

Experimental Design and Treatments. This study was conducted in a 2.2-ha block of mature apple trees planted in 1978 in an experimental orchard near Orondo, WA. The block was composed primarily of the 'Delicious' cultivars, 'Oregon Spur'/EM.9, and 'Red Spur', with 'Golden Delicious' and 'Winter Banana'/EM.9 pollenizers. The trees were planted 5.46 m between rows and 3.05 m between trees and maintained in a free-standing central leader system (≈4 m in height and 2.5 m in width). Orchard floor management consisted of a weed-free strip beneath the trees maintained with herbicides, and grass sod in the row middles. Trees were irrigated with under-tree impact sprinklers at approximately weekly intervals throughout the growing season. The experimental design was a randomized complete block with three treatments and three replicate blocks. Each replicate was nine to 10 rows × 14 to 15 trees, or ≈0.24 ha. Twenty trees were tagged in the center portion of each replicate, and random samples were taken from these tagged trees (except where noted).

The experimental arthropod control treatments consisted of varying frequency and timing of applications of mineral oil, Orchex 796 (Exxon, Houston, TX), applied during three growing seasons, 1997–1999. Orchex 796 is a light (C-23) paraffinic oil with the following characteristics: distillation range (20°C); minimum unsulfonated residue, 92%; viscosity, 77 s Saybolt Universal at 37.8°C; minimum paraffinic-based molecules, 60%; 50% distillation point, 267°C; pour point, −6°C; molecular weight, 330; and API gravity, 35.1. The treatments were 1) oil applications targeting the key direct pest of apple, codling moth (Oil/Direct Pests); 2) oil applications targeting indirect or secondary pests (Oil/Indirect Pests); and 3) a check that received no summer oil applications. All oil applications were made at a rate of 1% (vol:vol) with an airblast sprayer delivering 3,741 liters/ha.

The Oil/Direct Pest program was treated with oil based on the phenological development of codling moth (degree-days accumulated between 10 and 31°C, horizontal cut-off, based on the method of Welch et al. (1978). The target stages of codling moth were the eggs and neonate larvae. The program consisted of six to seven oil applications, three during the first generation of codling moth and three to four during the second (there are typically two generations per year in Washington) (Beers et al. 1993). In general, the first treatment for the first generation was applied at 250 °D (Degree-days) after biofix (the detection of the first codling moth male in a pheromone trap) and the first application for the second generation was timed for 1,250 °D after biofix (Table 1). Eggs and larvae of leafrollers *Pandemis pyrusana* Kearfott and obliquebanded leafroller, *Choristoneura rosaceana* (Harris), were a secondary target of these applications. These leafroller life stages were present during the third through sixth oil applications (Table 1).

Table 1. Dates of petroleum oil (Orchex 796) applications to treatments targeting direct and indirect pests of apple, 1997–1999

Timing	1997		1998		1999	
	Oil/Direct Pests	Oil/Indirect Pests	Oil/Direct Pests	Oil/Indirect Pests	Oil/Direct Pests	Oil/Indirect Pests
Delayed dormant			30 Mar.	30 Mar.	30 Mar.	30 Mar.
First cover	20 May		7 May	7 May	1 June	1 June
Second cover	6 June		23 May		14 June	
Third cover	25 June		12 June		28 June	
Fourth cover	24 July		14 July		29 July	29 July
Fifth cover	8 Aug.	8 Aug.	21 July		9 Aug.	
Sixth cover	21 Aug.	21 Aug.	30 July	30 July	23 Aug.	23 Aug.
Seventh cover	4 Sept.	4 Sept.		25 Aug.		

The Oil/Indirect Pest program was originally scheduled to be applied when thresholds of one or more indirect pests were reached. These pests included white apple leafhopper, *Typhlocyba pomaria* McAtee; leafminers; spider mites; and aphids. However, white apple leafhopper was the only secondary pest consistently present. Leafhopper populations were allowed to increase for the first generation during 1997, but all subsequent generations received one to three applications of oil. Applications were directed at nymphs, one application against the first generation, and two to three against the second generation. Mite populations were generally low throughout the experiment; however, moderate levels occurred during July 1999. Mite control in this year coincided with one of the second generation leafhopper oil applications. Apple aphids and leafminers were present at very low levels, but they were never high enough to trigger a specific oil application for their control. There was an outbreak of woolly apple aphid, *Eriosoma lanigerum* Hausmann, in summer 1998, which coincided with oil applications against the second leafhopper generation.

A sprayable formulation of the codling moth granulosis virus (seven applications) (Carpovirusine, Calliope, France) was used to suppress codling moth populations in the Oil/Indirect Pest program in 1997. In the same year, the check was left completely untreated with the intent to build populations of codling moth. The buildup of codling moth populations occurred rapidly, and pressure was so high by the end of the first year of the test (73% fruit damage) that some additional form of suppression was used over the entire experimental orchard during subsequent years. In 1998 and 1999, the codling moth mating disruption product Isomate-C plus (Pacific Biocontrol, Vancouver, WA) was applied to the entire orchard at a rate of 1,000 dispensers per hectare. To further reduce the extremely high codling moth population, two applications of diflubenzuron (Dimilin 25W, Uniroyal Chemical, Middlebury, CT) were made against the first generation (petal fall and again 10 d later), and one application of fenoxycarb (Comply 25WP, Novartis, Greensboro, NC) was made early in the second generation to the entire orchard, including the check, in 1998. No IGRs were applied in 1999.

Because the study orchard had history of integrated mite control it was expected that all programs would have low mite populations. This was confirmed in 1997, so in 1998 mite populations were artificially perturbed to examine the effect of oil applications on predator–prey relationships. Two applications of materials toxic to predatory mites, oxamyl (Vydate, DuPont, Wilmington, DE) in mid-June, and esfenvalerate in mid-September (Asana, DuPont, Wilmington, DE), were made to the entire orchard. An additional application of esfenvalerate was made in late July 1999. This material has been shown to dramatically increase mite populations when used during the postbloom period, even at low rates (Beers and Brunner 1999). A delayed dormant application of oil [1.5% (vol:vol)] was made to suppress San Jose scale, *Quadraspidiotus perniciosus* (Comstock), in late March 1998 and 1999, a timing that is also effective against overwintering eggs of European red mite, *Panonychus ulmi* (Koch).

Sampling. Codling moth, obliquebanded leafroller, and *P. pyrusana* adults were monitored weekly with pheromone traps (Pherocon 1CP wing trap, Trécé, Salinas, CA) hung in the trees at pink stage of bud development (Beers et al. 1993). Codling moth traps (in 1998–1999) were baited with a high-load lure (codlemone, 10 mg) because mating disruption was being used (Barrett 1995); a 1-mg lure was used in the absence of mating disruption in 1997. Trap catches were expressed as cumulative captures per season. Late instar leafroller larvae were sampled by examining 10–20 growing shoots at the top of the tree (using a ladder) from 20 tagged trees per replicate in May for the overwintering generation and late July to mid-August for the summer generation.

White apple leafhopper nymphs were sampled from late April through mid-June (first generation) and from mid-July through early September (second generation). The upper and lower surfaces of 10 leaves per tagged tree (200 per replicate) were examined in situ, and the number of nymphs was counted. Leafhopper parasitism by *Aphelopus* sp. was assessed by collecting adult leafhoppers during the flight of the first generation from the check in late July 1998 and mid-June 1999. Adults were collected with a hand-held vacuum (Black & Decker Dust Buster modified by Bioquip, Gardena, CA) and then stored in 70% ethanol and later examined for external evidence of *Aphelopus* sp. by using a dissecting microscope. Parasitism of overwintering leafhopper eggs by *Anagrus* sp. was evaluated by collecting a 10-cm branch section per tagged tree (20 sections per replicate). The bark over the surface of the overwintering eggs was removed with a scalpel and the eggs inspected for the presence of the fat body of the parasitoid.

Green aphid [a complex of apple aphid, *Aphis pomi* De Geer; spirea aphid, *Aphis spiraecola* Patch; and apple grain aphid, *Rhopalosiphum fitchii* (Sanderson)] populations were sampled every other week by counting the number of infested leaves on two shoots per tagged tree (40 shoots per replicate). Apple aphid predators (coccinellids, lacewings, *Deraeocoris* sp., *C. verbasci,* cecidomyiids, and syrphids) were sampled on the same shoots by counting the total number of predators per shoot. Rosy apple aphid, *Dysaphis plantaginea* Passerini, was sampled by walking around the periphery of a tagged tree for 5 min and counting the number of colonies.

Western tentiform leafminer, *Phyllonorycter elmaella* Doganlar & Mutuura, populations were sampled during the tissue-feeding stage of the first, second, and third generation by counting in situ the number of mines on five leaves per tagged tree (100 leaves per replicate). The phenology of the pest in nearby heavily infested blocks was used to determine the timing of the sample in each generation.

Although woolly apple aphid was not one of the target indirect pest species, an outbreak that occurred during July 1998 provided an opportunity to observe the effect of oil treatments. Populations were sampled by in situ examination of 100 shoots per tagged tree and counting the number of infested shoots, and the natural enemies associated with the aphid colonies. In addition, two heavily infested shoot samples per tree were collected on 10 trees per replicate to determine the species composition of the natural enemy complex. These shoots were placed in paper bags and transported to the laboratory in coolers where they were examined with a hand lens (10×). Woolly apple aphid samples were not taken in other years because populations failed to develop.

Mites were sampled every 2 to 3 wk by collecting 100 mature leaves (five per tree on the 20 tagged trees) per plot. Leaves from fruiting clusters were sampled at the beginning of the season (May through early June), and mid-shoot leaves at mid- and late-season (July and August). The leaves were collected in paper bags and kept cool until processing (within 24 h). Mites were removed from the leaves with a leaf brushing machine (Leedom Enterprises, MiWuk Village, CA). Motile stages of European red mite; twospotted spider mite, *Tetranychus urticae* Koch; McDaniel spider mite, *Tetranychus mcdanieli* McGregor; western predatory mite, *Galandromus occidentalis* (Nesbitt); a stigmaeid predatory mite, *Zetzellia mali* Ewing; and motile stages of apple rust mite, *Aculus schlechtendali* (Nalepa), were counted under binocular microscopy.

A fruit sample was taken just before harvest to determine damage or presence of direct and indirect pests. A maximum of 60 fruit (30 from the upper half of the canopy and 30 from the lower half) from each of the tagged trees (1,200 fruit per replicate) were examined.

A bioassay was performed to determine the effect of oil on woolly apple aphid. Dormant apple tree rootstock liners (MM.111 EMLA) were potted in 15-cm-diameter (3.8-liter) plastic pots with a peat–vermiculite–perlite mix. Trees were held in a greenhouse until they had grown to ≈0.5–1 m in height. The trees were artificially infested with woolly apple aphid. After colonies had developed, three colonies per tree were tagged, and all counts were made on these colonies. Treatments were assigned to individual trees in a completely randomized design with six replicates. Treatments [a 1% (vol:vol) solution of Orchex 796 and a conventional insecticide, triazamate (Aphistar 50W, Rohm and Haas, Philadelphia, PA)] were applied with a pressurized hand sprayer. The number of live aphids per colony was evaluated pretreatment and at 1, 3, 7, and 14 d after treatment.

Statistical Analysis. Data were analyzed using analysis of variance (ANOVA) (PROC GLM) (SAS Institute 1982). The Levene (1960) test was used to determine the homogeneity of variances, and data were transformed [$y = \log(y + 0.5)$] when necessary. Percentage data were transformed using $y = \text{arcsine}[\text{sqrt}(y/100)]$. Means were separated using the Waller–Duncan *k*-ratio *t*-test (*k*-ratio = 100). Cumulative insect-days for motile mites and leafhopper nymphs were calculated following the method of Ruppel (1983) with modifications to account for two discrete leafhopper generations. Leafhopper fruit damage (tarspots) at harvest was regressed against the respective cumulative insect-days of the pest on a tree-by-tree basis (1998–1999). European red mite egg infestation of the apple calyces was regressed against cumulative insect-days (1999 only), by using the composite data from each replicate.

Results

Leafroller larvae of the overwintering generations were present in low numbers during all seasons. Summer generation larval densities were somewhat higher, but there were no significant differences between treatments (Table 2). Apple aphid densities and the associated predator complex were very low throughout all three seasons, and few significant differences were detected among treatments (Table 2). The average number of leaves infested with aphids was always less than one per shoot, and the treatment threshold of two to three infested leaves per shoot was never reached. No rosy apple aphid colonies were observed during the evaluation period in any year of the study (data not shown). Western tentiform leafminer densities were very low (<1 mine per leaf) throughout the 3 yr of the study (data not shown).

P. pyrusana was the predominant leafroller species present in pheromone traps (16-fold higher than obliquebanded leafroller). Seasonal trap catches for *P. pyrusana* were highest in 1997 (1,415 moths), reduced somewhat by the IGRs applied in 1998 (810 moths) and returned to higher levels in 1999 (1,125 moths). Codling moth trap catches reflected the variation in pressure in the orchard from year to year as various control regimes were used. Density was highest the first season (963 moths), when oil and Carpo-

Table 2. Densities of leafroller larvae and green apple aphids under two horticultural oil-based programs (mean ± SEM), 1997–1999

Yr	Treatment	Leafroller larvae/100 shoots		No. aphid-infested leaves/shoot (seasonal avg)	Motile aphid predators/shoot (seasonal avg)
1997		22 May	1 Aug.		
	Oil/Direct Pests	0.2 ± 0.2a	8.8 ± 2.9a	0.11 ± 0.03a	0.16 ± 0.04a
	Oil/Secondary Pests	0.3 ± 0.3a	12.2 ± 3.2a	0.10 ± 0.03a	0.24 ± 0.06a
	Check	0.2 ± 0.2a	13.2 ± 1.6a	0.14 ± 0.04a	0.29 ± 0.07a
1998		18 May	24 July		
	Oil/Direct Pests	0.3 ± 0.1a	1.3 ± 0.4a	0.20 ± 0.06a	0.06 ± 0.01a
	Oil/Secondary Pests	0.2 ± 0.1a	8.3 ± 2.0a	0.22 ± 0.08a	0.05 ± 0.01a
	Check	0.3 ± 0.1a	12.6 ± 5.3a	0.22 ± 0.08a	0.06 ± 0.01a
1999		28 May	18 Aug.		
	Oil/Direct Pests	0.2 ± 0.2a	0.5 ± 0.3a	0.11 ± 0.03a	0.13 ± 0.04b
	Oil/Secondary Pests	0 ± 0a	0.7 ± 0.1a	0.10 ± 0.04a	0.17 ± 0.05ab
	Check	0 ± 0a	0.9 ± 0.2a	0.07 ± 0.02a	0.21 ± 0.06a

Means within the same columns and years followed by the same letter are not significantly different (Waller–Duncan *k*-ratio *t*-test, *k*-ratio = 100). For all ANOVAs, df = 2, 8. For leafroller larvae/100 shoots on 22 May 1997, $F = 0.73$, $P > 0.05$; on 1 Aug. 1997, $F = 0.65$, $P > 0.05$; on 18 May 1998, $F = 1.75$, $P > 0.05$; on 24 July 1998, $F = 1.36$, $P > 0.05$; on 28 May 1999, $F = 1.00$, $P > 0.05$; on 18 Aug. 1999, $F = 0.41$, $P > 0.05$. For numbers of infested leaves/shoot (seasonal averages), for 1997, $F = 2.10$, $P > 0.05$; for 1998, $F = 1.40$, $P > 0.05$; and for 1999, $F = 0.48$, $P > 0.05$. For motile aphid predators/shoot (seasonal averages), for 1997, $F = 0.50$, $P > 0.05$; for 1998, $F = 0.39$, $P > 0.05$; and for 1999, $F = 4.45$, $P > 0.05$.

virusine were used as the only control tactics, and the check was left entirely untreated. IGRs, oil, and mating disruption reduced moth levels in 1998 (386 moths), and mating disruption and oil maintained those levels through 1999 (336 moths).

Woolly apple aphid was not present in the orchard in 1997, but densities increased considerably in all treatments by mid-July 1998. The number of colonies in the Oil/Direct Pest program was approximately four-fold lower than the check by the first count (23 July), a statistically significantly difference (Table 3). By this date, the Oil/Direct Pest treatment had already received five of the total six oil cover sprays (Table 1). There was also a trend for the Oil/Indirect Pest program to have lower numbers of woolly apple aphid colonies on this date, although it had received only one oil application in early May. Predators also built to high levels in these colonies, which eventually resulted in a suppression of the aphid densities in the check and aided in suppression in the two oil programs. Mean densities on 5 August were not significantly different after the oil application of 30 July (applied to both oil programs). Although the field evaluation of aphid predators (primarily lacewings and syrphids) showed no difference among treatment means, the more detailed laboratory inspection showed a higher number of predators in the check. This was most likely a result of the higher aphid densities in the latter treatments, rather than a suppression of the natural enemy complex by the oil applications.

The potted tree bioassay confirmed the hypothesis that oil had activity against woolly apple aphids. There was a significant reduction in the aphid densities in the oil treatment by one day after treatment (DAT), although the long-term control was less than that of the conventional insecticide treatment (Table 4). This experiment demonstrates that even a single oil application would give measurable suppression of woolly apple aphid.

Overwintering leafhopper egg density was <0.1 per 10-cm shoot, and no significant differences were detected between programs (data not shown). Parasitism by *Anagrus* sp. was detected, but at very low levels (data not shown). Parasitism of adult leafhoppers by *Aphelopus* sp. was also low with only 5.6% ($n = 95$) and 3.9% ($n = 341$) parasitized in the check in 1998 and 1999.

Leafhopper nymphal densities were relatively high during the first year of the study (1997), but they were much lower in succeeding years, even in the check. Although the timing of oxamyl and esfenvalerate, both toxic to leafhoppers, was designed to minimize the impact on this pest, there may have been some neg-

Table 3. Densities of woolly apple aphid and associated natural enemies in two horticultural oil-based programs (mean ± SEM), 1998

Treatment	Colonies/100 shoots			Motile predators/100 shoots			Total predators (laboratory inspections)	
	23 July[a]	5 Aug.	19 Aug.	23 July	5 Aug.	19 Aug.	20 July	3 Aug.
Oil/Direct Pests	5.3 ± 3.4b	3.2 ± 1.9a	1.3 ± 1.1a	0.6 ± 0.2a	0.5 ± 0.2a	0.1 ± 0.1a	1.4 ± 0.7b	0.3 ± 0.2b
Oil/Secondary Pests	16.5 ± 1.6ab	6.1 ± 1.3a	3.0 ± 1.1a	1.4 ± 0.4a	1.0 ± 0.4a	0.2 ± 0.1a	1.5 ± 0.3b	2.2 ± 1.0b
Check	21.9 ± 6.2b	10.4 ± 4.1a	5.1 ± 2.5a	1.7 ± 0.4a	0.9 ± 0.3a	0.1 ± 0.1a	3.0 ± 0.6a	4.6 ± 1.0a

Means within columns followed by the same letter are not significantly different (Waller–Duncan *k*-ratio *t*-test, *k*-ratio = 100). For all ANOVAs, df = 2, 8. For colonies/100 shoots on 23 July, $F = 2.32$, $P > 0.05$; on 5 Aug., $F = 1.40$, $P > 0.05$; and on 19 Aug., $F = 1.24$, $P > 0.05$. For motile predators/100 shoots on 23 July, $F = 2.00$, $P > 0.05$; on 5 Aug., $F = 1.08$, $P > 0.05$; and on 19 Aug., $F = 0.89$, $P > 0.05$. For total predators (laboratory inspections) on 20 July, $F = 12.06$, $P = 0.02$; and on 3 Aug., $F = 3.39$, $P > 0.05$.

Table 4. Effect of Orchex 796 and triazamate on woolly apple aphids in a potted tree bioassay (mean ± SEM), 1999

Treatment	Rate	Live aphids/colony				
		Pretreatment	1 DAT	3 DAT[a]	7 DAT[a]	14 DAT[a]
Orchex 796	1% (vol:vol)	133 ± 12a	30 ± 7b	15 ± 4b	37 ± 12b	42 ± 15b
Triazamate 50 W	0.15 g/liter	166 ± 14a	27 ± 3b	0 ± 0c	0 ± 0c	0 ± 0c
Distilled water check		144 ± 20a	146 ± 21a	159 ± 28a	163 ± 28a	169 ± 25a

Means within columns followed by the same letter are not significantly different (Waller–Duncan k-ratio t-test, k-ratio = 100). For all ANOVAs, df = 2, 17. For the pretreatment evaluation, $F = 0.86$, $P > 0.05$; for 1 DAT, $F = 9.13$, $P < 0.01$; for 3 DAT, $F = 8.43$, $P < 0.01$; for 7 DAT, $F = 9.70$, $P < 0.01$; and for 14 DAT, $F = 13.04$, $P < 0.01$.

[a] Data transformed $\log(x + 0.5)$ before analysis.

ative effect. In 1997, there were 1.7–1.8 nymphs per leaf in the first leafhopper generation (check). In the second generation, nymphal densities were about three times higher, peaking at 5.3 nymphs per leaf in mid-August. Leafhopper densities were generally lower (less than two nymphs per leaf) for the remainder of the study. Seasonal total cumulative leafhopper-days reflected a significant reduction caused by oil applications (Table 5). The check densities were usually significantly higher than in either oil program. In 1998 and 1999, the Oil/Direct pest program had significantly lower leafhopper densities than the Oil/Indirect Pest program.

European red mites comprised the majority of the tetranychid mite complex throughout the study. Tetranychid mite densities were low throughout 1997 and increased only toward the end of the 1998 season in response to the application of oxamyl in midsummer, a compound that was disruptive of integrated mite control. The highest tetranychid mite densities occurred in 1999, likely due to the esfenvalerate application in fall 1998, peaking at ≈3.3 mites per leaf (check) in mid-June, with a second peak of 3.1 mites per leaf in late August. The Oil/Direct Pest program prevented the two peaks of activity that occurred in the check (data not shown). The Oil/Indirect Pest program suppressed the June peak but not the one that occurred in mid-August, before the 25 August oil application. Cumulative mite-days best demonstrate the overall impact of the Oil/Direct Pest and Oil/Indirect Pest programs on mites (Table 5). The greater number of oil applications in the former (six versus three) provided more suppression of mite densities than the Oil/Indirect Pest program but both had lower densities than the untreated check.

Apple rust mite densities were moderate in 1997 (peak of 70 mites per leaf), low in 1998 season (peak of nine mites per leaf), and higher in 1999 (peak of 216 mites per leaf). Overall, the variation between seasons exceeded the variation among programs. In all 3 yr, the check had significantly higher apple rust mite densities than the Oil/Direct Pest treatment, indicating that oil use suppressed this species (Table 5). In 1997 and 1999, there was a direct relationship between the number of oil applications and the degree of apple rust mite suppression, although the program means were not always significantly different.

Western predatory mite was the most abundant mite predator in all years, comprising >90% of the predatory mite complex. In 1997, predatory mites were relatively high, peaking at ≈1.75 mites per leaf (Oil/Indirect Pest program). This peak in late July occurred before the first oil application in this treatment, which took place on 8 August (Table 1). Predatory mites were most likely subsisting on apple rust mite, because the tetranychid mite population was very low that year. The Oil/Direct Pest program had significantly lower predatory mite densities than the

Table 5. Cumulative insect-days (means ± SEM) for leafhopper nymphs and pest and predatory mites in two horticultural oil-based programs, 1997–1999

Yr	Treatment	Leafhopper nymphs	Tetranychid mites	Predatory mites	Apple rust mite
1997	Oil/Direct Pests	38.6 ± 2.6b	0.1 ± 0.1a	3.0 ± 1.1b	113 ± 57b
	Oil/Indirect Pests	119.2 ± 5.3ab	0.3 ± 0.2a	58.7 ± 6.9a	807 ± 434ab
	Check	197.6 ± 7.9a	0.2 ± 0.1a	59.0 ± 9.7a	1,556 ± 202a
		Leafhopper nymphs[a]	Tetranychids	Predators[a]	Apple rust mite
1998	Oil/Direct Pests	1.6 ± 0.3c	0.5 ± 0.4a	0.8 ± 0.3c	2 ± 1b
	Oil/Indirect Pests	7.2 ± 0.9b	1.8 ± 0.7a	2.0 ± 0.2b	124 ± 21a
	Check	31.2 ± 4.2a	7.2 ± 4.6a	14.6 ± 1.0a	92 ± 5a
		Leafhopper nymphs[a]	Tetranychids[a]	Predators	Apple rust mite
1999	Oil/Direct Pests	3.8 ± 1.2c	6.7 ± 0.6c	6.9 ± 3.5a	1,157 ± 372b
	Oil/Indirect Pests	13.5 ± 2.9b	73.8 ± 22.0b	6.7 ± 2.4a	4,868 ± 1,401ab
	Check	41.3 ± 4.9a	158.4 ± 22.2a	6.8 ± 1.5a	7,252 ± 772a

Means within the same columns and years followed by the same letter are not significantly different (Waller–Duncan k-ratio t-test, k-ratio = 100). For all ANOVAs, df = 2, 8. For leafhopper nymphs, 1997, $F = 4.83$, $P > 0.05$; for 1998, $F = 32.89$, $P < 0.01$; and for 1999, $F = 10.10$, $P = 0.02$. For tetranychid mites, 1997, $F = 0.21$, $P > 0.05$; for 1998, $F = 1.35$, $P > 0.05$; and for 1999, $F = 34.54$, $P < 0.01$. For predatory mites, 1997, $F = 18.46$, $P < 0.01$; for 1998, $F = 46.31$, $P < 0.01$; and for 1999, $F = 0.12$, $P > 0.05$. For apple rust mites, 1997, $F = 7.40$, $P = 0.04$; for 1998, $F = 10.92$, $P = 0.02$; and for 1999, $F = 3.69$, $P > 0.05$.

[a] Data transformed $\log(x + 0.5)$ before analysis.

Table 6. Percentage of fruit damage by various pests, preharvest evaluation (early September) (mean ± SEM), 1997–1999

Yr/treatment	No. fruit examined	Codling moth sting	Codling moth entry	Codling moth total	Aphid leafroller	Leafhopper honeydew	Mite tarspots	San Jose eggs	Treatment scale	% clean fruit
1997										
Oil/Direct Pests	2,266	1.0 ± 1.0a	58.8 ± 7.1a	59.8 ± 8.1a	10.8 ± 2.5a	0.3 ± 0.1a	0.9 ± 0.5a	0 ± 0a	0.0 ± 0.0a	31.4 ± 6.8a
Oil/Indirect Pests	3,055	0.3 ± 0.3a	63.8 ± 10.4a	64.1 ± 10.6a	10.5 ± 4.1a	0.1 ± 0.1a	6.1 ± 4.0a	0 ± 0a	0.5 ± 0.3a	24.2 ± 7.3a
Check	2,842	0.1 ± 0.1a	72.5 ± 7.3a	72.6 ± 7.3a	12.2 ± 2.2a	0.3 ± 0.1a	11.3 ± 9.8a	0 ± 0a	0.0 ± 0.0a	18.7 ± 6.3a
1998										
Oil/Direct Pests	3,604	7.0 ± 1.6a	1.1 ± 0.1b	8.2 ± 1.6a	2.8 ± 0.4b	9.3 ± 3.9a	15.7 ± 1.4c	0.0 ± 0.0a	0.9 ± 0.1a	60.3 ± 3.2a
Oil/Indirect Pests	3,600	7.2 ± 1.3a	2.3 ± 0.3a	9.5 ± 1.6a	4.2 ± 1.2ab	8.5 ± 4.3a	38.4 ± 7.2b	0.2 ± 0.1a	1.8 ± 0.4a	42.6 ± 4.8b
Check	3,615	8.1 ± 1.1a	2.4 ± 0.2a	10.4 ± 1.0a	5.3 ± 0.4a	4.5 ± 1.8a	85.2 ± 1.6a	0.2 ± 0.2a	2.5 ± 1.1a	7.2 ± 0.4c
1999										
Oil/ Direct Pests	3,603	3.5 ± 1.3a	15.0 ± 5.2b	18.5 ± 6.4b	0.9 ± 0.1b	5.8 ± 0.7a	7.2 ± 3.6c	3.7 ± 2.9b	0.2 ± 0.0a	53.1 ± 6.6a
Oil/Indirect Pests	3,600	3.5 ± 0.4a	18.2 ± 2.9ab	21.7 ± 3.4ab	1.0 ± 0.3b	2.9 ± 0.5b	34.4 ± 8.2b	22.3 ± 0.6b	0.1 ± 0.1a	35.8 ± 9.3a
Check	3,600	4.0 ± 0.6a	23.4 ± 6.7a	27.5 ± 7.3a	2.0 ± 0.4a	4.4 ± 0.6ab	82.8 ± 5.6a	55.2 ± 11.9a	0.4 ± 0.3a	2.9 ± 1.6b

Means within the same columns and years followed by the same letter are not significantly different (Waller–Duncan *k*-ratio *t*-test, *k*-ratio = 100). For all ANOVAs, df = 2, 8. For codling moth stings, 1997, $F = 0.59$, $P > 0.05$; for 1998, $F = 0.18$, $P > 0.05$; and for 1999, $F = 3.96$, $P > 0.05$. For codling moth entries, 1997, $F = 0.25$, $P > 0.05$; for 1998, $F = 5.15$, $P > 0.05$; and for 1999, $F = 11.78$, $P = 0.02$. For total codling moth injuries, 1997, $F = 0.20$, $P > 0.05$; for 1998, $F = 0.39$, $P > 0.05$; and for 1999, $F = 12.26$, $P = 0.02$. For leafroller injuries, 1997, $F = 3.02$, $P > 0.05$; for 1998, $F = 3.99$, $P > 0.05$; and for 1999, $F = 6.29$, $P = 0.05$. For aphid honeydew, 1997, $F = 0.86$, $P > 0.05$; for 1998, $F = 0.58$, $P > 0.05$; and for 1999, $F = 3.66$, $P > 0.05$. For leafhopper tarspots, $F = 0.56$, $P > 0.05$; for 1998, $F = 38.24$, $P < 0.01$; and for 1999, $F = 19.2$, $P < 0.01$. For mite eggs, 1998, $F = 0.4$, $P > 0.05$; and for 1999, $F = 5.70$, $P > 0.05$. For San Jose scale damage, 1997, $F = 1.75$, $P > 0.05$; for 1998, $F = 1.69$, $P > 0.05$; and for 1999, $F = 1.22$, $P > 0.05$. For percentage clean fruit, 1997, $F = 0.49$, $P > 0.05$; for 1998, $F = 51.26$, $P < 0.01$; and for 1999, $F = 9.08$, $P = 0.03$.

check in 2 of the 3 yr of the study (Table 5). In 1998, predatory mite densities were building in the check by early June, but they were nearly eliminated by the oxamyl application on 12 June. Although the cumulative predator mite-days were low overall due to this application, there were significantly lower densities in the two oil programs, with the lowest densities occurring in the Oil/Direct Pest program, which had the highest number of oil applications. In 1999, predatory mite densities were low at the beginning of the season due to the esfenvalerate application in September 1998. They were again virtually eliminated by the late July (1999) application of the same material; thus, no program differences occurred. Overall, there were fewer predatory mites where high numbers of oil applications were used. However, in a large-plot field trial such as this, it is not possible to distinguish whether this was due to a direct effect of oil on the predatory mites or because of a reduction of their source of prey, either tetranychid or eriophyid mites.

Fruit Damage. Codling moth pressure in 1997 was very high, overwhelming any potential benefit of the oil applications and resulting in 60–73% crop injury at harvest. Although no significant treatment differences occurred in 1997, there was a trend for decreasing damage with increasing numbers of oil applications (Table 6). The use of mating disruption and IGRs in 1998 greatly reduced codling moth fruit damage levels overall, and the type of injury changed from primarily entries in 1997 to primarily stings (superficial fruit damage caused by aborted infestations) in 1998. In 1998, the Oil/Direct pest program significantly reduced the number of codling moth entries (successful larval infestation), although this reduction is not reflected in total codling moth damage. The use of mating disruption alone, plus the effect of the late July esfenvalerate, allowed slightly higher damage levels in 1999. In this year, however, there were significant differences among programs with the Oil/Direct Pest program having fewer codling moth entries and total injuries than the check.

Leafroller damage was highest in 1997 and was gradually reduced through the remaining 2 yr of the study. The IGRs used for codling moth and the esfenvalerate applications doubtless contributed to the reduction of leafroller damage. There was little relationship, however, between fruit damage at harvest and the numbers of larvae found in bud and shoot samples during the season, which were low throughout the study. Although the timing of oil applications in either treatment was not specific for leafrollers, their densities were potentially impacted by the second through fifth codling moth sprays (adults and summer generation larvae). Despite the nonspecific spray timing, the Oil/Direct Pest treatments had significantly lower levels of leafroller damage than the check in both 1998 and 1999 (Table 6).

Aphid honeydew damage on apples at harvest was very low in 1997, highest in 1998, and moderate in 1999 (Table 6). In most cases, the amount of honeydew present was small and would have been largely removed during fruit packing operations. The higher

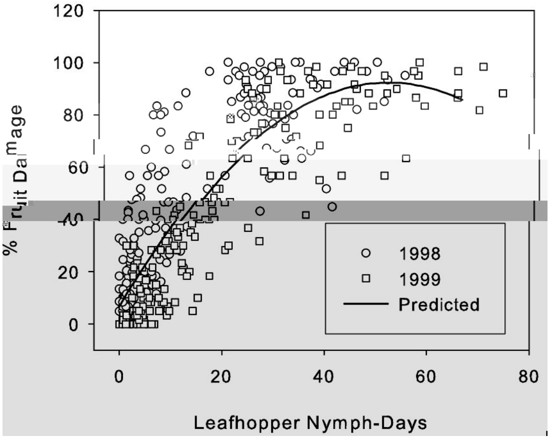

Fig. 1. Relationship between cumulative white apple leafhopper-days and fruit damage at harvest (tarspots), 1998–1999.

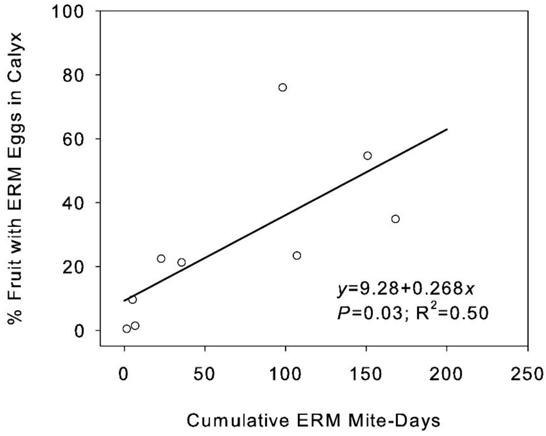

Fig. 2. Relationship between cumulative European red mite-days and infestation of apple calyces with eggs, 1999.

level of honeydew present in 1998 was due to woolly apple aphid, whereas the 1997 and 1999 damage was due to the green aphid complex. No consistent statistical differences occurred among programs for aphid control (Table 2).

Leafhopper tarspot damage was low in 1997 relative to the other 2 yr (Table 6), despite the high second generation densities. The differences between 1997 and subsequent years were due to using different criteria in the rating system in that year rather than differences in leafhopper densities. In 1997, only tarspotting that extended beyond the stem bowl of the fruit was counted, whereas in the 1998–1999 seasons, any incidence of tarspotting was counted as damage. There were no differences in leafhopper damage among programs in 1997. However, in 1998 and 1999, leafhopper damage was the most common form of fruit damage, with >80% fruit damage in the checks. The Oil/Direct Pest program provided the greatest reduction of fruit damage, despite the fact that the spray timing in this program was not specific for leafhoppers. As with the leafhopper nymph densities, the greater number of oil applications resulted in the greatest reduction of fruit damage.

Fruit damage by leafhoppers was directly related to cumulative nymph-days in both 1998 and 1999 (Fig. 1). The regression was significant for 1998 ($y = 11.827 + 3.9833x - 0.05x^2$, $F = 222.92$, $P = 0.0001$, $R^2 = 0.72$), 1999 ($y = -3.411 + 3.9885x - 0.0304x^2$, $F = 455.42$, $P = 0.0001$, $R^2 = 0.84$), and both years combined ($y = 6.6739 + 3.3214x - 0.0322x^2$, $F = 464.73$, $P = 0.0001$, $R^2 = 0.72$). For the combined regression, 50% fruit damage would occur at ≈15.35 cumulative nymph-days. If the grower considers leafhopper tarspot damage problematic, the nymph days–tarspotting relationship should allow for the development of a treatment threshold.

Due to the extremely low mite densities in 1997 and 1998, few or no fruit were found at harvest with European red mite eggs in the calyx (Table 6). In 1999, the incidence of eggs in the calyx was more common with the highest numbers of fruit affected being in the check (55.2%), reflecting the higher mite densities during that season. The level of calyx infestation is surprising given the moderate level of mite infestation (peak of three European red mites per leaf). There was a significant direct relationship ($y = 9.28 + 0.268x$, $P = 0.03$, $R^2 = 0.50$) between the fruit infestation level and the cumulative European red mite-days in that replicate (Fig. 2). Using this equation, cumulative mite-days as low as 150 can produce 50% infestation of the fruit calyces. Both oil treatments in 1999 reduced calyx infestation in comparison with the check (Table 6), although numerically the Oil/Direct Pest treatment had about six-fold lower percentage of infestation than the Oil/Indirect Pest treatment.

The level of San José scale fruit damage remained relatively low throughout the study (Table 6), likely because of the applications of oil at delayed dormant. The delayed dormant applications were made to the entire orchard, and no differences occurred between treatments. These results indicate that at least in the short term, oil applied at delayed dormant can, by itself, keep scale populations in check.

Overall, the levels of undamaged fruit in this study were much lower than would be acceptable in a commercial situation (Table 6). The Oil/Direct Pest program had the highest percentage of undamaged fruit in 1998 and 1999, which was significantly different from the check and the Oil/Indirect Pest program. In both of these years, the percentage of undamaged fruit was most influenced by the degree of leafhopper damage, and treatment differences are analogous. However, smaller (often nonsignificant) differences in other pest categories also helped the performance of the oil treatments.

The most consistent effect of oil on codling moth was reduction of the number of entries. Fewer entries likely reflected a reduced number of hatched eggs (ovicidal activity). Once hatched, oil provided no residual activity or deterrence to young larvae (Riedl et al. 1995) and thus there was no further effect of oil. Although both types of damage cause cullage, stings represent suppression of the succeeding generation, whereas entries represent survival and contribution to the next generation.

Discussion

The ovicidal effect of oil on codling moth eggs has been established for some time, although estimates of efficacy have varied considerably. Newcomer and Yothers (1932) found up to 97% mortality of codling moth eggs with lubricating oil [2% (vol:vol)] and 75% with a 1% (vol:vol). More recent work by Riedl et al. (1995) by using the same oil as in the current study, estimated only 20% mortality of eggs using an airblast application at a rate of 1% (vol:vol). Newcomer and Yothers (1932) found that oil residues did not deter ovipositing females and that neonate larval feeding was reduced for a only few days with the higher rate of oil (2%). Riedl et al. (1995), however, did find some oviposition deterrence (on fruit surfaces but not leaves, and only at rates >1%), but no deterrence of larval feeding, and no direct mortality of larvae or adults. These authors concluded that dilute applications of 1% oil may not be adequate for reducing codling moth egg hatch under orchard conditions. In contrast, VanBuskirk et al. (2002) successfully integrated oil applications (three applications, first generation) into an areawide pest management program on pear based on mating disruption, along with greatly reduced inputs of organophosphate insecticides. However, there was no check to isolate the effect of oil in this implementation study. Pear is also much less susceptible to codling moth damage, especially during the first generation (Van Steenwyk et al. 2004), when oil was used. These factors, plus the suppression of other pear pests, may be largely responsible for the overall success of the program.

A second factor operating in the current study was the high codling moth population pressure relative to commercial orchards. Mating disruption is thought to be a density-dependent technique (Cardé and Minks 1995) and thus was relatively ineffective at the high populations occurring in the test. The ovicidal effect of oil, although probably density independent, was not sufficient to compensate for the overwhelming effect of the high populations. With the densities present in our study, more frequent applications, and earlier first applications in each generation, would likely have provided better results. The oil rates and number of applications chosen in this study were a compromise between efficacy, cost, and risk of phytotoxicity.

The suppression of *P. pyrusana* injury in this study is a relatively novel finding, but the mechanism is currently unknown. Suppression of leafroller damage has been noted in a field test (Brunner et al. 1996), with the stage affected thought to be the egg. Bioassays have shown some negative effects on female oviposition behavior and larval feeding (Brunner et al. 1997). Although insufficient numbers of larvae were collected in this study to obtain parasitism data, natural enemies, especially *Colpoclypeus florus* (Walker), have proven to provide high levels of biological control where broad-spectrum pesticides are omitted (Pfannenstiel and Unruh 2003). Biological control, in combination with a moderate level of suppression with oil, may prove to be adequate to prevent economic injury by leafrollers.

The suppressive effect of oil on white apple leafhopper nymphs was established in preliminary tests (Beers 1996); thus, the high levels of control of nymphs and damage in this study were expected. The excellent performance of the Oil/Direct Pest program in controlling leafhoppers was due largely to the greater number of applications during the nymphal period but likely also to deterrence of female oviposition (Fernandez et al. 2001). This provides support for the premise that multiple oil applications aimed at codling moth will still be effective against some indirect pests, even though the timing is not specific for them. Although the higher number of oil applications in the Oil/Direct Pest program provided higher levels of suppression, a single application against each generation (targeting nymphs) would likely be sufficient to keep this indirect pest at subeconomic levels.

The suppression of various spider mite species by oil has been investigated since the 1920s (Yothers 1922). Although dormant or delayed dormant applications against the overwintering eggs of European red mite are the most common use of oil, there has been a resurgence of interest in summer (foliar) oil sprays for spider mite control (Agnello et al. 1994). Oil reduced densities of tetranychid mites, rust mites, and possibly predatory phytoseiid mites in this study. Although suppression of the latter two groups is considered detrimental to integrated control in Washington state (apple rust mite is the primary alternate prey of western predatory mite) (Hoyt 1969), there was no evidence that mite outbreaks would occur due to multiple summer oil applications.

The issue of aphid suppression with oil needs further investigation. The low densities of green apple aphid complex in this study did not provide an opportunity to examine this question; however, previous tests (E.H.B, unpublished data) indicated that Orchex 796 1% (vol:vol) provided useful levels of suppression of green apple aphids. There was also some promise for control of woolly apple aphid, a pest that is, in general, harder to manage than the green aphid complex. The neonicotinyl insecticides, an organophosphate replacement chemistry, are generally very toxic to aphids, but experience to date has proven them to be only moderately effective on woolly apple aphid (Beers et al. 2002). Thus, suppression by alternative techniques would be a welcome addition to the array of control tactics for this pest.

Mating disruption is recommended for codling moth control in Washington, although usually in combination with other tactics. Since its registration in 1990, the use of mating disruption has increased to ≈50% of Washington's apple acreage in 2003 (J.F.B., unpublished data). Over the same period, postbloom use of oil in apple orchards increased from 0.3% of the acreage treated in 1989 to 18.8% in 2000 (Brunner et al. 2003). Although prebloom use was essentially the same in both years (≈87% of the acreage treated, average of 1.1 applications), the average number of postbloom applications in 2000 was only one per season. This use pattern does not support the premise that the increased use of oil was for codling moth control, which requires multiple applications per generation. Instead, new alternatives to organophosphates are being used (e.g., acetamiprid and methoxyfenozide) (NASS 2004). The increased use of oil most likely reflects its use as an adjuvant for other insecticides.

Phytotoxicity and incompatibility issues remain as barriers to more widespread use of oils in the postbloom period on apple. Older studies on apple found both foliar phytotoxicity and fruit size reduction that seemed to be directly related to increasing numbers of oil applications (Spuler 1927). More recent studies on pear have found that certain cultivars experience reductions in fruit size and yield efficiency with three applications of oil over several years (Hilton et al. 2000). Although improved refinement techniques have made modern oils much safer than in the past, visible fruit and foliar phytotoxicity are still problems under certain environmental conditions or in combination with certain other spray materials (Smith et al. 2004). Several studies have documented reductions in photosynthesis of apple with petroleum oil (Ayers and Barden 1975). Recent studies on Washington apple show a decrease in photosynthesis after an application of Orchex 796 oil, along with some permanent fruit marking on 'Fuji' (L. E. Schrader, personal communication). Although there was recovery in photosynthesis rates after a single oil application, damage was cumulative over the season with multiple oil sprays. Changes in some measurements of fruit quality were found in some years where seasonal oil programs were used (Brunner et al. 1996). There was little or no evidence of oil injury to fruit in this study (data not shown), even at the highest numbers of oil applications. Although this evidence is far from conclusive, the perceived risk of plant damage and yield reduction persists.

Perhaps the best use of oil in apple pest control programs is for management of secondary pests. Oil is moderately effective with relatively few applications against spider mites, leafhoppers, and aphids, primarily because a lower level of suppression is economically acceptable. This use pattern minimizes risk of phytotoxicity and provides a low-cost alternative to conventional insecticides that is not disruptive of biological control. Overall, horticultural oil is a valuable, selective component of an IPM program in apple.

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