Management of Summer Populations of European Red Mite (Acari: Tetranychidae) on Apple with Horticultural Oil

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ABSTRACT A highly refined horticultural petroleum oil, Sunspray Ultra Fine, was evaluated in laboratory and field tests for efficacy against summer eggs and larvae of European red mite, *Panonychus ulmi* (Koch). Oil had significant ovicidal and residual larvicidal activity in dip treatments at rates as low as 0.00005%, but treatments using the same rates in a Potter spray tower caused less mortality. High-contact mortality of mite larvae sprayed in laboratory tests was obtained at rates of 0.25–1.00%. Field applications of oil by airblast sprayer were tested during the summer for their ability to suppress mite populations throughout the growing season. Effective control was achieved with three applications of oil at 3 and 2%, starting at the petal-fall stage and continuing on a 2–3-wk schedule. A rate of 1% provided control under conditions of moderate population pressure but required an additional spray in late July under severe population pressure. Rates of 0.25 and 0.05% resulted in unacceptable mite numbers by midsummer. Phytotoxicity caused by the oil was most severe at the higher rates, but oil caused no leaf drop even when trees were moisture-stressed. No effects of oil were seen on fruit finish or color, except for an increase in scarf skin of 'Law Rome' at the highest rates. High-pressure handgun oil sprays against a mixed population of mite eggs, immatures, and adults reduced motile forms by 79–95% at rates of ≥0.25%.

KEY WORDS acaricides, *Panonychus ulmi*, petroleum oil

DURING THE PAST SEVERAL YEARS, apple growers in New York and other regions in northeastern United States and Canada have experienced increasing difficulty controlling European red mites, *Panonychus ulmi* (Koch). These difficulties have been aggravated by a variety of factors, including the development of resistance to some of the most commonly used materials, dicofol (Dennehy et al. 1988) and cyhexatin (Welty et al. 1987); the unavailability or withdrawal of compounds because of regulatory decisions; and delays in the registration of new acaricides. One mite-control method that has remained effective is horticultural petroleum oil used before bloom (Chapman & Lienk 1966, Chapman 1967).

Oils have three principal advantages over conventional contact acaricides (Chapman 1967). First, they have been determined to pose a small human health hazard, thus the Food and Drug Administration exempts them from the requirement of a tolerance. A second advantage of oils is the apparent inability of insects and mites to develop resistance to them, most probably because of the oil's presumed smothering mode of action. Predatory mite populations are not as likely to be severely affected by these sprays, owing to the fact that the overwintering stages of these species (principally *Amblyseius fallacis* (Garman) and *Typhlodromus pyri* Scheuten) are adult females (Lienk et al. 1980), which may not be as susceptible to suffocation by the oil because of their motile nature. Perhaps most important, oils demonstrate reliable efficacy at relatively low cost.

Growers are interested in a strategy, used as recently as 15–20 yr ago, of combining a low rate of oil (0.95 liter/379 liters of finish spray solution) (0.25%) for mite suppression with insecticides and fungicides used during summer cover sprays. This was a common practice when azinphosmethyl and benomyl were the predominant materials used to control apple maggot, *Rhagoletis pomonella* (Walsh), and apple scab, *Venturia inaequalis* (Cooke) Winter, respectively. Currently, however, benomyl-resistant scab strains have been isolated from New York orchards (Gilpatrick 1982), and the summer insecticides and fungicides now used belong to many different chemical classes, so there are many unknowns regarding spray compatibilities, effectiveness, and timing for this practice to be recommended implicitly without field testing.

The development and refinement of petroleum oils suitable for verdant plant use has been discussed by Chapman (1967), Johnson (1985), and Davidson et al. (1991), including narrow-distillation range products specifically intended for summer use. Lawson & Weires (1991) dem-

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onstrated acceptable control of *P. ulmi* in an apple orchard by applying three widely spaced sprays of different oil formulations at various rates. They also showed the ovicidal efficacy of these products against overwintering eggs. More practical information is needed on the use of different oil rates during the summer on a preventive basis to maintain a constant, low level of mortality of susceptible mites during a period when populations are a mixture of all life stages. Current oil-use recommendations for mite control are based on the assumption that, because of oil's mode of action, mortality is generally confined to the eggs and motile forms are able to survive oil applications. However, this assumption has not been investigated systematically. Welty et al. (1988, 1989) demonstrated a 9- and 11-fold greater susceptibility of summer than winter eggs of *P. ulmi* to the ovicides hexythiazox and clofentezine. The objectives of our study were to determine susceptibility of summer eggs to a narrow-distillation petroleum oil to provide a basis for recommending its use for seasonal control as an alternative to contact materials.

Materials and Methods

1989 Laboratory Bioassays. Trials were conducted January–April using overwintering mite eggs on spur wood collected from commercial orchards the previous November and December. After storage at 2°C for 30–35 d to assure adequate egg chilling, the spurs were held in a rearing chamber at 25°C and 40% RH under a photoperiod of 16:8 (L:D) h to induce hatching, then placed in close proximity to the foliage of potted apple seedlings to allow colonization. Summer eggs were obtained by rearing the hatched mites to the adult stage on the seedlings and transferring them with a camel's-hair brush to the top surface of an excised leaf (20–25 adult females per leaf) set on moistened cotton in a petri dish. The excised leaves were bounded at the edges by moist cotton barriers to prevent mites from escaping. Dishes were placed in the rearing chamber to allow the adults to lay eggs for 24 h, after which the cotton barriers and all motile mites were removed and the eggs were counted before the treatment was administered. Serial dilutions of Sunspray Ultra Fine oil (viscosity, 68 s; 50% distillation point, 212.2°C; 10–90% distillation range, 18.3°C; unsulfonated residue, 94.0%; Mycogen, San Diego, CA) in distilled water were prepared to obtain test solutions of 3, 2, 1, 0.75, 0.50, 0.25, 0.10, 0.05, 0.005, 0.0005, 0.00005, and 0.000005%, but after several preliminary trials, it was determined that the range encompassing nearly complete mortality to total survival was represented by 0.05, 0.005, and 0.0005% oil solutions on a volume basis. Test leaves containing eggs were dipped for 5 s in 200 ml of a test solution that was stirred constantly until just before dipping to prevent phase separation. For uniformity, the three oil solutions and a distilled water check were mixed and tested concurrently using eggs from the same cohort with six replicate leaves containing 30–60 eggs per treatment. After dipping, the leaves were returned to their petri dishes in the rearing chamber. The next day, a bead of Tree Tanglefoot (Tanglefoot, Grand Rapids, MI) was placed around the perimeter of each leaf and the eggs were recounted. Leaves were examined for hatched larvae every 1–2 d, and ovicidal mortality was determined by comparing the number of unhatched eggs with the original number of post-treatment eggs.

Residual larvicidal effects of the oil solutions were investigated in a similar manner to parallel an orchard situation where the summer egg hatch occurs shortly before the application of an oil spray. Adult mites (progeny of the overwintered egg generation) were transferred to cotton-bounded excised leaves as described above, but the laying arena was confined to a narrow area immediately surrounding the leaf midrib to facilitate later manipulation. After the eggs were laid (usually 3–4 d) and all the adult mites were removed, this midrib portion of the leaf containing eggs was excised and placed onto the surface of another leaf that had been dipped in the oil-test solution the previous day. The same three concentrations of oil as in the ovicide trials were used as test solutions. Dipped leaves were placed on moist cotton in a loosely covered plastic crisper and held in the rearing chamber for 24 h at 25°C and 40% RH under a photoperiod of 16:8 (L:D) h to allow excess solution to run off or evaporate before midribs were placed on them. A barrier of Tanglefoot was placed around the leaf's perimeter to prevent mites from escaping, and 3–4 d were allowed for hatch to occur. The leaf surface was examined, and the numbers of live and dead larvae, plus those caught in the tanglefoot and those concealed on the undersurface of the midrib, were recorded and compared with the number of unhatched eggs on the midrib. At the higher oil concentrations, large numbers of larvae were sometimes found under the midrib (not contacting the treated surface) or caught in the tanglefoot barrier. Because such larvae could have been exhibiting an escape response to the oil residue, they were excluded from any calculations of larvicidal mortality, which was determined by comparing the number of dead and live larvae on the treated surface.

1990 Laboratory Bioassays. Trials were conducted January–May using spur wood collected the previous fall and all the same ovicidal and larvicidal assay procedures as in 1989. Serial dilutions of oil in distilled water were prepared to obtain test solutions of 0.25, 0.05, 0.005, 0.0005, and 0.00005% on a volume basis, which was a slight expansion of the concentration range used

previously. The entire series of ovicidal and residual larvicidal treatments was then repeated, except that instead of being dipped into the oil-test solutions, the leaves were treated using a Potter Precision Laboratory Spray Tower (Burkard Manufacturing, Rickmansworth, England), which is capable of producing a uniform-density spray mist of droplets in a narrow range of sizes. Each leaf treated was placed individually in the center of the target platform, and the spray reservoir was filled using 5 ml of oil solution that had been continuously agitated to prevent phase separation. The contents of the reservoir were then discharged at a pressure of 0.7 kg/cm^2 onto the target platform, a process requiring ≈25 s.

1991 Laboratory Bioassays. Ovicide-dip trials were conducted April–June the same way as in 1990, except that leaves containing the summer eggs were returned to the rearing chamber for a period of either 24 or 48 h to obtain test groups of eggs 24–48 or 48–72 h in age. Results of the 1990 summer field application trials indicated that European red mite larvae, nymphs, and adults appear to be adversely affected by contact with summer oil sprays. We therefore wished to supplement this field observation by using the Potter spray tower in the laboratory to expose motile stages of mites to a concentration series for mortality assessment. Summer eggs were obtained from mites hatching from overwintering eggs that been brought into the laboratory. During March and April, nymphs from these eggs were confined on leaves using Tanglefoot barriers, sprayed with different rates of oil, and examined 24 and 48 h after treatment to evaluate survival. Oil concentrations tested were 1.00, 0.75, 0.50, and 0.25%, and distilled water was used as a check treatment. Contact larvicide spray trials were conducted on a total of seven dates; two or three replicates were run on each date. Each replicate of the trial comprised 10 leaves (2 per concentration) treated on a given date, using mites of the same cohort for each day's trial. The leaves were maintained in the rearing chamber at 25°C and 40% RH under a photoperiod of 16:8 (L:D) h during the time between treatment and evaluation. Any mites that reached a quiescent stage after the treatment were tracked for 3–4 d to determine whether they would ultimately survive the effects of the oil spray.

1989 Airblast Field Trials. Trials were conducted in four orchard blocks on different research farms of the New York State Agricultural Experiment Station, Geneva: Station Creek ('Red Delicious', standard-sized trees), Darrow East ('McIntosh', semidwarf trees), Darrow West ('Red Delicious', dwarf trees), and Hansen ('Empire', semidwarf trees). Each block, which ranged in size from ≈0.5 to 1.0 ha, was divided into a small (10–15 trees) untreated check and two treatment sections which received either a full-season or half-season oil program. Spray applications were made using an airblast sprayer (Friend 375D; Friend Manufacturing, Gasport, NY) delivering 935 liters/ha. All the treatment plots received a 1% application of Sunspray 6E emulsifiable oil (viscosity, 75 s; 50% distillation point, 212.2°C; 10–90% distillation range, 26.7°C; unsulfonated residue, 94.0%; Sun Oil and Refining, Marcus Hook, PA) at the early tight-cluster bud stage (4 May), and applications of 0.25% Sunspray Ultra Fine at the following times: pink bud stage (15 May), petal fall (3 June), and first cover (22 June). The full-season plots additionally received applications of 0.25% Sunspray Ultra Fine at second cover (1 July), third cover (15 July), and fourth cover (2 August). On 11 July and 9 August, samples of 25 vegetative terminal leaves were collected from each of four trees per treatment plot, brought to the laboratory, and brushed with a mite-brushing machine (Leedom Engineering, Palo Alto, CA) so that numbers of European red mite eggs, immatures, and adults could be counted.

1990 Airblast Field Trials. A postbloom summer oil program was tested in two commercial orchards in Wayne County ('Law Rome', near Sodus, NY; and 'Ida Red', near Pultneyville, NY) and one research orchard (Station Creek, 'Empire' and 'Cortland') in Geneva. All received a 1% Sunspray 6E spray at the tight-cluster bud stage for early-season mite control. The growers applied these sprays in their respective orchards between 25 and 30 April, and the Station Creek orchard received an application of 1% Sunspray 6E on 27 April. The Sodus orchard was partitioned into six plots of 16 trees per plot (8 trees long by 2 trees wide) for airblast oil applications, plus an untreated check plot 5 trees long by 2 trees wide. The Pultneyville orchard was partitioned into three plots of 72 trees per plot (12 trees long by 6 trees wide), plus an untreated check plot 2 trees long by 6 trees wide. The Station Creek orchard was partitioned into three plots of 15 trees per plot (5 trees long by 3 trees wide), plus an untreated check plot 4 trees long by 3 trees wide.

Oil treatments were applied in all locations with an airblast sprayer as previously described. The summer oil program, using Sunspray Ultra Fine, began at the petal fall stage and continued on a 2–3-wk schedule for two or three cover sprays: Station Creek, 14 and 23 May, 14 June, and 20 July; Sodus, 24 May, 12 and 28 June; Pultneyville, 24 May, 12 and 27 June, and 18 July. The oil was applied at three different rates in each orchard in accordance with the range showing minimal to maximum effectiveness against European red mite eggs and larvae in the laboratory trials: high, 1.00%; medium, 0.25%; low, 0.05% (10, 2.5, and 0.5 ml/liter, respectively). The check received no postbloom oil or acaricides.

Leaf samples were taken for mite brushing starting in early June on a 1–2-wk schedule to track populations of European red mite eggs, immatures, and adults. Each sample consisted of 25 intermediate-aged leaves from each of four trees per treatment replicate. Because high mite numbers in the Pultneyville check and 0.05% oil plots began damaging the foliage by the sample taken on 27 July, a contact acaricide was applied on 2 August and no additional samples were collected from these plots. Fruit finish and injury evaluations were made in these orchards using fruit picked just before the respective harvest dates for each variety to assess the suitability of this program in commercial fresh fruit blocks. On each harvest date, 400 apples (100 from each of four trees) were selected randomly in each of the treatment plots and examined in the laboratory to evaluate fruit defects potentially attributable to the oil sprays, frost, or mechanical damage that might have been exacerbated by the oil. Defects were classified as either light (damage minimal or absent) or severe. Color ratings also were assigned to the fruit according to USDA grading standards (USDA 1976), classifying fruit into one of five categories according to percentage of red color; categories differed with the variety. Additionally, in the case of 'Law Rome', fruits were evaluated for incidence of scarf skin, a gray flecking or milky appearance characteristic of this variety that can cause a lowering of the fruit grade. The incidence levels, chosen arbitrarily, ranged from light (the lowest amount of flecking or discoloration seen in the samples) to moderate to severe (the highest levels that occurred).

1991 Airblast Field Trials. A postbloom summer oil program was tested in two commercial orchards in Wayne County ('Ida Red', the same farm as in 1990 near Sodus, NY; and the same 'Ida Red' blocks as in 1990 near Pultneyville, NY) and the same research orchard as in 1990 (Station Creek). As in 1990, all the orchards received a Sunspray 6E spray at the tight cluster bud stage for early-season control; the growers applied these sprays in their respective orchards between 24 and 28 April, and the Station Creek orchard received an application of 1.5% Sunspray 6E on 26 April. The orchards were partitioned into plots and airblast oil treatments were applied in the same manner as in the previous year. The summer oil program, using Sunspray Ultra Fine, began at petal fall and continued on a 2–3 wk schedule for two or three cover sprays: Station Creek, 20 and 30 May and 13 June; Sodus, 21 and 31 May, 18 June, and 24 July; Pultneyville, 21 and 31 May and 18 June. The oil was applied at three different rates in each orchard: high, 3%; medium, 2%; low, 1% (30, 20, and 10 ml/liter, respectively). The check received no postbloom oil or acaricides.

Leaf samples were taken to assess European red mite numbers and fruit samples were taken for evaluating finish and color in the same manner as in 1990. At the end of September, leaf-phytotoxicity evaluations were made by examining 50–100 terminal shoots throughout the canopy of each of three trees in each plot in all the orchards where these tests were conducted. Trees were under moisture stress because of weather conditions from May to August that were hotter (average temperatures 2.1–5.7°C above normal) and drier (monthly rainfall accumulations 3.0–8.6 cm less than normal) than is typical for this region (U.S. Dept. Commerce 1991). For this reason, and because of the relatively high oil rates used in these plots, leaves were examined for the presence of the circular, necrotic lesions (1–2 mm diameter) characteristic of oil damage (Lawson & Weires 1991). Each terminal was categorized as clean (no lesions), slight (average of less than 5 lesions per leaf), moderate (average of 5–10 lesions per leaf), or severe damage (average of >10 lesions per leaf).

1990 Handgun Field Trials. Sunspray Ultra Fine at three concentrations was tested in handgun applications for ovicidal efficacy compared with a standard contact acaricide (dicofol) against a population of mixed-age European red mite eggs and motile forms in a research orchard in Geneva, NY. Oil treatments were applied on 21 June and 9 July at the same rates as in the airblast trials, and dicofol (Kelthane 50% WP; Rohm and Haas, Philadelphia, PA) at 227 g (AI)/379 liters was applied on 21 and 29 June with a handgun sprayer (Friend Manufacturing, Gasport, NY) at a pressure of 1,026 kg/cm^2. All treatments, including unsprayed check trees, were applied to single-tree plots and were replicated three times using one 'Golden Delicious' and two 'Red Delicious' trees.

On the day of the 21 July treatment, after the spray residue was dry, 10 leaves per tree were collected from each of the plots and brought into the laboratory. A sufficient number of these leaves were used to obtain 100–600 eggs from each replicate tree so that approximately ≈1,000 eggs were evaluated per treatment. Eggs were counted on each leaf and all motile forms were removed from the upper surface with a camel's-hair brush. The leaves were then ringed with Tanglefoot and placed in a rearing chamber at 25°C and 40% RH under a 16:8 (L:D) h photoperiod on wet cotton in individual petri dishes. On the succeeding 2 d (24 and 48 h after treatment), all hatching larvae were counted and removed to separate out effects of the treatments on eggs that were very close to hatching. The leaves were maintained in the chamber and examined for hatch several times over the next 12 d until hatch was complete on the check leaves to determine the rate of hatch in the different treatments. Leaf samples, consisting of 25 intermediate-aged leaves from each of four trees per treatment replicate, were taken for mite brushing on 19 June,

Table 1. Mortality (SEM) of European red mite eggs and larvae treated by dip or spray applications of petroleum oil in the laboratory

% Oil	*n*	% Mortality	*n*	% Mortality
1989		Ovicide Tests (0–24-h Eggs)		Residual Larvicide Tests
Dip Treatments				
0.05	594	98.7 (1.6)	506	88.0 (11.1)
0.005	568	89.4 (11.1)	395	66.0 (35.9)
0.0005	550	69.0 (33.9)	336	55.8 (30.3)
0	522	19.3 (13.6)	435	0.2 (0.6)
1990		Ovicide Tests (0–24-h Eggs)		Residual Larvicide Tests
Dip Treatments				
0.25	476	100.0 (0.0)	84	100.0 (0.0)
0.05	473	99.2 (2.3)	123	100.0 (0.0)
0.005	464	95.0 (14.0)	178	100.0 (0.0)
0.0005	548	77.2 (26.8)	149	68.7 (39.1)
0.00005	401	51.9 (29.5)	125	57.2 (20.5)
0	458	18.1 (7.6)	112	17.4 (15.5)
Spray Treatments				
0.25	335	56.1 (31.2)	124	92.2 (13.7)
0.05	350	19.4 (10.9)	98	3.4 (4.2)
0.005	327	18.5 (10.8)	117	1.4 (1.7)
0.0005	316	13.8 (6.8)	103	12.8 (19.8)
0.00005	323	16.3 (9.2)	97	1.6 (3.2)
0	302	16.3 (5.5)	113	2.8 (4.1)
1991		Ovicide Tests		
		(24–48-h Eggs)		(48–72-h Eggs)
Dip Treatments				
0.25	212	100.0 (0.0)	252	98.0 (3.2)
0.05	195	100.0 (0.0)	185	100.0 (0.0)
0.005	203	99.2 (2.0)	246	97.0 (3.9)
0.0005	197	96.3 (9.1)	196	79.9 (25.2)
0.00005	196	100.0 (0.0)	201	73.0 (28.6)
0	225	20.5 (7.6)	200	13.9 (14.8)

Standard error of mean calculated among replicates for each treatment rate.

2 d before the first spray was applied, and on 28 June, 2 and 24 July, and 3 and 8 August. This permitted monitoring of European red mite eggs, immatures, and adults in all of the treatment plots.

1991 Handgun Field Trials. Sunspray Ultra Fine was tested at four concentrations for its ovicidal efficacy and residual control against a population of mixed-age European red mite eggs and motile forms in a research orchard at Geneva. Oil treatments were applied as described for 1990 on 12 July to single-tree ('Red Delicious') plots replicated four times at the following rates: 3, 2, 1, and 0.25% (30, 20, 10, and 2.5 ml/liter, respectively). Eggs were collected in the same manner as in the previous year and evaluated for hatch on 18 and 23 July, and any live mites were determined to have survived the treatments. Leaf samples, consisting of 5–10 intermediate-aged leaves from each of four trees per treatment replicate, were taken from the trees for direct visual examination under a dissecting microscope in the laboratory. Samples were taken on 9 July, 3 d before the handgun spray, and 3, 10, 18, and 42 d afterward to track populations of European red mite immatures and adults in all of the treatments.

Because of the nature and plot size of the airblast trials, true spatial replication was not possible within each site; therefore, no analysis of variance (ANOVA) or inferential statistical procedures were used on the summer mite counts from these treatments. Instead, the mean values are presented together with their standard errors. All mortality percentages, fruit color, and leaf-damage counts were subjected to an arcsine square root transformation. ANOVA and a least significant difference test (Proc ANOVA, SAS Institute 1985) were used to separate treatment means, with a comparisonwise error rate of <0.05.

Results and Discussion

1989 Laboratory Bioassays. Because of the high variance obtained in the analyses of the treatment effects, the laboratory assays were repeated several times. Total mortality was caused by all test solutions stronger than 0.05%, and no significant mortality resulted from test solutions weaker than 0.0005% (Table 1). In both the ovi-

Table 2. Contact mortality (SEM) of European red mite larvae sprayed with petroleum oil in the laboratory, 1991

% Oil	n	24-h reading		48-h reading	
		% Dead	% In barrier	% Dead	% In barrier
1.00	146	79.6 (28.7)	9.6 (13.4)	88.8 (13.5)	11.2 (13.5)
0.75	145	90.6 (12.0)	6.7 (9.3)	93.2 (9.3)	6.8 (9.3)
0.50	157	84.8 (21.6)	4.1 (8.1)	95.3 (9.2)	4.7 (9.2)
0.25	171	73.0 (18.6)	6.4 (8.7)	92.6 (9.0)	7.0 (9.1)
Check	168	3.9 (7.4)	4.8 (6.3)	6.2 (11.4)	6.3 (9.0)

Standard error of mean calculated among replicates for each treatment rate.

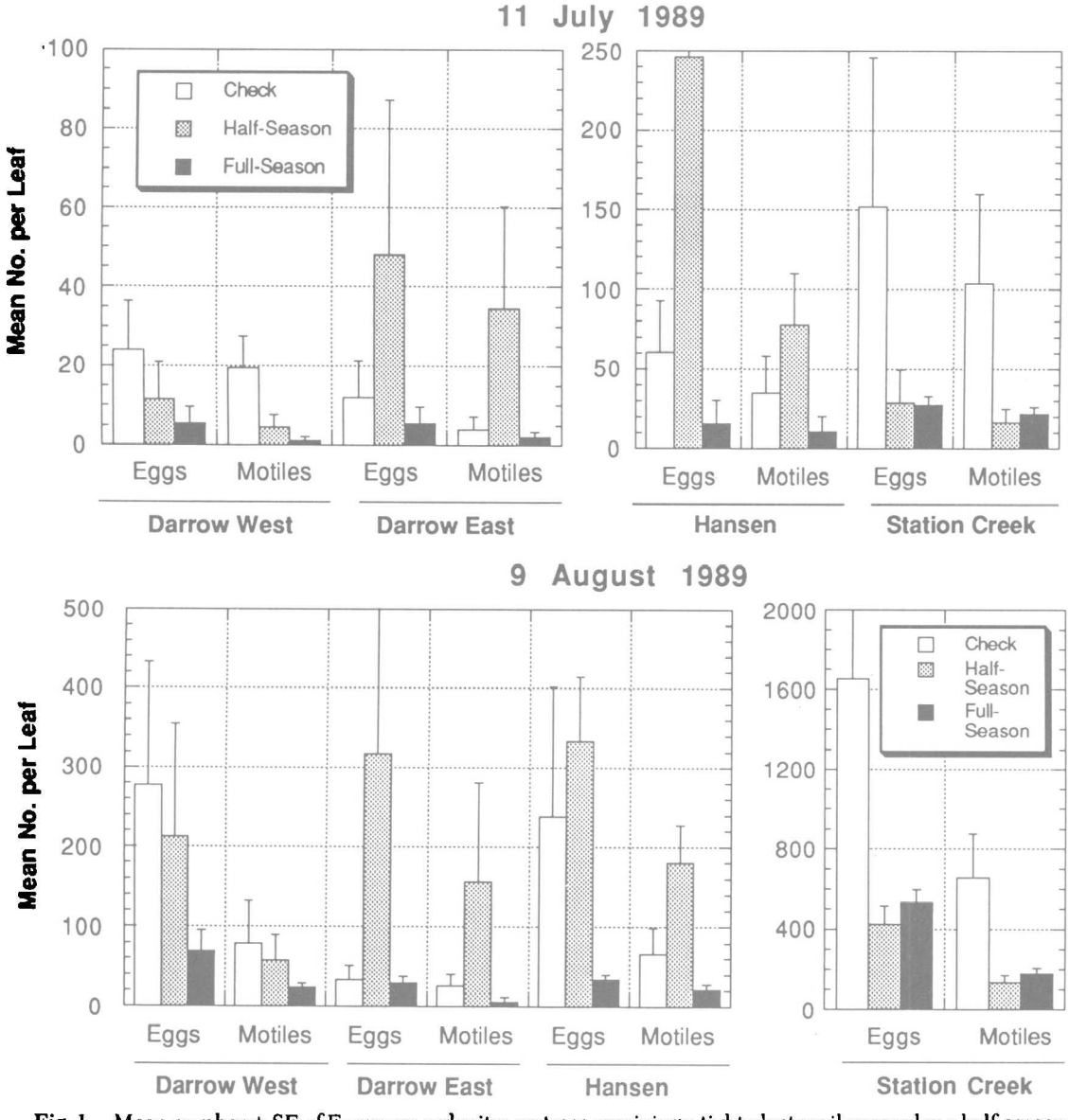

Fig. 1. Mean number ± SE of European red mites on trees receiving a tight-cluster oil spray plus a half-season (pink, petal fall, and first cover) or a full-season (half-season plus second, third, and fourth cover) program of 0.25% Sunspray Ultra Fine oil, Geneva.

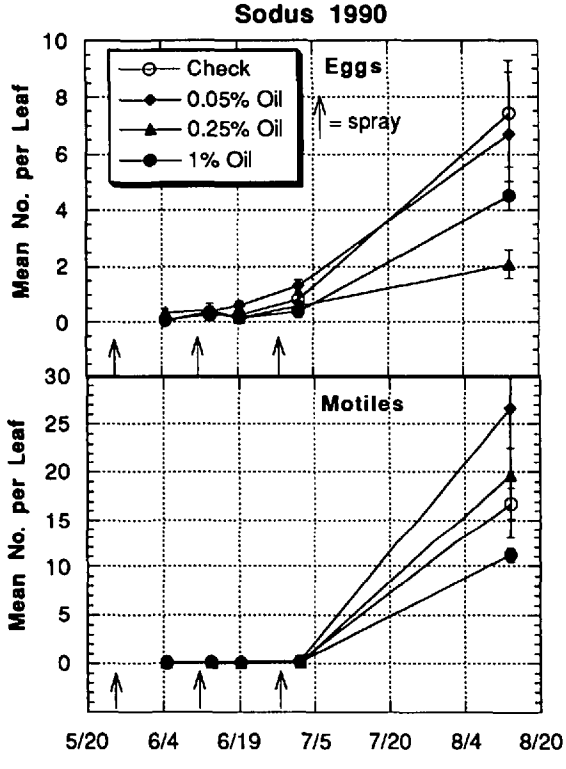

Fig. 2. Mean number ± SE of European red mites on trees receiving a tight-cluster oil spray plus three postbloom sprays of Sunspray Ultra Fine oil at different rates, Wayne County.

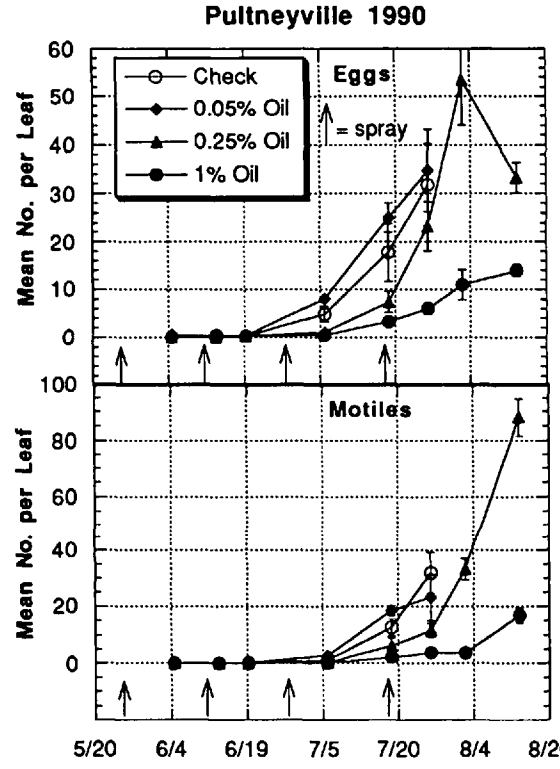

Fig. 3. Mean number ± SE of European red mites on trees receiving a tight-cluster oil spray plus four postbloom sprays of Sunspray Ultra Fine oil at different rates, Wayne County.

cidal and residual larvicidal tests, mite mortality decreased with concentration, and the lowest concentration (0.0005%) caused greater mortality than did the check. Our examination of residual larvicidal effects was intended to parallel a field situation where the summer eggs are not contacted by oil directly, and the larvae hatch onto the residue of a treated surface. The three concentrations tested using this indirect method of exposing European red mite larvae to oil also resulted in greater mortality than the check, suggesting that a summer oil treatment may be more than a contact pesticide.

1990 Laboratory Bioassays. As in the 1989 tests, 100% mortality was caused by the dip-solution treatment of 0.25%. However, unlike the 1989 egg-dip assays, the 0.00005% rate resulted in higher mortality than that obtained in the check. The residual mortality effects on larvae placed on treated leaves are similar to those of the eggs, with no difference among the three highest concentrations (0.25–0.005%) and then increasingly higher survival with lower concentrations. Although the Potter unit produces a spray of virtually ideal characteristics, the concentrations applied as a spray did not have the same effect on European red mite eggs as when the entire leaf was immersed in solutions of the same concentration. Mortality increased between the 0.05% and 0.25% treatments, indicating a transition point at which the discrete spray droplets were able to coalesce sufficiently to parallel the action of a continuous residue as in the dip trials.

1991 Laboratory Bioassays. Several repetitions of the ovicidal bioassays were conducted because of the high variance. As in the 1990 tests on 0–24-h-old eggs, the 0.25% treatment caused 100% mortality of the 24–48-h-old eggs, but 2% of the 48–72-h-old eggs survived this concentration (Table 1). As the oil concentrations decreased, the mortality responses were variable among the different age classes. The 24–48-h-old eggs were susceptible to all rates of oil. With the newly laid eggs and the oldest eggs, however, the two lowest rates—0.0005% and 0.00005%—caused less mortality in newly laid eggs and the oldest eggs than did the higher rates. Winter eggs become more susceptible to petroleum oil as they near hatching, which is the period from apple-bud dormancy to the tight-cluster stage. This corresponds to ≈39 and 6 d,

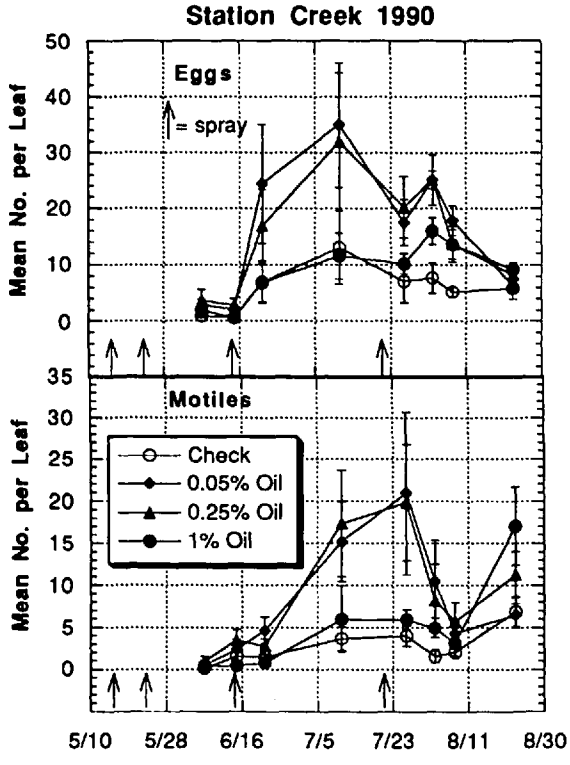

Fig. 4. Mean number ± SE of European red mites on trees receiving a tight-cluster oil spray plus four postbloom sprays of Sunspray Ultra Fine oil at different rates, Geneva.

respectively, before the start of hatching (Chapman & Pearce 1949). Welty et al. (1988, 1989) demonstrated that, as both summer and winter eggs progressed to within 1–2 d of hatching, their susceptibility to the acaricides hexythiazox and clofentezine decreased. Our results are similar in that the oldest age class of eggs tested (≈3–4 d from hatching) were less susceptible to the oil treatments than eggs 24 h younger.

Results of the contact larvicide spray trials show a mortality effect of all rates of oil tested (Table 2). Mites found in the tanglefoot barriers, which could not be counted as alive or dead, are reported separately. Our data show that newly emerged larvae and nymphs are unable to survive for >48 h after direct contact with these sprays. In these trials, low concentrations of oil caused up to 100% mortality of mites compared with field rates of 0.25–1.00% that generally do not control mite populations in the orchard. These low concentrations can be used under laboratory conditions because complete leaf coverage was achieved by immersing leaves in the oil mixtures or spraying them with an idealized spray, and degradation or volatilization of the residue was not influenced by weather.

1989 Airblast Field Trials. Population counts of European red mite life stages taken two times in each plot during the summer show the effect of treatment (Fig. 1). The untreated check plots at the Darrow East and Hansen locations had low numbers of mites. Late May rains and temperate early-summer weather were not favorable for European red mite population growth during the first part of July, although some treatment differences were clear in the Hansen block by this date. Above-average temperatures (3.2°C higher than normal) (U.S. Dept. Commerce 1991) in late July allowed rapid mite buildup before the August count, and, in most cases, the numbers of mites in the full-season plots were lower than those in the respective half-season and check plots. However, because of the large variability among the sample counts from one tree to the next, these differences were not always uniform. Although no systematic evaluation of leaf quality was made during the season, no injury to the foliage was evident in any of the treatment plots.

1990 Airblast Field Trials. The summer mite population was affected by oil concentration. The Sodus orchard (Fig. 2) had low summer mite population densities and never exceeded recommended thresholds (June, 2.5; July, 5.0; and August, 7.5 mites per leaf) (Wilcox et al. 1993) through July. Numbers started to increase in August, however, and on 14 August (6 wk after the last oil spray), mite numbers in the treatment plots varied inversely with the oil rate. Numbers increased more rapidly in the Pultneyville orchard (Fig. 3), and counts were lower in the 1% plots on all sample dates; threshold numbers were never reached in these trees, and mites remained below threshold even in the 0.25% plots until mid-July. The check and 0.05% plots received sprays of a conventional contact acaricide at the end of July to prevent foliar bronzing injury from mite feeding. Results of the oil treatments were similar at Station Creek (Fig. 4), except for low populations in the check trees. The predatory mite *Typhlodromus pyri* Scheuten was found at low levels (≈0.02 per leaf) in the 3 August 2% and 3% Pultneyville plots and in the 14 August 1% and 2% Sodus plots. The stigmaeid mite *Zetzellia mali* (Ewing) was found in the Station Creek plots on the 3, 8, and 23 August, sampling dates at levels of 0.7–2.7 per leaf, and, by 23 August, the numbers in the treated plots (2.3–2.7 per leaf) were significantly higher than those in the checks (1.6 per leaf) ($F = 3.74$; df = 6, 9; $P = 0.0538$. These counts are typical of predatory mite population levels in New York apple orchards but are not high enough to have influenced European red mite numbers in the oil-treated trees (Lienk et al. 1980). Overall, the 1% spray program successfully maintained mites below threshold levels for the period of the season that contact acaricides normally are used in commercial plantings.

Table 3. Fruit and leaf quality at harvest from trees receiving a prebloom oil spray and various postbloom oil spray programs, Wayne County and Geneva, 1990–1991

Parameter	Treatment			
	Check	0.05% Oil	0.25% Oil	1% Oil
		1990		
Sodus ('Law Rome', 24 Oct.)				
Scarf skin[a]				
Light	49.5a	35.8a	28.0a	27.0a
Moderate	33.5a	39.0a	41.8a	40.8a
Severe	17.0a	25.3ab	30.3b	32.3b
Fruit damage[a,b]				
Light	13.0a	12.5a	7.0b	14.0a
Severe	6.5a	2.8a	3.5a	2.5a
% Red category[a]				
<25%	6.8a	5.8a	8.8a	13.8a
25–40%	24.8a	21.5a	24.0a	35.5a
41–66%	24.0a	39.3a	41.5a	34.0a
67–80%	24.3a	25.8a	20.5a	14.0a
>80%	18.5a	8.0a	5.3a	3.3a
Station Creek ('Empire', 24 Sept.)				
Fruit damage[a,b]				
Light	4.3a	4.5a	5.0a	3.5a
Severe	0.3a	0.8a	0.5a	1.5a
% Red category[a]				
<25%	0.0a	0.3a	0.0a	1.0a
25–40%	7.0a	3.8a	2.8a	4.8a
41–66%	18.0a	21.8a	17.8a	13.8a
67–80%	35.5a	45.0b	42.5ab	45.3b
>80%	38.8a	34.5a	37.5a	35.3a
Pultneyville ('Ida Red', 8 Oct.)				
Fruit damage[a,b]				
Light	5.8ab	8.0a	3.3b	7.5a
Severe	0.5a	0.8a	0.8a	1.3a
% Red category[a]				
<25%	11.8a	15.0a	3.3b	2.8b
25–33%	26.3a	26.0a	23.0a	15.5b
34–50%	29.3a	29.0a	34.3a	28.3a
51–80%	26.3a	23.8a	31.8a	34.8a
>80%	9.5ab	8.3b	8.8b	18.8a
Station Creek ('Cortland', 24 Sept.)				
Fruit damage[a,b]				
Light	9.0a	8.8a	5.3a	9.3a
Severe	1.5a	4.0a	2.3a	1.8a
% Red category[a]				
<25%	4.5a	2.5b	2.5ab	0.8b
25–33%	23.3a	15.3ab	20.8a	9.5a
34–50%	28.3a	24.0a	26.3a	27.3a
51–80%	35.3a	39.5a	35.0a	39.0a
>80%	8.5a	17.0ab	13.0a	24.3b
		1991		
Station Creek ('Empire', 1 Oct.)				
Foliar lesions[a]				
Clean	9.0a	16.2a	2.2a	12.6a
Slight	69.7a	61.6a	49.9ab	39.2b
Moderate	21.3a	21.0a	40.1a	34.6a
Severe	0.0a	1.2ab	7.9ab	14.1b
% Red category[a]				
<25%	0.3a	0.0a	1.0a	0.0a
25–40%	2.5a	8.8a	13.0a	0.5a
41–66%	30.0a	33.5a	30.8a	23.3a
67–80%	41.5a	38.0a	40.3a	44.3a
>80%	30.3a	22.3a	17.0a	34.3a
Sodus ('Ida Red', 2 Oct.)				
Foliar lesions[a]				
Clean	92.3a	80.4a	63.1b	25.2c
Slight	7.7a	19.6ab	36.2bc	53.6c
Moderate	0.0a	0.0a	0.7a	18.9b
Severe	0.0a	0.0a	0.0a	1.7b
% Red category[a]				
<25%	0.5a	0.3a	0.3a	2.8b
25–33%	1.3a	3.8ab	2.8ab	6.3b
34–50%	18.8a	24.3a	21.5a	26.3a
51–80%	61.3a	56.0a	55.8a	54.0a
>80%	17.3ab	15.8ab	20.0a	10.3b

Table 3. Continued

Parameter	Treatment			
	Check	0.05% Oil	0.25% Oil	1% Oil
Pultneyville ('Ida Red', 2 Oct.)				
Foliar lesions[a]				
Clean	17.3a	32.7b	30.7b	10.8a
Slight	63.8ab	65.2a	52.9b	55.1ab
Moderate	18.1a	2.1b	15.7a	30.4a
Severe	0.8a	0.0a	0.7a	3.8a
% Red category[a]				
<25%	1.0a	0.0a	0.3a	0.3a
25–33%	8.3a	3.3a	8.5a	7.0a
34–50%	40.8a	28.5a	42.5a	38.0a
51–80%	50.0a	58.8a	44.5a	52.5a
>80%	0.0a	9.8c	4.5bc	2.8b
Station Creek ('Cortland', 16 Sept.)				
% Red category[a]				
<25%	2.8a	8.3b	3.3ab	5.0ab
25–33%	16.5a	20.5a	18.0a	18.0a
34–50%	33.8a	27.8a	29.8a	30.0a
51–80%	46.5a	36.3a	45.0a	45.8a
>80%	0.8a	6.5b	4.0ab	4.0b

Treatment means followed by the same letter are not significantly different (for 1990, df = 6, 9; Scarf skin: light, $F = 0.89$; $P = 0.5420$; moderate, $F = 1.32$; $P = 0.3385$; severe, $F = 1.91$; $P = 0.1834$; Fruit damage: 'Law Rome', light: $F = 2.82$; $P = 0.0791$; severe: $F = 0.79$; $P = 0.6000$; 'Empire', light: $F = 0.92$; $P = 0.5209$; severe: $F = 0.65$; $P = 0.6909$: 'Ida Red', light: $F = 2.59$; $P = 0.0964$; severe: $F = 0.30$; $P = 0.9219$; 'Cortland', light: $F = 0.78$; $P = 0.6072$; severe: $F = 1.28$; $P = 0.3538$; % Red category: 'Law Rome', 1: $F = 0.66$; $P = 0.6824$; 2: $F = 0.99$; $P = 0.4850$; 3: $F = 1.37$; $P = 0.3230$; 4: $F = 1.18$; $P = 0.3957$; 5: $F = 0.73$; $P = 0.6407$; 'Empire'; 1: $F = 1.72$; $P = 0.2219$; 2: $F = 3.73$; $P = 0.0380$; 3: $F = 2.64$; $P = 0.0925$; 4: $F = 2.19$; $P = 0.1398$; 5: $F = 2.80$; $P = 0.0805$; 'Ida Red'; 1: $F = 4.94$; $P = 0.0167$; 2: $F = 11.29$; $P = 0.0009$; 3: $F = 1.25$; $P = 0.3675$; 4: $F = 1.10$; $P = 0.4328$; 5: $F = 3.19$; $P = 0.0581$; 'Cortland'; 1: $F = 4.33$; $P = 0.0248$; 2: $F = 3.92$; $P = 0.0330$; 3: $F = 0.47$; $P = 0.8119$; 4: $F = 0.66$; $P = 0.6851$; 5: $F = 2.89$; $P = 0.0741$. For 1991, foliar lesions: df = 3, 8; Station Creek, clean: $F = 1.76$; $P = 0.2329$; slight: $F = 3.97$; $P = 0.0528$; moderate: $F = 2.47$; $P = 0.1360$; severe: $F = 3.43$; $P = 0.0724$; Sodus, clean: $F = 0.00$; $P = 1.0000$; slight: $F = 22.71$; $P = 0.00001$; moderate: $F = 10.86$; $P = 0.0010$; severe: $F = 83.88$; $P = 0.0001$; Pultneyville, clean: $F = 9.44$; $P = 0.0053$; slight: $F = 3.27$; $P = 0.0800$; moderate: $F = 11.93$; $P = 0.0025$; severe: $F = 0.49$; $P = 0.6964$); % Red category: df = 6, 9; 'Empire', 1: $F = 0.73$; $P = 0.5514$; 2: $F = 1.83$; $P = 0.1957$; 3: $F = 0.56$; $P = 0.6484$; 4: $F = 0.22$; $P = 0.8788$; 5: $F = 1.49$; $P = 0.2662$; Sodus 'Ida Red', 1: $F = 3.34$; $P = 0.0334$; 2: $F = 2.54$; $P = 0.0767$; 3: $F = 1.35$; $P = 0.2783$; 4: $F = 0.74$; $P = 0.5377$; 5: $F = 1.58$; $P = 0.2154$; Pultneyville 'Ida Red', 1: $F = 0.45$; $P = 0.7246$; 2: $F = 1.74$; $P = 0.2112$; 3: $F = 1.84$; $P = 0.1932$; 4: $F = 1.25$; $P = 0.3351$; 5: $F = 6.93$; $P = 0.0058$; 'Cortland', 1: $F = 1.83$; $P = 0.1946$; 2: $F = 0.29$; $P = 0.8352$; 3: $F = 0.62$; $P = 0.6163$; 4: $F = 0.69$; $P = 0.5768$; 5: $F = 3.66$; $P = 0.0041$); least significant difference test [SAS Institute 1985]). Percentages subject to arcsine square root transformation before analysis.

[a] Average percentage fruit or leaves per category.

[b] Fruit surface damage attributable to frost or mechanical injury.

Fruit quality harvest evaluations show that the higher oil concentrations significantly affected the proportion of 'Law Rome' fruit with severe scarf skin; levels at the 0.25 and 1% rates were approximately double the check incidence (Table 3). The proportion of fruit with light or moderate damage was not affected by any of the treatments. The fruit-damage category was included to address the possible interaction of oil and weather-related injury, which, in turn, is often indistinguishable from certain types of physical bruising. The oil treatment did not appear to have any bearing on this type of injury in any of the varieties. The only treatment differences found in the color ratings were in direct relationship to the oil concentration, where greater proportions of the 'Cortland' and 'Ida Red' sometimes occurred in the higher color categories with increasing oil concentration.

1991 Airblast Field Trials. The mite population was affected by oil concentration. The Pultneyville orchard (Fig. 5) had low summer mite populations, and no above-threshold counts were seen in the treated plots throughout the entire season. Numbers of mites in the check plots increased in August, however, and remained high. Mite populations increased more rapidly in the Sodus orchard (Fig. 6), which had severe population pressure during most of the summer. Numbers in all plots remained below threshold into July but exceeded acceptable levels in the 1% trees by the middle of that month. This necessitated the additional application of the 1% treatment on 24 July, which reduced mite numbers, but only for approximately 2 wk. The 2 and 3% treatments kept the mites below threshold levels all season, but counts were significantly lower in the 3% plots on all sample dates from 15 July through August. The mite population at the Station Creek orchard (Fig. 7) remained low throughout the season and never exceeded the threshold.

At the Pultneyville site, *T. pyri* was present in the samples on 28 June and thereafter, but numbers were higher in the treatment plots (1.1–2.9 per leaf) than in the checks (0.2–0.3 per leaf)

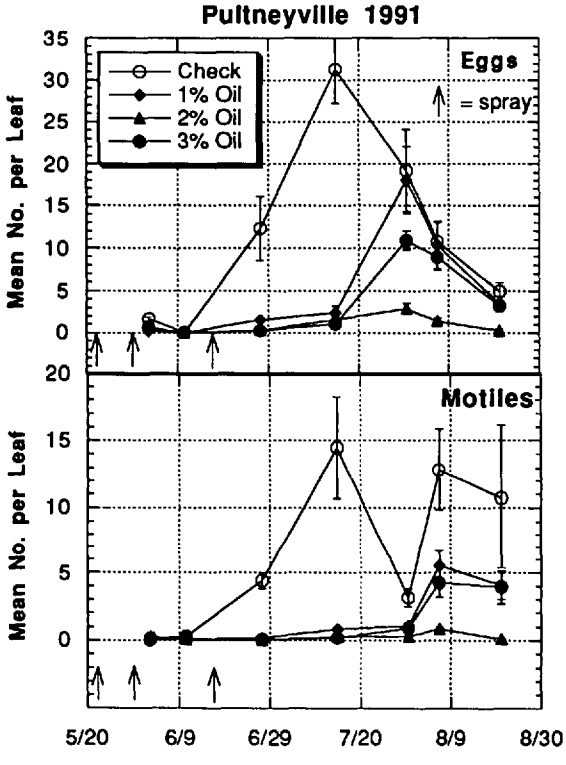

Fig. 5. Mean number ± SE of European red mites on trees receiving a tight-cluster oil spray plus three postbloom sprays of Sunspray Ultra Fine oil at different rates, Wayne County.

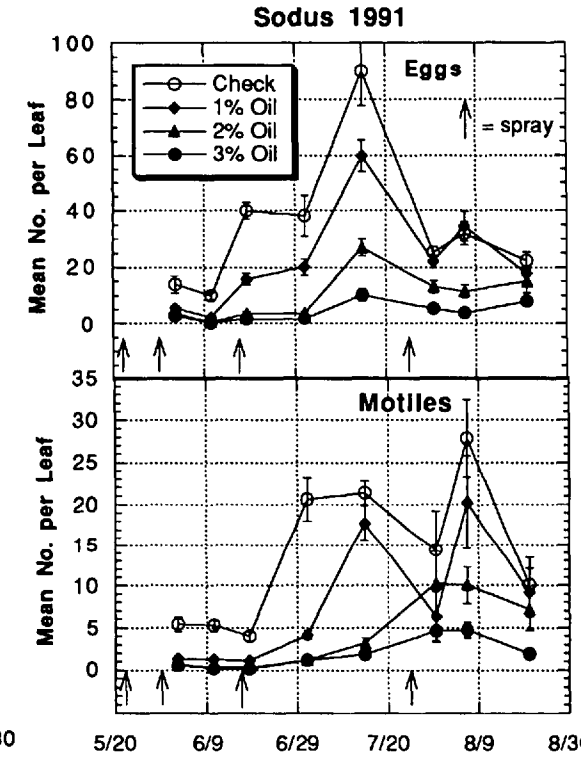

Fig. 6. Mean number ± SE of European red mites on trees receiving a tight-cluster oil spray plus three or four postbloom sprays of Sunspray Ultra Fine oil at different rates, Wayne County. The 24 July spray was applied to the 1% plots only.

only on 31 July (F = 7.53; df = 6, 9; P = 0.0041) and 7 August (F = 11.16; df = 6, 9; P = 0.0010). The check plots had significantly higher numbers of predator mites than oil-treated trees only on 28 June (F = 6.86; df = 6, 9; P = 0.0057). At the Sodus site, *T. pyri* was seen on 31 July and 7 and 21 August, and numbers in the 3% plots (0.6 per leaf) were greater than in the checks (0.3 per leaf) only on the last of these dates (F = 2.98; df = 7, 24; P = 0.0513. At the Station Creek site, *Z. mali* was present on 28 June and on all subsequent sample dates, but its numbers in the treatment plots (2.5 per leaf in 3% oil trees) exceeded those in the checks (1.3 per leaf) only on 29 July (F = 2.28; df = 6, 9; P = 0.1483. In general, the 2% and 3% oil treatments successfully controlled mites during a severe mite infestation without the need for contact acaricides. The 1% rate at the Sodus site required additional applications to prevent unacceptably high numbers.

Phytotoxicity occurred mainly in those portions of the canopy where the spray had dried unevenly or had accumulated after the application, such as locations adjacent to the sprayer and at the ends of leaf terminals (Table 3). Oil concentration significantly affected the proportion of foliar shoots with severe lesions, causing levels 2-fold higher with the 3 than the 2% rate in the 'Empire' trees at Station Creek. Although the data for 'Ida Red' were more variable, leaf damage tended to increase with higher oil concentration. The high temperatures and moisture stress experienced during the summer of 1991 contributed to overall poor leaf quality in many orchards around the state, and leaf damage observed at Station Creek and Pultneyville were confounded by the occurrence of similar lesions in all the trees caused by nutrient deficiencies. No leaf drop and no damage to fruit finish was observed in any of the plots.

As in the 1990 trials, none of the oil treatments affected fruit color. Oil-treated fruit from the Pultneyville site was >80% red 2.8–9.8% of the time, whereas none of the check fruit was placed in this category (Table 3). At the Station Creek 'Cortland' site, higher proportions (4.0–6.5%) of fruit receiving 1.0 and 3.0% oil sprays was classified similarly (>80% red) than was fruit from check trees (0.8%). Although it is not possible to ascribe enhanced red color to the oil treatments, it is clear that the oil had no adverse effect on

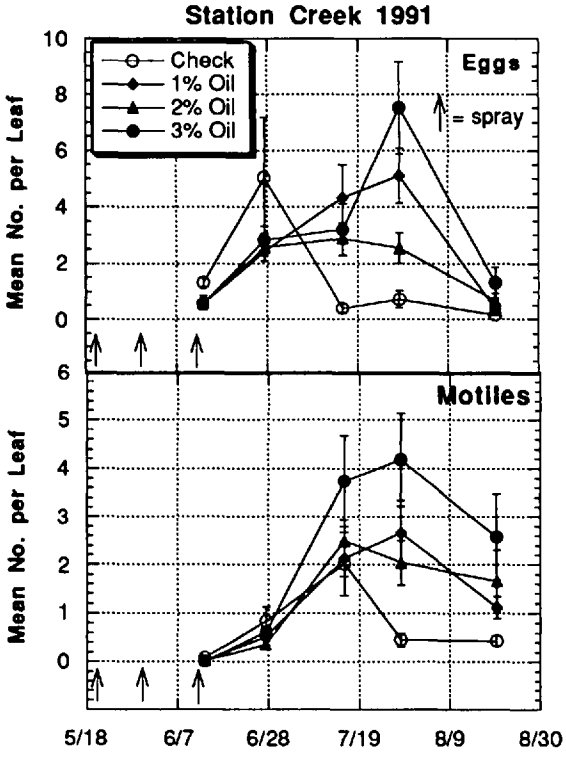

Fig. 7. Mean number ± SE of European red mites on trees receiving a tight-cluster oil spray plus three postbloom sprays of Sunspray Ultra Fine oil at different rates, Geneva.

fruit color for the 2 yr these evaluations were conducted.

1990 Handgun Field Trials. Oil sprays applied by handgun had a significant effect on egg survival, although less than the laboratory assays (Table 4). Percentage of egg hatch decreased at the higher oil rates, although none of the mean values were statistically different. The large variability in the readings was similar to that observed in the laboratory ovicide tests. Despite the apparently low egg mortality in the treated trees, the low subsequent population counts on 28 June and 2 July, 7 and 11 d after the application date, indicate that population growth was being suppressed in the treated plots (Table 4). This trend continued until 24 July in the 1% treatment, 33 d after spraying. These results parallel those of the airblast trials and suggest that oil residue on the leaf surface may have larvicidal activity against the immature mites.

1991 Handgun Field Trials. Oil treatments caused greater egg mortality than was observed during the 1990 trials, including those rates tested both years. Percentage of hatch was <10% in all treatments ($F = 0.55$; df = 6, 9; $P = 0.7612$) (Table 4). Mortality of mites that survived after hatch was not significantly different among treatments. Approximately 25% of the mites that hatched out of eggs treated with the 0.25% rate survived (29 mites out of 524 eggs). However, this was not significantly different from the higher rates, where almost none survived ($F = 1.50$; df = 6, 9; $P = 0.2801$).

Similar results were obtained from the orchard counts of mite numbers in the sprayed trees (Table 4). The initial postspray counts (on 15 July, 3 d after treatment) show a >95% reduction in motile forms with a concentration of 1% or higher, and, in the 0.25% oil plots, the reduction is 79%. Populations in all plots peaked 1 wk later, then subsided to below-threshold levels by August. These results indicate that the rates tested may reduce mite numbers effectively, by both contact and residual activity, if spray coverage is optimal.

In conclusion, our results demonstrate that summer oil applications can control European red mites effectively in apple orchards. In the laboratory, both contact (immersion and spray) and residual oil treatments, at low application rates, can kill the larval and egg stages of the mite. Although an optimal oil treatment is capable of mite population suppression during the summer, growers must address the problems of achieving optimum spray coverage under normal field conditions using standard airblast sprayers. Caution is necessary in exercising mite control strategies that include the use of petroleum oil products. Oil has not been an effective rescue treatment for extremely high populations (unpublished data), and it is incompatible with sulfur-based fungicides. Also, as seen in 1991, conditions of high temperature and moisture stress increase phytotoxicity caused by oil sprays. The scarf evaluations indicated that certain varieties may be sensitive to summer oil applications. However, apple mite management programs can include summer applications of highly refined horticultural oils, which may be tank mixed with other crop protectant materials to limit European red mite population growth.

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Table 4. Hatch, residual larval mortality, and summer populations of European red mite on trees receiving handgun sprays of petroleum oil, Geneva, 1990–1991

Parameter	Treatment[a]						
	Check	0.05% Oil	0.25% Oil	1% Oil	2% Oil	3% Oil	Dicofol
				1990			
Ovicide Test, cumulative % hatch							
Days after treatment							
1	2.94a	1.15a	1.11a	1.57a	—	—	—
2	7.00a	3.75a	1.49a	3.20a	—	—	—
4	28.80a	18.34a	14.06a	12.58a	—	—	—
5	47.75a	36.86a	22.07a	19.38a	—	—	—
6	63.48a	55.68a	33.99a	34.62a	—	—	—
8	68.27a	68.20a	37.51a	36.82a	—	—	—
12–14	63.38a	70.33a	41.69a	37.27a	—	—	—
European red mite/leaf[b]							
19 June							
Eggs	113.3a	85.2a	108.6a	77.9a	—	—	98.8a
Motiles	47.8a	33.3a	56.7a	29.0a	—	—	32.0a
28 June							
Eggs	146.6a	131.4a	90.5a	99.0a	—	—	84.5a
Motiles	8.1a	6.1b	1.4b	0.8b	—	—	1.8b
2 July							
Eggs	87.7a	67.0a	28.6a	33.9a	—	—	32.5a
Motiles	121.2a	14.6b	3.7b	3.5b	—	—	18.4b
24 July							
Eggs	39.0a	18.3a	21.2a	21.2a	—	—	19.2a
Motiles	56.4a	28.4ab	32.6a	8.8bc	—	—	8.9c
3 August							
Eggs	39.8ab	31.0b	54.4ab	39.0ab	—	—	70.2a
Motiles	14.5a	5.5a	25.5a	15.7a	—	—	6.3a
8 August							
Eggs	10.8b	11.3b	27.8a	16.5ab	—	—	21.5a
Motiles	4.7ab	4.3a	14.5bc	15.5c	—	—	6.6abc
				1991			
Ovicide & residual larval test							
n	—	—	524	419	422	517	—
% Hatch	—	—	9.0a	3.7a	4.8a	4.8a	—
% Larval mortality	—	—	75.8a	95.0a	100.0a	100.0a	—
European red mite/leaf[b]							
9 July							
Immatures	—	—	62.1a	120.7a	135.2a	67.0a	—
Adults	—	—	25.7a	32.6a	43.2a	30.8a	—
15 July							
Immatures	—	—	13.2a	4.4ab	2.0ab	0.9b	
Adults	—	—	6.2a	2.4ab	1.8ab	0.3b	—
22 July							
Immatures	—	—	15.8a	4.1a	1.1a	1.1a	—
Adults	—	—	14.9a	16.9a	16.1a	14.6a	—
30 July							
Immatures	—	—	7.1a	8.2a	3.9a	3.9a	—
Adults	—	—	7.1a	6.1a	2.9a	1.8a	—
23 August							
Immatures	—	—	0.6a	0.3a	0.5a	0.6a	—
Adults	—	—	0.3a	0.1a	0.2a	0.1a	—

Treatment means followed by the same letter are not significantly different (1990 ovicide test: df = 5, 6; 1 d: $F = 1.07$; $P = 0.4603$; 2 d: $F = 1.26$; $P = 0.3889$; 4 d: $F = 0.65$; $P = 0.6739$; 5 d, $F = 1.09$; $P = 0.4518$; 6 d: $F = 0.97$; $P = 0.5034$; 8 d: $F = 1.10$; $P = 0.4457$; 12–14 d: $F = 1.13$; $P = 0.4348$; 1990 mites/leaf: df = 6, 8; 19 June: eggs, $F = 1.75$; $P = 0.2274$; motiles, $F = 2.79$; $P = 0.0909$; 28 June: eggs, $F = 2.37$; $P = 0.1288$; motiles, $F = 8.03$; $P = 0.0048$; 2 July: eggs, $F = 1.40$; $P = 0.3218$; motiles, $F = 7.84$; $P = 0.0052$; 24 July: eggs, $F = 2.75$; $P = 0.0932$; motiles, $F = 8.08$; $P = 0.0048$; 3 August: eggs, $F = 3.21$; $P = 0.0652$; motiles, $F = 0.88$; $P = 0.5513$; 8 August: eggs, $F = 3.39$; $P = 0.0575$; motiles, $F = 2.37$; $P = 0.1291$; 1991 mites/leaf: df = 6, 9; 9 July: immatures, $F = 0.69$; $P = 0.6667$; adults, $F = 0.47$; $P = 0.8132$; 15 July: immatures, $F = 1.78$; $P = 0.2095$; adults, $F = 1.47$; $P = 0.2879$; 22 July: immatures, $F = 0.91$; $P = 0.5285$; adults, $F = 0.27$; $P = 0.9374$; 30 July: immatures, $F = 0.38$; $P = 0.8764$; adults, $F = 0.73$; $P = 0.6376$; 23 August: immatures, $F = 1.20$; $P = 0.3864$; adults, $F = 0.34$; $P = 0.9002$; least significant difference test [SAS Institute 1985]). Counts were transformed before analysis using $\log_{10}(x + 0.5)$.

[a] Treatment dates, 1990: oil, 21 June and 9 July; dicofol: 21 and 29 June; 1991; oil, 12 July.

[b] Average number of eggs, motile forms (adults + immatures), immatures, or adults per leaf.

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