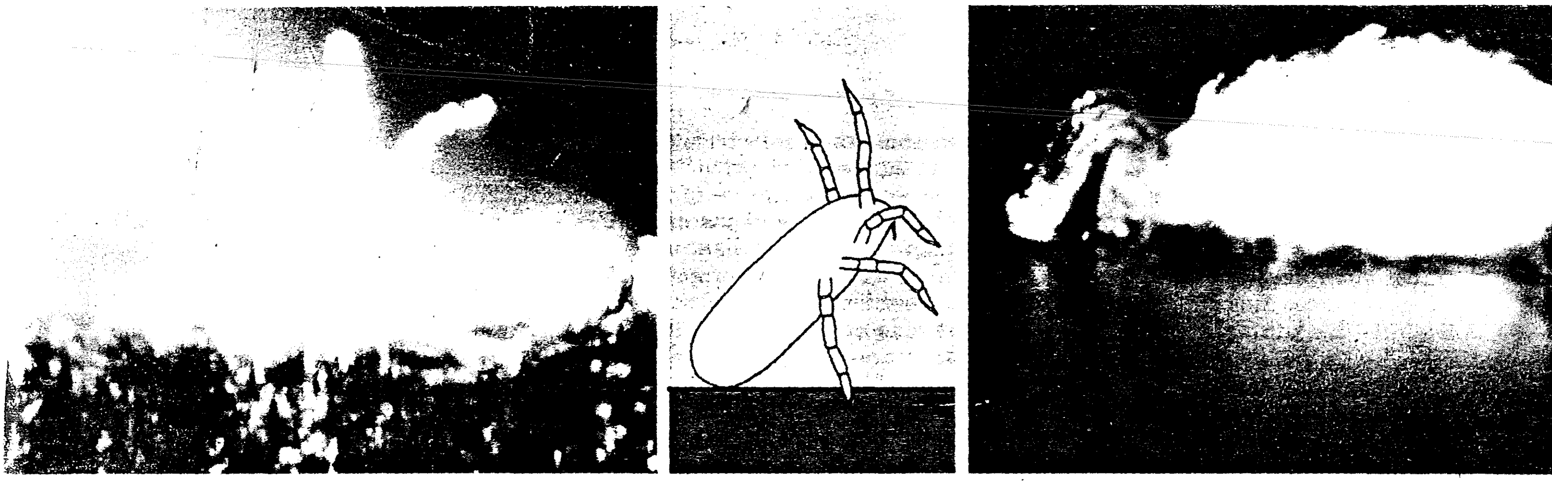

Hungry adult female spider mite predator prepares for dispersal by standing on its rear legs and raising its first two pairs of legs (see drawing), enabling it to be carried from tree to tree by low to moderate winds. Well-fed females lower their bodies to the leaf surface (right), so they cannot be picked up by breezes. The dispersal trait permits growers to inoculate almond orchards by placing predator mites in one tree in nine.

Aerial movements of mites in almonds: implications for pest management

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Spider mites and predatory mites can live all year on deciduous trees and vines. During the growing season they colonize the foliage, and during winter they overwinter under bark and in crevices in a state of dormancy (diapause). Spider mites and predatory mites can move from plant to plant by walking or they can be accidentally transferred by other organisms. Spider mites are also known to disperse aerially, and clusters of spider mite females can sometimes be seen on the tips of branches before their dispersal. Some spider mite species drop from leaves on thin silk strands and are picked up by the wind.

The predatory mite *Metaseiulus occidentalis* (Nesbitt) can move from leaf to leaf and from branch to branch by walking. Because this mite is so tiny, the distances it travels are relatively small. Yet releasing pesticide-resistant strains of *M. occidentalis* into individual almond trees (one tree in nine) successfully inoculated entire orchards. Walking, alone, did not seem sufficient to account for the relatively rapid spread of this wingless predator.

Hungry predator females have an explicit dispersal behavior in the laboratory. They stand on their rear legs with their first two pairs of legs off the substrate in low to moderate winds. In contrast, well-fed females lower their bodies to the substrate and cease moving; such females are not picked up by wind speeds of about 5 feet per second.

Seasonal dispersal patterns

In a series of experiments in two Livingston, California, almond orchards during 1982 and 1983, we sought to learn how aerial dispersal might influence a pest management program in almonds that focuses on inoculative releases of pesticide-resistant predators.

During 1982, clear plexiglass panels (about 3 by 6.5 inches) were greased on one side and placed vertically on towers outside two orchards. The towers were on all four sides of the two orchards, and panels were installed about 6, 12, and 18 feet above ground level on each tower, with two panels at each height directed toward the orchard and two directed away from it. The 12 panels of each tower were replaced every week or two weeks and, with the aid of a dissecting microscope, spider mites and predators were counted. Panels were continuously present from May 5 until September 1 outside the Livingston-I orchard and from May 26 until August 11 outside the second orchard, Livingston-III. Foliage counts were also taken to estimate spider mite and predator densities in each.

Peak dispersal of spider mites occurred in late July to early August in Livingston-I and in mid- to late July in Livingston-III. Peak dispersal of predators occurred in early August in Livingston-I and in mid-July in Livingston-III. Few predators dispersed immediately before those dates. Adult females constituted more than 90 percent of the spider mites and predators on the greased panels. This result suggests that (1) females are the primary dispersants and (2) a single, mated female is capable of initiating a new colony.

Most mites moved out of the orchards via prevailing winds from the northwest. About 92 percent of the spider mites and 94 percent of the predators leaving Livingston-I during the season were trapped on panels *facing* the orchard on its south and east sides. Likewise, 96 percent of the spider mites and 82 percent of the predators leaving Livingston-III were trapped on the south and east towers on panels facing the orchard. We found no consistent differences in numbers of mites trapped at the three heights.

Movements within the orchard

A total of 96 panels were hung during 1982 in each orchard, four each at two heights — about 15 and 8 feet above the ground — between tree rows at six sites in each orchard. The greased surfaces at each height were oriented north, south, east, or west to determine whether mite movements within the orchard were random. Panels were replaced each week or every two weeks.

Consistent differences in numbers of spider mites or predators trapped on panels at either height facing the four directions did not occur, although significant differences were sometimes found. The results suggest that prevailing winds from the northwest sometimes influence mite movements within the orchard but that wind turbulence within the orchard usually results in relatively random movement of spider mites and predators throughout the orchard.

Movement in and out of orchards

More predators left the two orchards than entered them. The total number of *M. occidentalis* trapped on six panels facing *away* from the south side of Livingston-I during the entire 1982 season was 22; two were trapped on panels facing west, none on panels facing north, and three on panels facing east. These 27 predators were presumed to be entering the orchard, although some could have been leaving but were trapped by eddying winds. In contrast, 103, 5, 6 and 84 predators were trapped over the season on panels facing *toward* the orchard south, west, north and east, respectively, and these 198 predators presumably represent the proportion leaving. No significant differences in catches at the three heights were found.

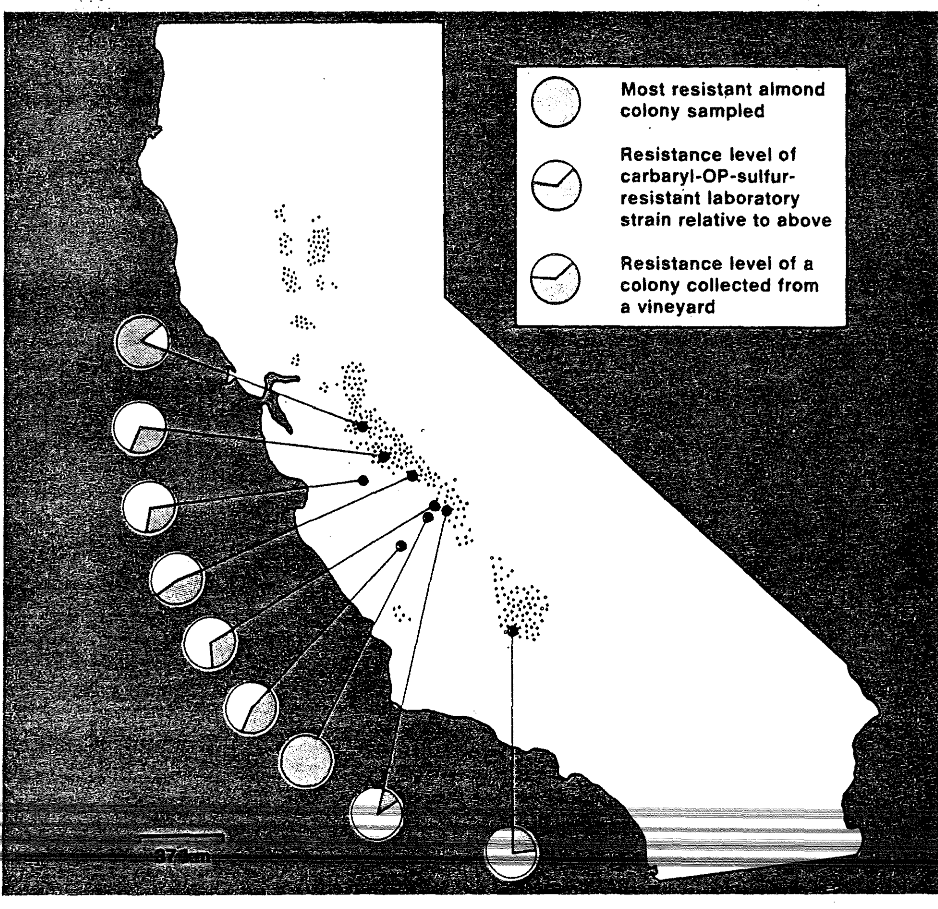
Our findings suggest that relatively few pesticide-susceptible *M. occidentalis* entered Livingston-I during 1982. Similar results were obtained for Livingston-III.

If we conservatively assume that each almond tree has half a million leaves and that on each leaf there is an average 0.1 predator, we can conclude that there are at least 50,000 predators per tree. Each acre contains 70 trees, or a minimum of 3.5 million predators. Very large numbers of susceptible predators would have to enter the orchard over the season to have an effect on the Sevin-resistance level in the orchard population, and a Sevin application during the season would select against the immigrants into the orchard.

To estimate the number of spider mites leaving each side of the orchard, we assumed that the numbers trapped on the panels were directly proportional to the number leaving the air space on the entire side of the orchard. If these assumptions are correct, then at least 170 million spider mite females left the south side of and 30 million left the east side of the 14-acre Livingston-I orchard. Likewise, 230 and 1,100 million spider mite females left the south and east sides, respectively, of the 45-acre Livingston-III orchard during 1982.

Making the same assumptions, we estimated that 8.1 and 8.3 million *M. occidentalis* females left the south and east sides of Livingston-I during 1982, while 40 and 97 million predators left the larger Livingston-III orchard.

These large numbers may or may not have an impact on recipient orchards or vineyards. Mortality during dispersal is likely to be high, and only a few may successfully colonize a new site. Furthermore, it is likely that 200 million, or even 1,100 million spider mites represent only a small proportion of the spider mites in most orchards. If we conservatively assume that there is one spider mite on each leaf over a season, and each almond tree has about half a million leaves, then an almond orchard with 70 trees per acre may conservatively have 35 million spider mites per acre over a season. Arrival of additional spider mites may go unnoticed unless the orchard lacks predators or has low densities of spider mites because of acaricide applications.



Guthion resistance levels in nine native populations of *M. occidentalis* from almond orchards. The fully shaded circle indicates the highest LC_{50} value (10.3 lb. a.i./100 gal. water). The partially shaded circles indicate proportionally lower LC_{50} values. Resistance levels of a Guthion-resistant laboratory colony and a vineyard-collected colony are shown for comparison. Each dot represents 100 acres of almonds.

Daily dispersal patterns

Greased Perspex plastic panels measuring 2 by 4-feet were placed on two towers on the south side of Livingston-I during the weeks of July 18 through July 25 and July 25 through August 1, 1983, to learn the predators' daily dispersal patterns. Panels were replaced every 2 hours for 24 hours during the first week and every 4 hours for 48 hours during the second week. The plastic was cut in strips and the mites were counted with a dissecting miscroscope. Weather data (temperature, relative humidity, wind speed, and wind direction) were recorded each time the panels were replaced.

Neither spider mites (*Panonychus ulmi* and *Tetranychus pacificus*) nor *M. occidentalis* dispersed uniformly throughout the day. More than 80 percent of the dispersal occurred between 4:00 and 10:00 p.m. During this time, temperatures declined from the daily peak, wind speeds increased from a low of 200 feet per minute to 1,000 feet per minute, and relative humidity increased from 30 to 46 percent.

Survey for Sevin resistance in surrounding orchards

Fifteen almond orchards surrounding Livingston-I and III, where Sevin-OP-resistant predators were released in 1981 and 1982, were surveyed to determine whether Sevin-resistant predators had successfully colonized them. Colonies were collected between July 19 and July 26, 1983, and 40 to 50 adult females from each colony were tested with 2.4 grams active ingredient carbaryl (Sevin) per liter distilled water. Seven-OP-resistant and Sevin-susceptible laboratory colonies were tested at the same time as the controls. Native *M. occidentalis* typically exhibit 0 to 4 percent survival rates at this dosage, as do susceptible laboratory colonies. The Sevin-resistant colony typically has a 70 to 85 percent survival rate.

Four of the 15 colonies exhibited measurable levels of Sevin resistance. Eleven colonies did not survive the test dose and are assumed to be susceptible to Sevin. Colonies with 6, 6, 14, and 34 percent survival rates were located south and east of the release sites, as expected if aerial dispersal is primarily via prevailing winds from the northwest. These four orchards are about 0.5 mile from the nearest release site. In other tests, both spider mites and predators were trapped in large numbers at least 640 feet southeast of Livingston-I in 1983, and 70 percent of the hungry adult females survived for at least 12 hours at 86°F under 30 percent relative humidity.

Guthion resistance in native predators

Native *M. occidentalis* were collected from nine almond orchards from 1980 through 1982. Colonies were tested in fall 1982 with Guthion (azinphos-methyl), using a slide dip technique. Doses tested were 0.5, 1, 2, 4, 8, and 16 pounds active ingredient per 100 gallons distilled water. At least 100 females were tested at each dose, and females were scored after 48 hours at 78°F under an 18-hour daylength. LC_{50} values were calculated using a logit analysis. Colonies were obtained from Modesto in Stanislaus County; Wasco in Kern County; North Avenue, Caruthers, Los Banos, Raisin City, and Three Rocks in Fresno County; Livingston in Merced County; and Road 20 in Madera County. A colony collected from a Fresno County vineyard in June 1980 and the Sevin-OP-sulfur-resistant laboratory colony were compared at the same time.

Variability in Guthion LC_{50} values is high in native predators from these almond orchards (see map). The lowest (1.2 pounds active ingredient per 100 gallons water) and the highest (10.3 pounds) LC_{50} values are from orchards located near each other in the central part of the valley. LC_{50} values from the other orchards range from 2 to 4 pounds active ingredient per 100 gallons of water. These values probably reflect differing pesticide treatment histories for the orchards, although treatment histories were not obtained. Because growers typically apply Guthion at rates of 1.5 to 2 pounds 50 wettable powder (WP) per acre, these resistance levels are surprisingly high.

Conclusions

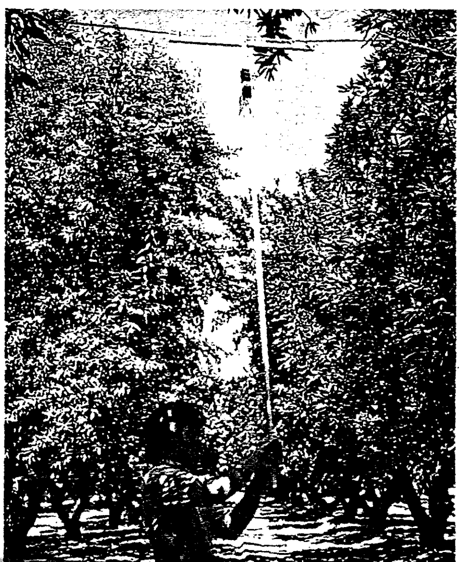
Peak aerial dispersal of spider mites and predators occurred in July and early August of 1982 and 1983. Most predators and spider mites left the Livingston almond orchards on prevailing winds from the northwest. Within the orchard, prevailing winds had less influence, and dispersal was usually random. Dispersal is not random during the day, but appears to occur in late afternoon and early evening.

The Sevin-resistant predators collected from four almond orchards 0.5 mile from sites where Sevin-OP-resistant predators were released in 1981 and 1982 document the aerial movement and establishment of the Sevin-resistant strain. However, growers wishing to use the Sevin-OP-resistant strain of *M. occidentalis* in their orchards should release it, as dispersal is too slow, and the numbers dispersing are too low relative to the densities of native predators that are often already present, to provide a useful inoculation level.

Few predators were trapped on the panels facing away from the orchards, suggesting that relatively few predators entered compared with the numbers resident in the orchard. This suggests that dilution of the Sevin-resistant populations is minimal, particularly if Sevin is used once every few years. Similar conclusions were reached after comparison of Sevin-resistance levels in six to eight other release sites.

OP-resistance levels in native *M. occidentalis* are sufficiently high that growers should be able to use low-to-moderate rates of Guthion, Diazinon, or Imidan (phosmet) without disrupting their predator populations. The variable OP-resistance levels, however, indicate that the San Joaquin Valley does not contain a single interbreeding population of *M. occidentalis*.

In orchards where abundant native predators are well distributed, growers may be able to adopt the mite management program. This involves monitoring spider mites and predators and use of lower-than-label rates of selective acaricides, if predator populations have successfully survived previous Guthion, Diazinon, or Imidan applications.



Greased panels inside Livingston almond orchard are checked by former research assistant Darryl Castro to determine if spider mites and predators disperse aerially between rows of trees.

Sevin cannot be used with native populations in the central and southern San Joaquin Valley, because they are very susceptible to it.

Aerial movements of spider mites and predator mites provide a mechanism for between-tree, between-row, and longer range movements within and out of almond orchards. Recognizing that such movements occur is important for pest management programs. Orchard "hot spots" can serve as the infestation foci for the entire orchard, justifying spot treatments of spider mites, particularly when predator densities are low. Large-scale aerial movements of spider mites could also explain the rapid buildup of infestations in almond orchard treetops occasionally seen in July and August when densities during the preceding two weeks were exceptionally low. While rapid population increases can be due to the very high reproductive rates of spider mites in the hot, dry San Joaquin Valley climate, they may be due in some cases to immigration of large numbers of spider mites into the orchard from surrounding crops with outbreak populations.

Aerial movements are hazardous to both spider mites and predators, and probably relatively few are able to colonize successfully a new site a long distance away. A colonizing predator must find prey upon its arrival; it must survive hot, dry conditions during the journey; it must not be subjected to pesticides it cannot tolerate; and it must compete successfully with any native predators in the recipient orchard. If Sevin is not applied in the newly colonized orchard, the Sevin resistance gene cannot increase in frequency. Therefore, rapid natural spread and increase of the Sevin-resistant predator strain is unlikely unless Sevin is applied to recipient orchards. It is unknown whether these predators (or spider mites) can disperse very long distances (hundreds of miles) in a single dispersal. It will be interesting to learn if isolated populations of the Sevin-resistant predators are detected such distances from release sites.

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