ability in infiltration rate measurements.

The results of trial 3 clearly demonstrate the benefits of surface-applied gypsum in promoting cumulative infiltration and in maintaining high infiltration rates. The cumulative 24-hour infiltration resulting from surface-applied phosphogypsum was more than three times the amount in trial 1, where the phosphogypsum was cultivated into the soil. The final 24-hour rate for the surface application was nearly 10 times the rate in trial 1 (table 2). It appears that cultivation in trial 1 either dispersed the gypsum throughout the top 4 to 6 inches of soil, thereby diluting its effectiveness, or removed it entirely from the soil surface.

The effect of trenching in trial 3 was less apparent because of the lateral movement of water in the untrenched plots.

Management implications

The Wyman soil in this orchard has poor aggregate stability, as measured by the percentage of stable aggregates remaining after dunking in water (table 3). The low stability is a reflection of low organic carbon, high sand, and low clay contents. In addition, the low but significant exchangeable sodium percentage, when combined with the low salt content (saturation extract electrical conductivity = 0.55 decisiemen per meter) is conducive to clay dispersion and aggregate breakdown.

This study shows that phosphogypsum at 5 tons per acre improves water penetration. Phosphogypsum adds salts to the soil solution as irrigation water enters the soil, thereby promoting aggregate stability. However, it is effective only if it remains on the soil surface before irrigation. At this time, we do not now how long the treatment will remain effective, but we do know that gypsum is ineffective when disked into the soil.

Traffic compacts the subsoil and crushes the few surface aggregates. Deep tillage is required to break up established compaction pans and significantly improves water penetration, but this treatment is short-lived if there is continual traffic over the soil. Reduced traffic after deep tillage may be beneficial.

We have not determined whether the phosphogypsum application or deep tilalge are economical, or if the improvement in water infiltration results in better tree health, vigor, yield, or crop quality.

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Managing spider mites in almonds with pesticide-resistant predators

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During the past three years, we have investigated the use of pesticide-resistant strains of a spider mite predator released into almond orchards as components of an integrated management program. This predatory mite, *Metaseiulus occidentalis* (Nesbitt) provides effective biological control of the Pacific and two-spotted spider mites, *Tetranychus pacificus* McGregor and *T. urticae* Koch, respectively, as well as the European red mite, *Panonychus ulmi* (Koch).

Some insecticides used to control the navel orangeworm, *Amyelois transitella* (Walker) and the peach twig borer, *Anarsia lineatella* Zell., however, can disrupt this biological control. Sevin (carbaryl) and Pounce or Ambush (permethrin) can induce serious spider mite outbreaks, in part because they kill native strains of *M. occidentalis* and other predators of spider mites.

Almonds at hull split, near harvest time. Pesticide-resistant predators help control spider mites in California almond orchards.

Conventional rates of pesticides that are specific for spider mites, such as Omite (propargite), Plictran (cyhexatin), or Vendex (hexakis), can also disrupt biological control by the predatory mite. If most of the spider mites are killed, these obligate predators will starve or disperse out of the orchard because of the lack of food.

We genetically selected *M. occidentalis* in the laboratory for resistance to the insecticides Sevin and Pounce/Ambush, then developed strains resistant to several pesticides through laboratory crosses and selection. One strain is resistant to Sevin and organophosphorus (OP) insecticides such as Guthion (azinphosmethyl), Diazinon, and Imidan (phosmet), and another is resistant to OP, Sevin, and sulfure pesticides. These resistant strains were evaluated in the laboratory, greenhouse, and small field plots for their ability to become established, control spider mites, overwinter, and survive pesticide applications. The Sevin-OP and Sevin-OP-sulfur resistant strains performed well in these small trials, so large scale releases were made.

During the 1981, 1982, and 1983 field seasons, we inoculated commercial almond orchards with the Sevin-OP- and Sevin-OP-sulfur-resistant predators. To do so, we reared large numbers of predators, using a greenhouse of a soybean field plot method (see *California Agriculture*, January-February 1982). Low rates of the selective acaricides Omite or Plictran were evaluated for possible use in adjusting the spider mite:predator ratio, thereby helping the predator

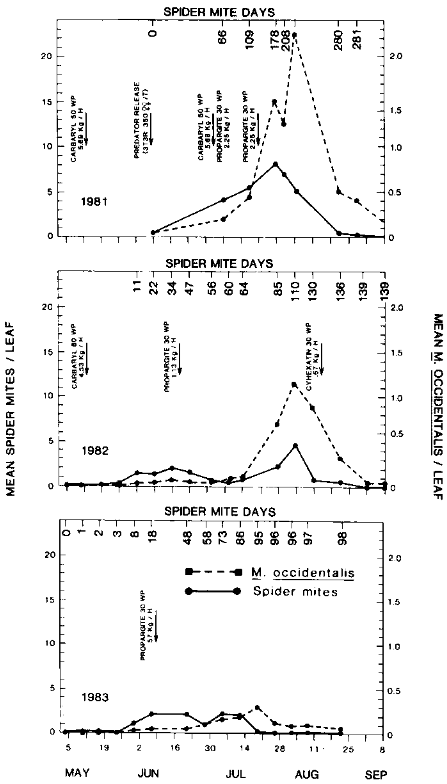

Fig. 1 Sevin-OP-resistant predators gave limited spider mite control during first season in Livingston orchard but overwintered successfully. By 1983, they provided good control with help of selective acaricides. Foliage damage, as estimated by spider-mite-days, was reduced.

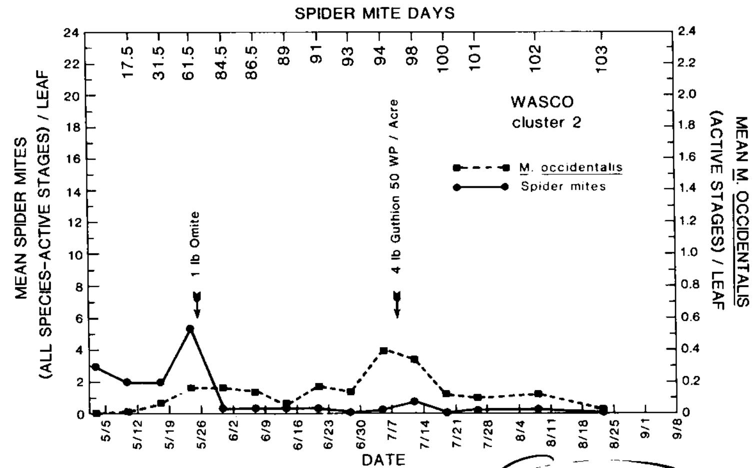

Fig. 2 In a section of the Wasco almond orchard, accumulated spider-mite-days in 1983 were well below the damage threshold (130). No miticides were needed after the May Omite application.

mites to maintain a low density of spider mites and prevent excessive damage to foliage.

Each year we monitored six to eight commercial almond orchards from Livingston to Bakersfield. Foliage samples were collected, chilled, and brushed with a mite-brushing machine. Active stages of spider mites and *M. occidentalis* were counted with a dissecting microscope to obtain estimates of mean mites per leaf, predator:spider mite ratios, and spider-mite-days.

A spider-mite-day is one spider mite feeding for one day, and provides an estimate of foliage damage. We found that if more than 130 to 140 spider-mite-days accumulate during the season in an almond orchard, some defoliation is likely. If fewer than 130 spider-mite-days accumulate, almond foliage appears green and defoliation does not occur in well-irrigated orchards.

Following is a summary of a portion of our results on use of low rates of selective acaricides when resistant predators are present and on the efficacy and persistence of resistant predators at release sites.

Livingston orchard

About 350 Sevin-OP-resistant predator females were released into every third tree in every third row (one tree in nine) in June 1981 after Sevin was applied in May to control peach twig borer and navel orangeworm. Sevin reduced the native *M. occidentalis* population, and the released strain was able to replace the native predators in the 14-acre Livingston orchard. Sevin was applied again at hullsplit for navel orangeworm, and helped to ensure that the predators in the orchard were resistant to Sevin (fig 1).

During the first season, the predators provided limited control of the spider mites, and Omite (2 pounds 30 WP per acre) was applied in early and late July to assist them. Because the predator releases were inoculative, complete control of spider mites was not expected. About 281 spider mite days accumulated during 1981 in this orchard, (fig. 1) and a small amount of defoliation occurred in dusty portions of the orchard along a dirt road.

The Sevin-OP-resistant predators successfully overwintered and survived a May 1982 application of Sevin. During 1982, 139 spider-mite-days accumulated over the season, and no defoliation occurred. A lower-than-label rate of Omite (1 pound 30 WP per acre) applied in June to assist the predators allowed them to suppress the spider mites until August. At that time, a low rate of Plictran (0.5 pound 50 WP per acre) was applied to prevent additional foliage damage after the orchard was dried up for harvest (fig. 1).

The Sevin-OP-resistant predators overwintered successfully during 1982-83 and provided excellent control of the spider mites during 1983. A very low rate of Omite (0.5 pound 30 WP per acre) was applied in June to adjust the predator:spider mite ratio, but no other acaricides were required (fig. 1).

During 1981 and 1982, Pacific and two-spotted spider mites predominated in this orchard. During 1983, European red mite predominated, and the fact that *M. occidentalis* was able to control this spider mite is noteworthy.

Wasco orchard

Sevin-OP-resistant *M. occidentalis* were released into a 15-acre almond orchard near Wasco in 1981. The predators became established, overwintered, and controlled spider mites in an orchard previously known for its serious spider mite problems. Establishment was successful even though this orchard was sprayed during 1981 with the pyrethroid permethrin, which is highly toxic to this predator strain. The orchard also was sprayed with an acaricide at full label rates in 1981. The resulting lack of prey for several weeks should have disrupted the establishment and presistence of *M. occidentalis*. By 1983, however, the predators were numerous and well distributed in the orchard.

In a representative section of the orchard, only 103 spider-mite-days accumulated during 1983 (fig. 2), well below our threshold of 130 spider-mite-days. Omite (1 pound 30 WP per acre) was applied in May, because the predator:spider mite ratio and feeding damage (61 spider-mite-days) indicated the predators needed help in providing rapid control. Guthion was applied at hullsplit, but no acaricide applications were required during the rest of the season. In 1893, European red mite was the major spider mite in the orchard, yet *M. occidentalis* controlled this pest satisfactorily. Unless excessive amounts of acaricides are applied in the future, or an insecticide is applied to which this predator strain is susceptible (such as Ambush/Pounce), the predators are likely to continue providing biological control of spider mites in this block. The orchard should be monitored so that selective acaricides can be applied, if necessary, to keep spider-mite-days be-

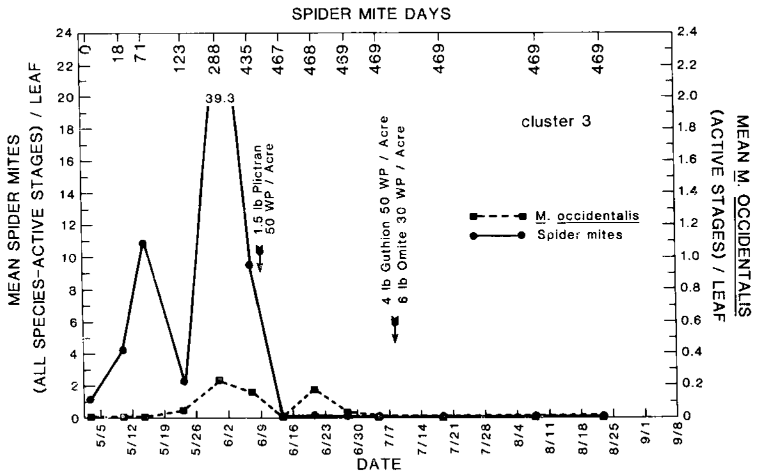

Fig. 3 In Three Rocks almond orchard, under conventional spider mite control, unassisted predators could not prevent European red mite damage, and defoliation occurred.

low 130.

Similar results were obtained during 1983 in four other almond orchards, where low rates of selective acaricides (1 pound 30 WP Omite or 0.5 to 0.75 pound 50 WP Plictran per acre) were applied in June to adjust the predator-:spider mite ratio.

The predator:spider mite interactions in the Livingston and Wasco orchards contrast with those in another orchard, where acaricides were applied in a conventional manner (fig. 3). The comparison shows the value of assisting the predators early in the season before too many spider-mite-days accumulate.

Three Rocks orchard

Sevin-OP-resistant *M. occidentalis* had been released in the 80-acre Three Rocks orchard during 1981, and predators were present in low densities in May and June 1983. Despite the predators' presence, European red mites increased dramatically, and 288 spider-mite-days had accumulated in one section of the orchard by early June (fig. 3), leading to defoliation.

On May 12, the predator:spider mite ratio was very poor, although only 18 spider-mite-days had accumulated. This ratio would have led to an acaricide application, if our management guidelines had been used. In the Wasco orchard, where the same number (17.5) of spider-mite-days had accumulated by that same date, the low rate of Omite applied in May helped the predators sufficiently to prevent defoliation, and additional acaricide applications were unnecessary (fig. 2). In the Three Rocks orchard, over 400 spider-mite-days had accumulated by the time Plictran (1.5 pounds 50 WP per acre) was applied (three weeks late) in early June. The July Omite application was probably unnecessary and may even have been disruptive, becaue the predators didn't have sufficient prey to recover. As a result, an inadequate overwintering population of diapausing predators may mean that the spider mite:predator ratio is out of balance at the beginning of the 1984 season.

Predator persistence

Persistence of the Sevin-OP-resistant predator strain in the release sites has been good. This strain was released into a Bakersfield (Bidart) orchard in August 1979. Sevin was applied only once, in 1980, yet the colonies that we recovered from this orchard and tested in 1981, 1982, and 1983 had high levels of Sevin resistance. The most recent colony collected in the fall of 1983 exhibited 76 percent survival at the standard test dose (2.4 grams active ingredient carbaryl per 100 liters distilled water). This indicates a very high level of resistance after four years: the resistant laboratory colony commonly exhibits 75 to 85 percent survival under these conditions, whereas a susceptible colony typically has 0 to 5 percent survival. Clearly, large numbers of susceptible native *M. occidentalis* have not eliminated the resistant strain in the Bakersfield orchard, nor has natural selection against the Sevin resistance gene reduced its gene frequency.

A colony of *M. occidentalis* collected from the Wasco orchard was also tested in June 1983 with the standard dose of Sevin. It exhibited a 62 percent survival rate, indicating that a high level of Sevin resistance exists, even through only one Sevin application was made in this orchard (during 1982) after the 1981 release.

Conclusions

During the last three years, we have found that the laboratory-selected, pesticide-resistant strains of *M. occidentalis* can be mass-reared and released, and can control spider mites in commercial San Joaquin Valley almond orchards, particularly if they are assisted by selective acaricides at lower-than-label rates. These low rates should be applied early in the season (preferably in May or June) to adjust the predator:spider mite ratio and prevent excessive foliage damage.

To determine when an application is required, it is necessary to monitor the spider mites and predators. One monitoring method, which can be used after mid-June in orchards where Pacific or two-spotted spider mites predominate, is the presence-absence system, in which population estimates are based on the number of leaves on which mites are present. (See California Agriculture, May-June 1984, "Sampling *Tetranychus* spider mites in almonds.") Another method, suitable for use in May and June to monitor European red mites as well as Pacific and two-spotted spider mites, involves brushing active stages of spider mites and predators from foliage and counting them. The second system is more laborious than the presence-absence method or other visual observations in the orchard, and it requires a brushing machine and dissecting microscope, but it provides detailed information. This information (mean mtes per leaf, accumulated spider-mite-days, and predator:spider mite ratio) allows cost-effective management of spider mites in almonds based on a predictive model of spider mite-predator interaction. This model will be described in detail elsewhere.

Although spider mite management with predators and selective acaricides is not as simple as conventional chemical control, it offers mite control as good as, or better than, conventional chemical control and is less expensive. This program focuses on managing mites at low densities rather than attempting to eradicate them from almond orchards.

Our studies have shown that an indigenous biological control agent can be taken into the laboratory, genetically selected, and returned to commercial almond orchards as the primary component in a cost-effective integrated program for spider mite control. The program monitors, predicts spider mite and predator interactions, and uses carefully-timed applications of optimal rates of selective acaricides when the situation dictates.

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