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Variegated and Western Grape Leafhoppers

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Leafhoppers are major arthropod pests in raisin vineyards. They cause direct damage by feeding on grape leaves and indirect damage by being a nuisance to workers. Two leafhopper species are found: western grape leafhopper, *Erythroneura elegantula* Osborn, and variegated leafhopper, *Erythroneura variabilis* Beamer. While these leafhoppers are closely related, important biological differences between the two species result in different types of economic damage and the need for different control measures.

The western grape leafhopper has been a pest of California vineyards since the 1870s. Today it can be found throughout the Central Valley and the north and central coast regions. Before the variegated leafhopper moved into the Central Valley, the western grape leafhopper was the primary leafhopper pest. It usually reaches its highest densities early in the season (first or second generation) and declines thereafter (third generation). In most raisin vineyards it does not reach damaging population densities. Its low density is in part the result of the action of egg parasites (*Anagrus* species) that are very effective against this pest. Also, competitive displacement by the more successful variegated leafhopper has probably played a contributing role. Grape leafhopper populations still reach damaging levels in some regions of the foothills and along the west side of the Central Valley.

The variegated leafhopper was first described in 1922 from specimens collected in Arizona vineyards. In 1929 it was reported in southern California, and in the 1980s it became established in the San Joaquin Valley. At present, the variegated leafhopper can be found from the Coachella Valley to as far north as the Sacramento and north coast regions. In some years, variegated leafhopper populations can build to levels that cause defoliation and economic loss. High population densities occur in part because the egg parasites that are so effective against western grape leafhoppers are less effective against the variegated leafhopper. The result can be greater economic damage to the crop because variegated leafhoppers cause more feeding damage than western grape leafhoppers. Control programs for this species begin with careful monitoring and include combinations of biological, cultural, and chemical controls.

DESCRIPTION AND BIOLOGY

Adult leafhoppers are about $\frac{1}{8}$ inch (3 mm) long. The western grape leafhopper adult has a white back that is overlaid with red, brown and black markings (Plate 23.1). The color and intensity of the markings change during the adult's lifetime; they are poorly distinguished on newly molted adults but very distinctive on overwintering adults. The adult variegated leafhopper has a full mixture of brown, red, and white markings (Plate 23.2), which gives it a much darker appearance than the lighter-colored western grape leafhopper. The variegated leafhopper also has very distinctive colors during the winter and poorly distinguished colors just after a molt, when it appears to be almost white for 2 to 3 days.

Adult leafhoppers deposit eggs into grape leaf tissue. The eggs are tiny (0.03 inch [0.8 mm]) and can only be viewed through a hand lens or microscope. Live eggs are colorless to milky white. The egg shapes and placement differ for the two species. Western grape leafhopper eggs are kidney-bean–shaped. The female adults deposit them under a thin layer of leaf epidermal cells in the interveinal regions of both the upper and lower leaf surfaces. The eggs bulge upward so that they appear to lie on the leaf surface. Variegated leafhopper eggs are thinner and more cigar-shaped than western grape leafhopper eggs. They are laid under several layers of leaf epidermal cells, usually parallel to or within a leaf vein. Because they are buried deeper in the leaf, variegated leafhopper eggs are harder to see and are easily mistaken for parts of a leaf vein.

Western grape leafhopper and variegated leafhop-

per nymphs have five development stages. The first instar emerges through a slit it makes at one end of the egg. First instars of both species are pale white and about $\frac{1}{32}$ inch (0.8 mm) long (Plate 23.3). For this reason newly emerged western grape leafhopper nymphs are hard to distinguish from variegated leafhopper nymphs. As the nymphs develop, changes in their color and shape make it easier to distinguish one species from the other (Plate 23.4 western grape leafhopper, Plate 23.5 variegated leafhopper). Second through fifth instar western grape leafhoppers are pale white like the first instar. Each successive instar is larger, with wingpads visible in the fourth and fifth instars (although the nymphs cannot fly). The fifth instar is about $\frac{1}{10}$ inch (2.5 mm) long, almost as large as the adult. In contrast, second through fifth instars of the variegated leafhopper are darker than the first instar. The second and third instars are light yellow with a faint orange stripe on each side. The fourth and fifth instars are a reddish-brown throughout with wingpads clearly visible. The fifth instar variegated leafhopper is $\frac{1}{10}$ inch (2.5 mm) long, and unlike the grape leafhopper its abdomen curves slightly upward.

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SEASONAL DEVELOPMENT

Leafhoppers overwinter as adults. This is a key factor in their biological control and, ultimately, their pest status. In cold or wet weather, overwintering adults seek shelter in protected habitats such as in ditch banks or under vine bark or dead leaves. They do not hibernate, and can be active as long as temperatures are above 50.5°F (10.3°C). While adults cannot feed on the dormant vines, they do feed on many types of green vegetation (e.g., weeds and citrus) during this period. The adult leafhoppers overwinter inside the vineyard or outside its borders, wherever they can find a protected habitat and green vegetation. Because the adults are relatively good fliers and can migrate into the vineyard, the removal of ground vegetation inside the vineyard will not necessarily eliminate leafhoppers the following spring.

Overwintering adults move onto vines shortly after bud break (late February to March in the San Joaquin Valley; late January to February in the Coachella Valley and Arizona). The reproductive organs of these overwintered adults are not fully developed. In spring, changes in photoperiod (the ratio of day hours to night hours) and temperature induce adult females to break this reproductive diapause. The maturation process is completed only after the female has fed on grape leaves. For this reason, leafhopper phenology is closely tied to vine development.

When grapevines break bud and develop shoots, adult leafhoppers move between the vines and the protective ground cover or duff on the vineyard floor. In most years, egg laying (*oviposition*) begins when shoots have about three leaves, typically in mid-March in the Coachella Valley and Arizona and mid-April in the San Joaquin Valley. Oviposition can continue for many weeks (mid-April to mid-May in the San Joaquin Valley), but because leafhoppers lay eggs only on fully developed leaves, most eggs are concentrated on the first six basal leaves. The oviposition schedules of the two leafhopper species differ slightly: western grape leafhopper adults oviposit earlier and their immatures develop more quickly than those of the variegated leafhopper, resulting in peak nymph counts that are 7 to 10 days ahead of the variegated leafhopper.

The development rate of eggs, nymphs, and adults is driven primarily by temperature. For this reason, leafhoppers have three to four generations per season in the central and southern San Joaquin Valley and five to seven in the Coachella Valley and Arizona. Eggs from overwintering adults represent the beginning of the new year's first leafhopper generation. The time from oviposition to egg hatch is about 20 days for the first generation and 10 to 14 days for summer generations. Development of nymphs from the first to fifth instar takes about 3 weeks in the spring and about 2 weeks in the summer. After molting to the adult stage, leafhoppers feed for a few days before mating and laying eggs for the next generation. The development time can be described more accurately in terms of accumulated heat units or degree-days (DD). Turnover for each western grape leafhopper generation averages 1,500 DD over 50.5°F. Development of variegated leafhopper is a bit slower, requiring about 1,528 DD. Because the leafhoppers' growth is temperature dependent, their development and their number of generations will vary not only by region but by vineyard management practices that affect temperatures (e.g., cover cropping and trellis systems). Also, leafhopper generations become less discrete as the season progresses, and by the end of the summer there are simultaneous overlapping generations with all leafhopper stages present.

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DAMAGE

Leafhoppers cause direct and indirect economic damage to raisin vineyards. Direct damage occurs when feeding nymphs and adults puncture individual leaf cells with their needle-like mouthparts and suck out the contents. Destroyed leaf cells become visible as tiny white spots. Continued leafhopper feeding results in the accumulation of many destroyed cells, which turn the leaf white and then brown. The damaged leaf has a reduced photosynthetic capacity (Figure 23.1)

and eventually will senesce and fall off. The extent of feeding damage to the vine varies depending on leafhopper population density, vineyard condition, and the location of the damaged leaves (i.e., whether they are shaded or exposed to sunlight).

To relate pest density to economic loss, researchers have developed a measurement they call the *economic injury level* (EIL), which is the number of pests per unit of measurement (e.g., a grape leaf) that will cause economic damage. Basically, the EIL is reached when the damage caused by a pest exceeds the cost of controlling the pest. The EIL can help growers and PCAs make control decisions. For example, most raisin vineyards can tolerate about a 20 percent loss of photosynthetically active leaf area without economic damage. A single nymph has the potential to damage 1 percent of the leaf area; therefore, the EIL for leafhoppers is an average count of about 20 nymphs per leaf. At that point a control action should be taken to prevent leaf loss in excess of 20 percent and economic damage. However, an EIL can be difficult to accurately assess. Although the type of feeding damage is similar, a variegated leafhopper can cause 50 percent more leaf damage than a western grape leafhopper, but there is no difference in the suggested EIL for these species. EILs are also likely to change among vineyards. For example, vigorously growing vines can withstand a greater leafhopper population density without suffering economic damage than can poorly growing vines.

Adult leafhoppers can also inflict indirect economic damage by being a nuisance to field crews. On vines with a heavy leafhopper infestation there can be more than 1,000,000 adult leafhoppers per acre. When disturbed, the adult leafhoppers scatter, flying into the eyes, ears, noses, and mouths of workers. This can lower worker productivity at harvest and may prompt harvest crews to leave more grape bunches on the vines.

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MONITORING

Proper monitoring is an essential component of an integrated pest management (IPM) program. A good sampling program can reduce insecticide costs by forecasting changes in pest densities, better enabling the farm manager to take actions only when necessary and still protect the crop. It can also provide important historical data for each vineyard by mapping problem blocks that need special attention. What makes a good monitoring program? Farm managers should work with a system that provides consistent and reliable results. The standard method used to sample western grape and variegated leafhoppers is the direct examination of leaves for nymphs, not egg or adult counts. Leaf
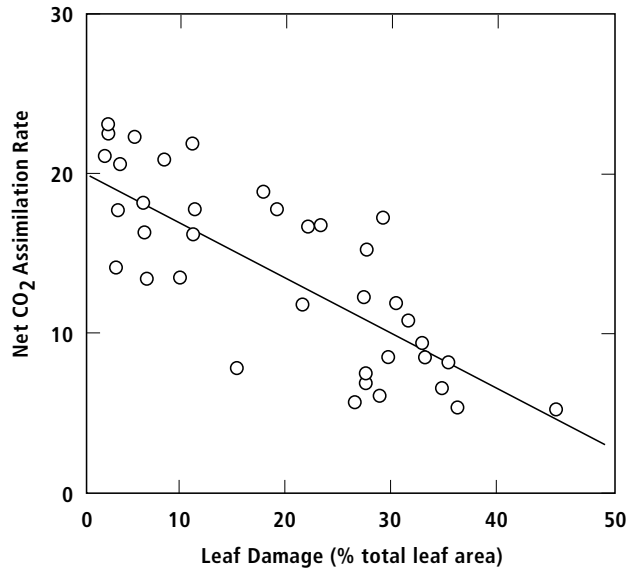

Figure 23.1 Leafhopper feeding kills leaf cells, measured here as a percentage of the total leaf area, and as a result decreases photosynthesis. Typically, one leafhopper causes a 1 percent reduction in leaf photosynthesis.

samples should be quantifiable so that decisions are not based on a subjective assessment of relative abundance (e.g., "high" leafhopper densities) but on an objectively based population estimate (e.g., 23 nymphs per leaf). Monitoring should be fast and have direct application to management decisions. Control decisions are based on the average number of nymphs per leaf or the accumulation of nymphal days. Nymph population density varies by location and time of the season, so you need to follow a number of guidelines that help to ensure an accurate sample.

First, take samples throughout the vineyard block, selecting five or more locations, each spaced at least five vine rows from the others. Avoid the end vines, sampling at least 10 to 20 vines down the row. Select a few leaves at each location so that at least 20 to 40 leaves are counted for each block. This sampling design was developed based on blocks of 10 to 40 acres.

Second, sample leaves from the appropriate location on the vine. Overwintering adults deposit their eggs on the mature basal leaves and the emerging nymphs generally do not move far. For this reason, the cane may have more than 20 leaves but still have the first-generation nymphs concentrated on the six basal leaves. For the second, third, and subsequent generations, samples taken at mid-shoot distances (nodes four to eight) give the most accurate counts. (Note that the variegated leafhopper can oviposit on older leaves and, for this reason, basal leaves can still have high variegated leafhopper counts late in the season.)

Third, select leaves that represent average pest den-

sity and help to forecast damaging pest numbers. A biased selection of leaves will give a false average and can lead to inappropriate control actions and added control costs. Therefore, select leaves at random. On each selected leaf, count nymphs on both the upper and lower surfaces (note that the nymphs will run crab-like across the leaf, often moving from one side to the other during the count). On a score card, keep numbers of variegated and western grape leafhoppers separate. Control decisions are based on a combined count of both species; however, because western grape leafhopper counts may get lower as the season progresses, high counts in the first brood often do not provide an accurate forecast of third-brood densities. Also, be careful not to count the cast-off leafhopper skins as live leafhopper nymphs when monitoring population levels. Leafhoppers molt between each developmental stage and, when they molt from the fifth instar to the adult, the cast-off skin remains on the leaf and looks like a leafhopper nymph: white to almost translucent for the western grape leafhopper and gray-brown for the variegated leafhopper. Note that at low leafhopper densities you must sample more leaves to get an accurate count. If random counts seem especially low, select leaves that show signs of leafhopper damage to indicate the potential or worst-case leafhopper population density. Similarly, in vineyards where leafhopper densities are uneven throughout the block, you have to sample many different areas to get an accurate assessment. Map out these problem areas and make sure they are included in the sample.

Fourth, take samples frequently, every week or at least once every two weeks. The most common economic injury levels are based on average peak nymph population densities, which typically occur in late May to early June (first generation) and mid- to late July (second generation) in the San Joaquin Valley. The timing of these peak leafhopper densities will vary from year to year, so it is best to sample weekly during the second and third leafhopper generations, when control decisions typically are made. Reliance solely on peak nymph counts may not give you an accurate estimate of leafhopper damage. Peak counts base the control decision on only one sample and can miss these population changes. Leafhopper adults are long-lived and have an egg laying period that can spread over many weeks. If eggs hatch in a relatively short time, there can be a very high peak nymph density preceded and followed by periods of lower nymph densities. If eggs hatch over an extended period, there may be a lower peak nymph density but far more damage throughout the season.

Fifth, determine the need to treat based on an average nymph count. Treatment decisions should be based on this average and not on the highest number of nymphs found. To find the average number of nymphs per leaf, add the number of nymphs from each sample and divide by the number of leaves sampled. Because western grape leafhopper densities typically decline as the season progresses, high counts in the first generation are not a good indication that the vineyard may need treatment. In most vineyards the treatment decision should be based on variegated leafhopper nymph counts in the second brood or nymph counts and adult populations in the third brood.

You can use weekly counts of leafhopper nymphs to follow the course of population abundance over the season. You can also use them to calculate *nymphal-days,* which provide an estimation of the accumulated nymph density and feeding damage (see Table 23.1). To calculate nymphal-days, record the average nymphs per leaf for each weekly count. Because nymphal-days are cumulative, calculate the average nymphal-days for the current and previous sample dates. Determine the number of days in each sample period and then calculate nymphal-days by multiplying the average number of nymphs per day per period times the number of days in that period. Table 23.1 shows hypothetical nymph counts and the calculation of nymphal-days. There are economic injury levels based on nymphal-days for variegated leafhopper (for more information, see *Grape Pest Management* in References); however, nymphal-days are not commonly used for making treatment decisions.

Biological Controls

Natural enemies of leafhoppers are present in all vineyards. There are, however, critical differences in the abundance and effectiveness among natural enemy species. Vineyard location, cultural practices, soil characteristics, and climate are just a few of the factors that can influence natural enemies. For this reason, the extent of pest regulation can vary considerably among vineyards and seasons. The most important leafhopper natural enemies are parasitoids, although the more visible leafhopper natural enemies are predators.

Parasitoids. Tiny (0.02 inch [0.4 mm]) wasps that parasitize leafhopper eggs kill the greatest number of leafhoppers (Plate 23.6). The wasps are in the genus *Anagrus* (insect family Mymaridae). An adult female *Anagrus* can detect leafhopper eggs embedded inside the leaf. Using her ovipositor, the *Anagrus* can lay an egg into a leafhopper egg. There, the parasitoid completes its entire development, turning a part of the leafhopper egg red and ultimately turning the entire egg a golden brown as the parasitoid nears the adult stage. The adult wasp exits the leafhopper egg by chewing a round hole through the egg and leaf tissue. This round

Table 23.1 Calculations of nymphal-days for variegated leafhoppers in two vineyards*

Sample date	Average nymphs per leaf	Average nymphs per sample period	Period length (*days*)	Nymphal-days	Cumulative nymphal-days
Moderate peak leafhopper counts					
June 23	0	0	—	0	0
June 30	3.6	(3.6 + 0) ÷ 2 = 1.8	7	1.8 × 7 = 12.6	12.6
July 7	7.6	(7.6 + 3.6) ÷ 2 = 5.6	7	5.6 × 7 = 39.2	51.8
July 14	10.8	(10.8 + 7.6) ÷ 2 = 9.2	7	9.2 × 7 = 64.4	116.2
July 21	13.2	(13.2 + 10.8) ÷ 2 = 12.0	7	12.0 × 7 = 84.0	200.2
July 28	15.6	(15.6 + 13.2) ÷ 2 = 14.4	7	14.4 × 7 = 100.8	301.0
August 4	12.4	(12.4 + 15.6) ÷ 2 = 14.0	7	14.0 × 7 = 98.0	399.0
Single high peak leafhopper count					
June 23	0	0	—	0	0
June 30	3.0	(3.0 + 0) ÷ 2 = 1.5	7	1.5 × 7 = 10.5	10.5
July 7	4.4	(4.4 + 3.0 ÷ 2 = 5.6	7	5.6 × 7 = 39.2	49.7
July 14	9.6	(9.6 + 4.4) ÷ 2 = 7.0	7	7.0 × 7 = 49.0	98.7
July 21	24.2	(24.2 + 9.6) ÷ 2 = 16.9	7	16.9 × 7 = 118.3	217.0
July 28	10.6	(24.2 × 10.6) ÷ 2 = 17.4	7	17.4 × 7 = 121.8	338.8
August 4	2.8	(10.6 × 2.8) ÷ 2 = 6.7	7	6.7 × 7 = 46.9	385.7

*These calculations of nymphal days from the average variegated leafhopper nymph counts on leaves collected during the second leafhopper generation in two different vineyards show first a leafhopper population with steady, moderate peak nymph counts, and second, a leafhopper population with a single high peak nymph count, both leading to similar cumulative nymphal-days.

exit hole is easily distinguished from the slit left by an emerging leafhopper nymph (Plates 23.7 and 23.8).

Unlike predators, which consume many prey over their lifetime, *Anagrus* develop to the adult stage within a single egg. These parasites are effective at reducing western grape leafhopper numbers because each female can oviposit into many leafhopper eggs. Also, because there can be as many as three *Anagrus* generations for each leafhopper generation, the *Anagrus* population will increase in response to increasing leafhopper numbers. They also kill the leafhopper in the egg stage, before the nymph or adult leafhopper can cause damage. Adult *Anagrus* can barely be seen without the aid of a hand lens; however, these parasitoids are found in all vineyards, and by the end of the season they outnumber all other leafhopper natural enemies.

In many raisin vineyards, the action of *Anagrus* alone can control the western grape leafhopper, often parasitizing more than 90 percent of grape leafhopper eggs in the second and third generations (there are some regional differences). In contrast, their parasitism levels on variegated leafhoppers are rarely more than 20 percent in the second generation or 40 percent in the third generation. One reason for this difference is the location of leafhopper eggs in the leaf. Western grape leafhopper eggs are closer to the leaf surface and more exposed to *Anagrus*. In contrast, variegated leafhopper eggs are placed within or close to leaf veins and deeper in the leaf tissue, and are more difficult for *Anagrus* to find. The lowered effectiveness of *Anagrus* on variegated leafhopper eggs is one reason this leafhopper species reaches damaging population densities.

Anagrus overwinter as larvae inside leafhopper eggs. Because the western grape and variegated leafhoppers overwinter as adults, *Anagrus* species must find alternate leafhopper host species that overwinter in the egg stage. Research conducted in the 1960s demonstrated that *Anagrus* species (at that time referred to as *Anagrus epos*) overwintered in the eggs of the blackberry leafhopper (*Dikrella californica* [Lawson]). In the 1980s, researchers found that other leafhopper species also served as overwintering hosts for *Anagrus;* most notably the prune leafhopper (*Edwardsiana prunicola* [Edwards]). Because there were apparent differences in the *Anagrus* collected on grapes, blackberries, and prunes, a renewed effort was made to understand *Anagrus* species taxonomy and overwintering leafhopper host associations. Currently, we know that leafhoppers on blackberry, prune, rose (rose leafhopper, *Edwardsiana rosae* [L.]), almond, and apple (white apple leafhopper, *Typhlocyba pomaria* [McAtee]) can serve as hosts for some of the *Anagrus* species that attack the western grape and variegated leafhoppers. Undoubtedly, there are still other overwintering hosts, although these host relationships have not yet been identified.

Recent work has also clarified parasite taxonomy, indicating that there are at least two *Anagrus* species that attack grape and variegated leafhoppers in California. These parasitoids were formerly clumped under a single name: *Anagrus epos* Girault. They are, in fact, part of a complex of closely related species. The new names are *Anagrus erythroneurae* S. Triapitsyn & Chiappini and *Anagrus daanei* S. Triapitsyn. More important

than changes in nomenclature is a better understanding of biological differences. For example, *Anagrus erythroneurae* thrives in hot summer temperatures, which may be one reason it is the most common parasitoid collected in Central Valley vineyards. *Anagrus daanei* is more common in the cooler regions and accounts for less than 10 percent of the *Anagrus* parasitoids collected on grapevines. Both species can overwinter in blackberry or prune leafhopper eggs. In the 1970s, blackberries were planted around vineyards as a refuge for overwintering *Anagrus*. In the 1990s, a similar refuge system has been attempted with prune trees, which are being planted at the edges of vineyards and even interplanted with grapevines. Observations indicate that these plantings have not consistently increased the percentage egg parasitism of variegated leafhoppers. We believe the primary reason for the failure of these refuges is their small size relative to the vineyard. A small refuge of blackberry bushes or prune trees will produce a correspondingly small number of blackberry or prune leafhoppers. During the summer and early fall, there can be millions of *Anagrus* in each vineyard block. This onslaught of parasitoids, mostly *Anagrus erythroneurae,* will overwhelm the relatively small numbers leafhoppers in blackberry or prune refuges. The result will be a very high percentage of parasitism on blackberry or prune leafhoppers, severely reducing or eliminating those leafhopper populations and thereby reducing the number of overwintering *Anagrus.*

Another parasitic wasp, the dryinid *Aphelopus albopictus* Ashmead, attacks western grape leafhopper but rarely attacks variegated leafhopper. The adult wasp places an egg in the abdomen of third, fourth, or fifth instar leafhoppers. Once the leafhopper reaches the adult stage, the parasitoid egg hatches and grows within in a sack that protrudes from the leafhopper's abdomen. When the parasitoid reaches the pupal stage, it detaches from the leafhopper, falls to the ground and pupates in the soil. Parasitized leafhoppers are infertile. This parasitoid can be an important natural enemy of the western grape leafhopper: one study showed parasitism averaging between 10 and 40 percent. Again, *Aphelopus albopictus* only attacks the western grape leafhopper, economically the less important of the two leafhopper pests in raisin vineyards.

Predators. Spiders are the most abundant leafhopper predators. In San Joaquin Valley vineyards, more than 50 spider species have been collected, but the vast majority of the spider community comprises fewer than 10 species. Spiders can be grouped by their predatory habits. Large nocturnal hunters such as the agrarian sac spider (*Cheiracanthium inclusum*) and an antmimic spider (*Trachelas pacificus*) are commonly found in grape bunches in summer and under bark in fall and winter (Plate 23.9). Medium-sized, day-active hunters such as jumping spiders (*Metaphidippus vitis* and *Metaphidippus johnsoni*) and the lynx spider (*Oxyopes scalaris*) (Plate 23.10) find their prey by sight and can jump many times their body length to pounce on and capture leafhoppers. There are many "sit-and-wait" webbuilding spiders. These include small but very common cobweb weavers (*Theridion dilutum* and *Theridion melanurum*) and a dwarf spider (*Erigone dentosa*). These spiders construct small, irregular webs, typically on the underside of leaves and within the bunches. The most obvious sit-and-wait webbuilders are a funnel weaver (*Hololena nedra*), which constructs a large, funnel-shaped web on the upper side of the leaf, and an orb weaver (*Neoscona oaxacensis*). *Neoscona* is the largest spider commonly found (full grown body size approximately ¾ inch [2 cm]). In the spring, *Neoscona* spiderlings (approximately ⅛ inch [3 mm]) spin webs on the grape foliage or trellis wire, but as they mature they string webs between grapevine rows.

In laboratory studies, the number of leafhoppers killed varied among tested spider species. *Trachelas* and the agrarian sac spider each ate an average of 12 leafhoppers a day, the lynx spider consumed 1 to 2 leafhoppers a day, and one of the jumping spiders would not feed on leafhoppers. In field studies, exclusion experiments (removing spiders from the vines) have shown that the spider community as a whole reduces leafhopper numbers. Nevertheless, there is little hard evidence that spiders can control leafhopper populations or that they are a driving force in leafhopper population changes.

The tiger fly (*Coenosia humilis*) is a predator that catches its prey in the air. The fly is common in raisin vineyards and has been observed feeding on adult leafhoppers. As a larva, the tiger fly lives as a maggot in the soil where it feeds on earthworms. To date, no studies have been conducted to determine its impact on leafhopper numbers.

Green lacewing larvae make up the next most common predator group (Plate 23.11). In San Joaquin Valley vineyards, researchers found five different lacewing species: *Chrysoperla carnea* (Stephens), *Chrysoperla comanche* Banks, *Chrysopa oculata* Say, *Chrysopa nigricornis* Burmeister, and *Chrysopa coloradensis* Banks. When cover crops were present, the most common adult collected was *C. oculata,* which was typically found on cover crops and weeds but rarely found on the vines. The most common lacewing species on the vines were *C. comanche* and *C. carnea,* although numbers of these predators were low (fewer than 1 larva per 1,000 leaves). Because lacewings can be voracious leafhopper predators, with each larva consuming an average of 252 large leafhopper nymphs in laboratory studies (Figure 23.2), some growers have released insectary-

reared green lacewings. In field studies, releases of *C. carnea* eggs significantly reduced leafhopper densities in only 9 of 20 trials. Furthermore, the average reduction of leafhoppers in *C. carnea*-release plots was only 9.6 percent below no-release plots. One reason for the low percentage of leafhopper reduction was the commercial release process, which led to high mortality of lacewing eggs and poor dispersal of eggs. Researchers are currently working on improved release methods.

The whirligig mite (*Anystis agilis*) is a relatively large (about ¹⁄₂₅ inch [1.0 mm]) red predatory mite that feeds on most soft-bodied insects, including early instars of grape and variegated leafhoppers. Its common name is descriptive of its rapid, sometimes circular movement on the leaf. However, it is not found in high numbers in raisin vineyards, and its slow population increase (only 2 to 3 generations per year) reduces its ability to respond quickly to increases in leafhopper abundance.

Other predators found in California vineyards include the convergent ladybird beetle, big-eyed bugs (*Geocoris* spp.), and nabid bugs (*Nabis americoferis*). There is little information on the importance of these predators for leafhopper control; however, because they are usually found at very low densities, it is unlikely that they play a significant role.

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CULTURAL CONTROLS

Leafhoppers prefer vigorously growing vines; cultural practices (e.g., fertilization) or other factors (e.g., vine age or soil condition) that affect vine vigor may also change leafhopper densities. As an example, one practice that can affect vine vigor is the amount of water applied (Figure 23.3). Experiments have shown that excess irrigation can result in greater nymph survival and size, greater numbers of adults, and more eggs deposited per adult.

Cover crops are popularly associated with the attraction of beneficial insects and the reduction of pest densities. However, with the exception of DOV systems, it is unusual for raisin growers to maintain continuous ground covers because of the need to work up and terrace the middles for harvest. Experiments in which cover crops were maintained throughout the growing season typically show no reduction in first- or second-generation leafhopper nymph abundance and a reduction of about 15 to 20 percent in late-season abundance. In most instances this level of reduction was too small to be economically important. Further, the mechanism leading to this reduction remains unclear. The addition of cover crops did not consistently lead to higher predator numbers on grapevines or parasitism by *Anagrus* species. Therefore, changes
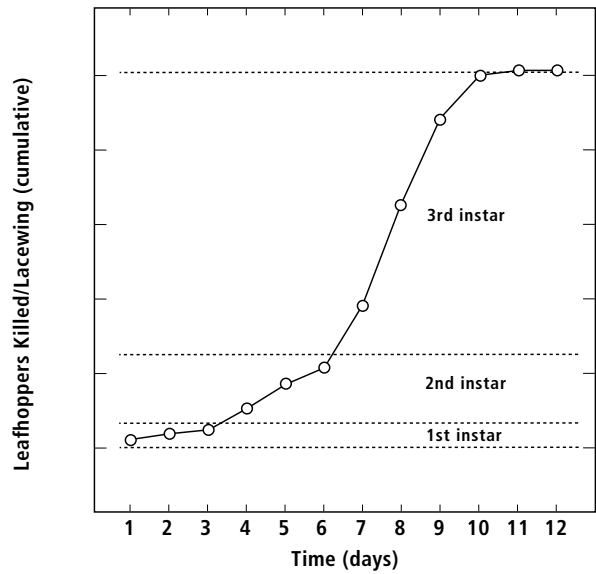

Figure 23.2 Average number of fourth or fifth instar leafhoppers killed by the comanche green lacewing (*Chrysoperla comanche*), under laboratory conditions, during the lacewing's larval development
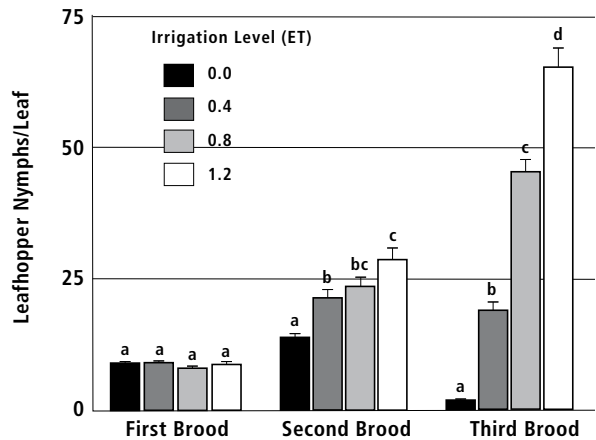

Figure 23.3 Peak nymph density in the first, second, and third leafhopper generations in a lysimeter block where different amounts of irrigation water can be applied. Irrigation treatments represent fractions of water applied to vines growing in the lysimeter; the decrease in leafhopper numbers in the third generation in treatments with deficit irrigation (ET = 0.0 and 0.4) corresponds to a decline in vine vigor in those treatments. Within each leafhopper generation in this figure, treatment means separated by different letters are significantly different (Tukey's Multiple Comparison Test, $P<0.05$).

in leafhopper densities are most likely due to a combination of effects, most importantly a competition by the cover crop with the vines for water and nutrients—resulting in lowered vine vigor.

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CHEMICAL CONTROLS

Chemical control remains the most common technique for decreasing leafhopper abundance. The goals of IPM include increasing the efficiency of insecticides. This includes reducing the number of insecticide sprays and using less-toxic and more specific insecticides. To maximize insecticide effectiveness and long-term usefulness, work with your pest control advisor and farm advisor to determine the best program for your vineyard. Remember that insecticide products and their effectiveness can change in just a few seasons, so keep abreast of changes in product use. To check on insecticides currently registered for raisin grape, look at the *UC IPM Pest Management Guidelines for Grape* (available on the Worldwide Web at http://www.ipm.ucdavis.edu). To improve the effectiveness of a registered material, we suggest the   following:

First, apply the insecticide against the appropriate leafhopper generation. It is not recommended that the overwintering generation (adults on new shoots just after bud break) be treated. This spray timing would not give natural enemies or cultural practices a chance to contribute to leafhopper control. Similarly, it is not recommended that the first-generation nymphs be treated, as they feed mainly on shaded leaves, doing little damage. Moreover, leafhopper densities in the first generation are not always an indication of subsequent population densities; on occasion, second or third generation populations will decline even in the absence of insecticide applications. The most common spray timings are in the second or third leafhopper generations. By waiting until these later generations, you can have

time to properly monitor leafhopper densities and determine appropriate control actions. Application in the third or later generations is often made not to control nymphs, but rather to reduce adult populations that are hampering worker productivity and harvest operations.

Second, when you decide that pesticide application is needed, time the application to the most appropriate leafhopper stage. Some insecticides kill by both contact and fumigation. Less-toxic materials such as soaps and oils kill by contact only. While there are some materials, such as imidacloprid, that are effective against adults, no insecticides are known to be effective against leafhopper eggs. Therefore, treatments should be applied when the greatest proportion of eggs in the targeted leafhopper generation have hatched, but before the nymphs molt to adulthood. A good indication that egg hatch is complete is the development of some of the nymphs to the fifth instar. For the less-toxic materials it is especially important that you target the leafhopper nymph and that you use enough material to ensure good coverage (e.g., 100 to 150 gallons per acre [936 to 1,404 L/ha] at full canopy). Insecticides whose mode of action is insect growth regulation should be applied earlier, when some of the nymphs have developed to the third instar. Insecticides used in the third and later generations often target the adults and later instars. These materials should have a short preharvest interval and should be "soft" on beneficials. Timing is less crucial and should be scheduled with harvest times in mind.

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