Many grape growers are managing floor vegetation, either in the form of sown cover crops or resident vegetation, as one component of their integrated pest management (IPM) program. In vineyards and other perennial agricultural systems, the use of cover crops is popularly associated with attracting beneficial insects and lowering pest densities (Hall 1992; Bugg et al. 1995; Hendricks 1995). Studies in apple (Leius 1967; Altieri and Schmidt 1985; Wyss, Niggli, and Nentwig 1995), almond (Heimpel and Rosenheim 1996), and pecan (Bugg and Dutcher 1989; Bugg, Dutcher, and McNeill 1991) orchards have shown an increase in overall natural enemy numbers after the addition of managed floor vegetation. However, diversification of the cropping system can increase or decrease beneficials as well as pests (Russell 1989), and sowing cover crops does not automatically lead to lower pest densities. In fact, in the above-mentioned studies, the increase in beneficial insects led to a significant decrease in pest populations in only two instances (Leius 1967; Wyss, Niggli, and Nentwig 1995).

The role of cover crops in vineyard IPM is not well understood, and the use of cover crops to help manage vineyard pests is a controversial practice. Similar to studies in orchards, studies in vineyards have not shown that the addition of ground covers consistently leads to lower pest densities (Zalom and Hanna 1992b; Zalom et al. 1993; Costello and Daane 1993, 1994, 1995a; Mayse et al. 1995). This is due, in part, to the wide variety of cover crops and cover crop management practices used, to differences in the arthropod community among vineyards, and to annual fluctuations in pest and natural enemy populations. This chapter summarizes the current knowledge of cover cropping on leafhopper, moth, mealybug, and mite pests and their natural enemies. It begins with a brief discussion of the theoretical benefits of plant diversification (i.e., management of cover crops or resident vegetation) and pest management. For those arthropods that have a well-known biology, the theoretical and practical aspects of ground covers for pest management are discussed.
Vineyard Natural Enemies

There has been a great deal of discussion on the benefits of plant diversity in pest management (see Root 1973; van Emden and Williams 1974; Murdoch 1975; Perrin 1980; Risch, Andow, and Altieri 1983; Russell 1989; Andow 1991). In theory, natural enemy populations increase in more diverse ecosystems because cover crops or other floor vegetation provide natural enemies with additional habitat, food, or both. Habitat enhancement is the increased availability of shelter because of a broader range of environmental conditions and oviposition and overwintering sites. The availability of alternate food is important during periods when the most common prey are not present (e.g., between generations or in the dormant season). Alternate food can be other prey species (e.g., aphids on the cover crop) or food for adult predators or parasitoids (e.g., pollen, nectar, or honeydew). There have been few attempts to document how these theories apply to grape pests and their natural enemies. Of those that have been conducted, most have focused on leafhoppers. This discussion begins with the potential changes cover crops can have on two major groups of natural enemies: predators and parasitoids.

Predators

Predators are typically larger than their prey; they require more than one prey individual during their development, whereas parasitoids develop on a single host. Predators commonly feed on prey as both larvae and adults. The convergent lady beetle (Hippodamia convergens) is an example of an insect that is predatory in both the larval and adult stages. The common green lacewing (Chrysoperla carnea) is a predator only in the larval stage; the adult feeds on pollen, nectar and honeydew. The predator community on the vines is dominated by various spider species; in our surveys, spiders comprised greater than 90 percent of the predators that fed on insects (Costello and Daane forthcoming). Other predators found include the whirligig mite (Anystis agilis), lacewings (Chrysopa spp. and Chrysoperla spp.), bigeyed bugs (Geocoris spp.), a nabid bug (Nabis americoferis), a tiger fly (Coenosia humilis), and the convergent lady beetle. Additionally, predators that feed on spider mites include predatory mites (Galendromus occidentalis, Metaseiulus mcgregor, Amlyseius californicus, and Euseius nr. hibisci), six-spotted thrips (Scolothrips sexmaculatus), minute pirate bugs (Orius spp.), and the spider mite destroyer (Stethorus picipes). For each of these species, alternate prey found in the cover crop can be important because these predators must feed on many prey throughout their lifetime to reach the adult stage and reproduce. Cover crops can help increase predator numbers by providing habitat and alternate food sources, and most insects and mites in the cover crop are potential prey. Still, for a cover crop to have a practical effect on predator activity, either the predator or the prey must move between the cover crop and the vines.

Most of these predators are generalists in their feeding behavior—they feed on a variety of prey species (e.g., leafhoppers, flies, moth larvae). Generalist predators are considered to be poor “trackers” of pest populations because they often do not have corresponding increases or decreases in their numbers that mirror changes in pest numbers. (In order for a natural enemy population to curtail a rapid increase in pest numbers, it must have a corresponding increase in the number of pests that are killed, which commonly occurs through an increase in the number of natural enemies.) However, generalist predators can be effective natural enemies if their numbers are high before the pest population increases in density. Under these circumstances, the generalist predator community might slow or prevent the initiation of a rapid rise in pest numbers.

To be economically important, any increase in predator numbers because of cover cropping must contribute to a decrease in pest density, and the effects of cover cropping should be relatively consistent. We believe that it is difficult to predict how a cover crop will affect the predator community on grapevines. For example, we found that 8 species commonly make up greater than 80 percent of the spider complex. Behavioral and ecological differences among these species (daily activity period, feeding behavior, habitat preference, etc.) dictate that cover cropping will not affect the spider community uniformly. In addition, the composition of the 8 dominant spider species can vary dramatically between vineyards. This variation is illustrated by differences in two nearby San Joaquin Valley vineyards. In a table grape vineyard, 3 species made up 67 percent of all spiders: an antmimic spider (Trachelas pacificus), the agrarian sac spider (Cheiracanthium inclusum), and a lynx spider (Oxyopes scalaris). In a nearby raisin vineyard, 75 percent of the spider community was comprised of 3 other species: cobweb weavers (Theridion dilutum and T. melanurum) and a funnel weaver (Hololena nedra).

Parasitoids
Most parasitoids of vineyard pests are small wasps (in the insect order Hymenoptera) or flies (in the insect order Diptera, family Tachinidae). Female parasitoids lay eggs near, on, or inside their hosts (i.e., the pest). Parasitoid larvae develop by feeding on their hosts, typically developing as white maggot-like larvae inside or attached to the outside of their hosts. Unlike predators, parasitoids develop from the egg to adult stage on a single host. Many hosts are killed when adult parasitoids lay eggs on new hosts or when they host-feed (i.e., when they puncture the host integument and feed on the exuding fluids). This type of biology enables the parasitoid to better track its host population, increasing or decreasing in numbers with the pest population and operating effectively at low or high pest densities.

Unlike generalist predators, most of the parasitoids found in vineyards are relatively specific in their selection of a host. For example, leafhopper parasitoids do not attack mealybugs, whereas most generalist predators can attack leafhoppers and mealybugs. Therefore, it is less likely that cover crops provide alternate hosts for specialized parasitoids, compared with generalist predators, because most insects feeding on the cover crop are not acceptable host species for the parasitoid. Cover crops can provide alternate food for adult parasitoids that feed on carbohydrate sources (e.g., sugars in plant nectar). Although parasitoid larvae develop in or on their hosts, many adult parasitoid species must feed on water and carbohydrates to mature their eggs and increase their longevity. Some plant species that have floral or extrafloral nectaries and can be used as cover crops or border plantings are common vetch, coeanothus, coyote bush, buckwheat, sweet alyssum, yarrow, carrot, coriander, fennel, parsley, toothpick ammi, dill, and caraway.

Vineyard Pests

Leafhoppers

Two leafhopper species can cause serious economic damage to grapevines: the western grape leafhopper (*Erythroneura elegantula*) (plate 8-1) and the variegated leafhopper (*E. variabilis*) (plate 8-2). While leafhoppers are a primary insect pest, their abundance and economic injury varies among vineyards, regions, and seasons (Wilson, Flaherty, and Peacock 1992; Wilson et al. 1992). Leafhopper feeding kills leaf cells, which decreases photosynthesis and can lead to defoliation. As leafhoppers feed they produce honeydew, which can encourage sooty mold growth, reducing the value of table grapes. Adult leafhoppers, flying at harvest, can be a hindrance to vineyard workers.

Growers and several teams of researchers have observed leafhopper densities below economic injury levels in vineyards with sown cover crops or resident vegetation. For this reason, it has become popular to grow cover crops for improved leafhopper control. Because of the severity of leafhopper damage and the observed association of cover crops with leafhopper suppression, more research has been conducted on the effects of cover crops on leafhoppers than any other vineyard pest. However, in experimental studies that had replicated cover crop and control (no cover crop) plots, the results have been inconsistent. For example, whereas some studies found that leafhopper densities were lower in cover-cropped vineyards (Roltisch et al. forthcoming), others have shown no effect (Mayse et al. 1995), and still others have found positive effects in some years and no effects in other years (Zalom and Hanna 1992b; Zalom et al. 1993; Costello and Daane 1993, 1994, 1995a; Daane, Yokota, and Costello 1996).

Our experiments were conducted over multiple years in four distinctively different San Joaquin Valley vineyards: juice grapes in Parlier (cv. Thompson Seedless); table grapes in Reedley (cv. Ruby Seedless); raisin grapes in Del Rey (cv. Thompson Seedless); and wine grapes in Woodbridge (cv. Cabernet Sauvignon). With the exception of the juice vineyard (a 4-acre research block at the UC Kearney Agricultural Center), the studies were conducted on 10- to 20-acre (4- to 8-ha) commercial blocks. At each site, blocks were divided into replicated sections with or without cover crops.

We did not find that cover crops lowered numbers of first-generation leafhopper nymphs in any of our trials, and at only one site (wine grapes) were they lower in the second generation. However, third generation nymphal densities were significantly lower in cover-cropped plots in all years at the juice and table grape sites (figs. 8-1A, 8-1B), although differences were never seen at the raisin site (fig. 8-1C). Third-generation nymphal densities were significantly lower in cover-cropped plots in 2 out of 3 years (1995 and 1996) at the wine site (fig. 8-1D). We suspect we would have seen the same effect in 1994 were it not for some early defoliation, in the no-cover treatment and a corresponding crash in nymph density there. In 1995 and 1996, there was no defoliation, and leafhopper nymph densities were significantly lower in the cover-cropped plots.
For all study sites and years combined, the average reduction of leafhopper densities was 15 percent, but in only one case did this reduce the population below the acceptable level of about 15 to 20 nymphs per leaf (fig. 8-1B, 1994). In other years, leafhopper densities were so low (e.g., fig. 8-1B, 1995) or so high (e.g., fig. 8-1B, 1993) that the addition of cover crops and the resultant reduction in leafhopper numbers did not make a practical change. In the raisin vineyard, where the cover crop was plowed down in July to prepare for harvest, there were no significant differences between the cover-cropped and no-cover plots (fig. 8-1C). Finally, cover crops did not act to dampen population fluctuations between years: the difference in leafhopper densities between cover-cropped and no-cover plots was often less than between-season differences in the same vineyard (fig. 8-1B, 8-1D).

An important question remains: what caused lowered leafhopper densities in cover crop plots? In our studies and others (e.g., Zalom and Hanna 1992b; Mayse et al. 1995; Hanna, Zalom, and Elmore 1996; Roltsch et al. forthcoming) the mechanisms through which leafhopper populations were lowered are not clear. Three possible explanations are discussed below: an increase in predator numbers, an increase in parasitoid numbers, or a change in the vine or vineyard condition that made it a poorer host for leafhoppers.

**Predators of leafhoppers.** The most common leafhopper predators are spiders, which exist in vineyards as a community of species (plate 8-3). Our exclusion studies and others (Zalom et al. 1993) show that spiders are important predators of leafhoppers. At 3 of the 4 study sites mentioned above, the addition of cover crops did not typically result in a significant increase in season-wide spider numbers on vines, as shown in figure 8-2 (data from only one year at each site are presented because there was little variation.

**Figure 8-1.** Mean third-generation leafhopper abundance (±SEM) in four different vineyards shows a trend of lowered leafhopper numbers in plots with ground covers as compared with plots without ground covers. In each grouping, means followed by different letters are significantly different (Tukey HSD test, $P < 0.05$). (A) juice grapes in Parlier, CA; (B) table grapes in Reedley, CA; (C) raisin grapes in Del Rey, CA; and (D) wine grapes in Woodbridge, CA.
The one exception was the raisin site, where overall spider density was 77 percent higher with a cover crop (fig. 8-2C).

Although cover crops rarely affected total spider numbers on the vines, in at least one study vineyard cover crops influenced the relative abundance of the spiders present (Costello and Daane 1998). Figure 8-3 shows that the abundance of Trachelas pacificus, the dominant spider at the table grape site, was 60 percent higher in August and September in plots with ground covers. Spider species composition is important in pest management, as each species impacts pest populations differently. For example, in laboratory studies, Trachelas ate about 12 leafhopper nymphs per day, cobweb weavers (Theridion spp.) ate only 1 to 2 nymphs per day, and a funnel weaver (Hololena nedra) fed only on leafhopper adults. Trachelas does not often comprise a high proportion of spiders found in vineyards; at the raisin site Trachelas abundance was low, and the cobweb and funnel weavers were the dominant spiders. The feeding behavior of the cobweb weavers and funnel weavers may lessen their impact as biological control agents of leafhoppers, as suggested by the lack of difference in leafhopper numbers between cover crops and clean cultivation at the raisin site. Cover crops never influenced the density of the agrarian sac spider, even where it was a dominant species (the wine grape and juice sites). Although increasing diversity with cover crops may favor predators such as Trachelas at certain sites, what makes Trachelas the dominant species at one site but cobweb and funnel weavers or the agrarian sac spider the dominant species at another site depends on more than the presence or absence of cover crops. Factors such as vine cultivar, soil type, regional climate, vineyard age, and management practices such as cover cropping and pesticide use all play a role in influencing predator species composition.

The abundance of other leafhopper predators at the four study sites was low, and the addition of cover crops rarely resulted in a meaningful increase in their numbers. One exception was the whirligig mite, a generalist predator that feeds on most small, soft-bodied insects, including early-instar leafhoppers. The whirligig mite has two generations each year, with peak densities in late spring and late summer. This mite will lay eggs on the ground or on grape foliage. Cover crops appear to serve as an additional habitat for whirligig mites in spring and between generations during midsummer. At one of our study sites, whirligig mite densities were significantly increased in plots with ground covers in one year (fig. 8-4A); however, in the second year of the study, whirligig mites were virtually absent (fig. 8-4B). Indeed, at all our other study sites, whirligig mite densities were quite low compared with other predators. For example, at the table grape site the average density of the whirligig mite was less than 0.1 mites per vine while the dominant spider, Trachelas, averaged 5.9 spiders per vine. Whirligig mites are more common in coastal vineyards, which may make its response to cover cropping more reliable there. However, we know of no formal studies that have attempted to test this.

Another generalist predator is a tiger fly (Coenosia humilis). This fly is quite common in San Joaquin Valley vineyards. The adult captures its prey on the wing and has been observed feeding on leafhopper adults. Immature Coenosia feed on earthworms in the soil. Therefore, Coenosia could be increased by the presence of cover crops if they
contribute to an increase in soil organic matter (and hence, earthworm numbers), but this has never been tested formally.

Lacewings are commonly found in vineyards. They can be good predators of leafhoppers under laboratory conditions (Daane et al. 1993) and have been augmented into vineyards to suppress leafhopper densities (Daane et al. 1996c). However, resident lacewing densities on the vines in vineyards with or without cover crops have not been observed to impact leafhopper numbers (see the discussion of moth pests, below).

Overall predator abundance in the four study vineyards (cover crops and vines combined) increased because many predators reside in the cover crop. Do these predators migrate to the vines? Our results suggests that there is little movement between cover crops and vines, and therefore the cover crops do not provide an important alternate habitat for vine-dwelling spiders. The great difference in spider species composition between the vine and the cover crops is shown for the table grape site (fig. 8-5). There, Trachelas comprised 47 percent of the spiders found on the vines but only 2 percent of all spiders collected in the ground covers. On the ground covers, 67 percent of the spiders collected belong to four species (Oxyopes salticus, O. scalaris, Pardosa ramulosa, and Erigone dentosa), but these same species comprised less than 15 percent of the spiders collected on the vines. It is more likely that the cover crop provides additional prey for predators residing in the vines, as there is constant movement of mobile prey (e.g., flies, midges, aphids, etc.) between the cover crop and the vines.

Parasitoids of leafhoppers. Anagrus spp., the most important leafhopper parasitoids, are tiny wasps (0.001 inches [0.25 mm] long) that parasitize leafhopper eggs (plate 8-4). Using her ovipositor (the analogous organ to the stinger of a bee), the female Anagrus lays an egg into the leafhopper egg. There, the parasitoid completes its entire egg, larval, and pupal development and does not emerge until it has reached the adult stage. We found no consistent dif-

Figure 8-3. Mean Trachelas pacificus density (±SEM) on vines in plots with and without ground cover in the months of August and September for sampling years 1993–95. During these months, T. pacificus density was higher in the ground-cover treatment than the no-cover treatment during these months ($P = 0.017$).

Figure 8-4. Whirligig mite abundance (±SEM) on vines in plots with and without ground cover in a wine block show that mid- and late-season abundance was higher on vines in plots with ground covers in 1993, but few whirligig mites were found in either treatment in 1994.
ferences in the percentage of egg parasitism between cover-cropped and clean-cultivated plots. This runs counter to the theory that cover crops can provide alternative food sources for natural enemies, which in this case is nectar for parasitoids. Although *Anagrus* can use a carbohydrate source for increased adult longevity, small droplets of honeydew are produced by leafhoppers and cover the grape leaves. These honeydew droplets probably provide the needed carbohydrates for adult *Anagrus*, reducing the parasitoids’ need to look for a supplemental food source in the cover crop. On occasion, we found that the percentage of eggs parasitized was greater in cover-cropped plots; however, this difference cannot be easily explained by any single factor, such as an increase in *Anagrus* numbers. This is illustrated by data from the wine grape study site, where there was no difference in the number of parasitized eggs between cover-cropped and no-cover plots (fig. 8-6A), but the total number of leafhopper eggs was lower on vines in cover-cropped plots (fig. 8-6B). Because adult *Anagrus* had fewer eggs to parasitize in the cover-cropped plots, the same number of *Anagrus* (assuming equal fecundity and searching abilities) could result in the higher percentage of parasitism observed in the cover-cropped plots (fig. 8-6C).

Western grape leafhopper nymphs are also attacked by the parasitoid *Aphelopus albopictis*. The egg laid by the female wasp in the leafhopper nymph hatches once the leafhopper molts to the adult stage, and the *Aphelopus* larva develops within the leafhopper adult. As the parasitoid develops, it feeds on the leafhopper and eventually destroys its reproductive capabilities. Eventually the parasitoid emerges from the leafhopper and drops to the ground to pupate. Therefore, *Aphelopus* might be better conserved by no-till practices that do not destroy the pupae in the soil. Unfortunately, there are no studies that attempt to correlate *Aphelopus* abundance and cover crops. Further, *Aphelopus* does not attack the variegated leafhopper, the more important of the two leafhopper pests in the San Joaquin Valley, Southern California, and Arizona.

Vine condition and leafhopper abundance. The
effects that cover crops have on the water or nutrient status of the vines or on the vineyard environment may influence leafhopper populations. Because some cover crops can compete with grapevines for water and nutrients, they can reduce vine vigor (see chapters 4 and 7), which may, in turn, affect leafhopper abundance. At 3 of the 4 vineyards studied (table, wine, and juice), permanent ground covers lowered vine vigor as indicated by a decline in petiole nitrate levels, pruning weights, or berry weights as compared with clean cultivated plots (Daane, Yokota, and Costello 1996; Costello and Daane 1997a). At these sites there was a reduction in leafhoppers in all but one year (fig. 8-1A, 8-1B, 8-1D). At the raisin site, cover crops were tilled under by midseason, and there was no measurable vine stress. At this site there were no differences in leafhopper numbers between cover and no cover, although leafhopper densities were relatively low overall (fig. 8-1C).

Our results suggest that lower leafhopper numbers on vines with cover crops can largely be a result of reduction in vine vigor. Leafhoppers prefer vigorously growing vines (Wilson, Flaherty, and Peacock 1992; Wilson et al. 1992); overwatered and overfertilized vineyards produce excess leaf growth, which is not good for fruit quality, yield, or leafhopper control. The relationship between irrigation levels and leafhopper numbers was shown experimentally in a lysimeter study at the UC Kearney Agricultural Center. Results showed that excess amounts of irrigation water did not increase yields and resulted in significantly higher leafhopper nymph and adult densities, larger leafhopper size, and more leafhopper eggs (Daane et al. 1995a, 1995b). Similarly, Mayse, Roltsch, and Roy (1991) found that increased levels of leaf nitrate corresponded with higher leafhopper nymph densities. Manipulating vine condition for leafhopper control may be a double-edged sword. Whereas vigorously growing vines tend to have more leafhoppers, they can withstand higher leafhopper densities with less economic damage; conversely, while poorly growing vines tend to have fewer leafhoppers, low leafhopper densities can cause greater economic damage on poorly growing vines.

Cover crops and overwintering leafhoppers. Variegated and western grape leafhoppers overwinter as adults; they do not feed on dormant vines, but must feed on some vegetation during warm periods to keep from desiccating. During these periods, leafhoppers can be found on many types of succulent vegetation, including cover crops. Removing floor vegetation from the vineyard has been suggested as one method to reduce overwintering populations, but there have been no formal studies to investigate the effectiveness of such practices. It should be noted that leafhopper adults can migrate into the vineyard from up to 1 mile (1.6 km) away, so removing vegetation does not ensure a low first-generation leafhopper population. Also, the predators abundant in cover crops in spring may help to reduce the migrating adult leafhopper populations.

Summary. In our studies, cover crops that were maintained throughout the season usually resulted in a statistically significant reduction in late-season leafhopper nymph abundance. However, in most instances the level of reduction was not economically important. Spiders are the most common group of leafhopper predators, and exclusion experiments have shown that natural populations of spiders do help reduce leafhopper abundance. Nevertheless, our studies did not show a consistent increase in spider abundance or a change in spider species composition in cover-cropped vineyards. Also, there was no evidence that cover cropping over several years increased spider abundance on the vines early in the season. There was an increase in predator numbers in the vineyard (vines and cover crop); however, results suggest little predator movement between the vines and the cover crop. Leafhopper adults and alternate prey may move between the two habitats, although there have been no formal studies on this. Similarly, we found no relationship between percentage of parasitism by leafhopper egg parasitoids (Anagr us spp.) and cover cropping management practices. Ground covers that are managed for the duration of a season can compete with the vines for water and nutrients and, under some circumstances, the resulting reductions in vine vigor will lower leafhopper numbers. Cover crops may be used as one component of a leafhopper pest management program, but they should not be relied on as the primary control mechanism. Careful monitoring, cultural controls, and conservation of natural enemies by using “soft” pesticides remain the most consistent management techniques.

Moth Pests

Many moth species can be economically important in grape vineyards. The most important are omnivorous leafroller (OLR, Platynota stultana) (plate 8-5), orange tortrix (OT, Argyrotaenia citrana), grape leaffolder (GLF, Desmia funeralis), western grape-leaf skeletonizer (WGLS, Harrisinia brillians), and cutworms (CW, Peridroma saucia and Orthodes rufula). OLR and OT larvae feed on leaves, devel-
Opposing flowers, and grape clusters. These two pests reduce grape quality in two ways: by directly feeding on flowers and developing berries and by providing an entry site for bunch rotting pathogens. GLF attacks the leaves, rolling them into a tight tube and feeding inside its created habitat. WGLS also feeds on leaves; the smaller larval stages feed on the underside of the leaf, leaving only the veins and upper cuticle intact. The larger larval stages skeletonize the entire leaf surface. In severe infestations, WGLS can defoliate vines. CW attacks vines in early spring, with larvae feeding on the developing buds.

Some resident vegetation can host moth larvae, including the pests described above, and are thought to be an overwintering site for these pests. OLr, the major moth pest in the San Joaquin Valley, can be found on California mugwort (Artemisia douglasiana), mallow (Malva spp.), mare’s tail (Conyza canadensis), lambquarters (Chenopodium album), panicle willow herb (Epilobium paniculatum), and pigweed (Amaranthus spp.). OT, which is a pest in coastal vineyards and has a biology similar to OLr, can be found on mallow, curly dock (Rumex crispus), filaree (Erodium spp.), mustard (Brassica spp.), California poppy (Eschscholzia californica), oat (Avena spp.), and barley (Hordeum spp.). These plant species can then act as a source of moth pests that later may infest grape bunches but may also serve as an alternate food source for moth parasitoids (see below). There is no evidence, however, that having an abundance of these weed species in a vineyard leads to either greater parasitism levels or greater pest damage. Less is known about the host status of commonly grown cover crop species for OLr, OT, or CW. Varela et al. (1995) found no difference in cutworm damage among several cover crop treatments. Periodic mowing of the cover crop, which usually begins in spring, probably makes it difficult for any pest larvae to complete their development by feeding on the cover crop.

Predators of moth pests. There have been no formal studies of the effects of cover crops on the population densities of the above moth pests. Green lacewings, one of the better predators of moth larvae, can feed on all larval stages. We surveyed green lacewing species in commercial vineyards and found that lacewing density was higher in vineyards (grapevines and cover crop combined) with cover crops than without cover crops. However, most lacewing larvae and adults were collected on the cover crops and not on the vines. For example, there were five different lacewing species in the

vineyard (Chrysoperla comanche, Chrysoperla carnea, Chrysopa oculata, Chrysopa nigricornis, and Chrysopa coloradensis). By far the most common species was C. oculata; however, this species was collected almost exclusively on the cover crop. It was common to have adult green lacewing densities in sweep net samples that were 100 times higher on the cover crop than on the vines. Chrysoperla comanche and C. carnea were the most common species found on the vines. Even in vineyards with cover crops, the combined density of C. comanche and C. carnea was low (about 1 lacewing larva per 1,000 leaves), which was similar to the lacewing density in vineyards without cover crops.

Most of the generalist predators discussed in the leafhopper section (i.e., many spider species, predatory bugs, and the whirligig mite) will attack OLr, OT, GLF, and CW larvae. Although there is no experimental evidence, it is probable that some of the spiders that inhabit grape bunches, such as Trachelas and the agrarian sac spider, will prey on moth larvae in the field. Only Trachelas and the whirligig mite have been shown to have a response to cover cropping (see the section on leafhoppers above).

Parasitoids of moth pests. The eggs and larvae of these moth pests are attacked by parasitoids. Eggs are attacked by a small wasp (Trichogramma), and larvae of OLr, OT, GLF, and CW are attacked by a number of wasps in the ichneumonid, braconid, bethylid, chalcid, and eulophid families, as well as parasitic flies in the tachinid family. GLF is attacked by a number of parasitic wasps, most importantly a braconid parasitoid (Bracon cushmani), and also by the same parasitic flies that attack OLr. WGLS is attacked by a braconid wasp (Apanetes harrisinae) and a parasitic fly (Ametatoria misella). These parasitoid groups come from a diverse taxonomic assemblage; for this reason, we suspect that cover crops might have a different effect on each of these parasitoid species, similar to their varying effect on spider species.

There are only a few studies that investigated whether these parasitoids control moth pests in vineyards and no studies that investigated the influence of cover crops on the level of parasitism. Most, if not all, these parasitoids feed on the extrafloral nectar found in some cover crop components. Theoretically, then, adult parasitoids can increase their longevity by feeding on cover crop nectar, but whether that leads to increased parasitism and lower pest damage has not been shown. We note

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from our field observations that the numbers of moth pests and their parasitoids increase throughout the season, but nectar from fall-sown cover crops is only available in March, April, and May. After this, most cover crops go to seed and die, removing any nectar source for the duration of the season. It is possible to plant summer nectar-bearing cover crops such as buckwheat, but the efficacy of this practice is not known.

**Summary.** There have been few formal studies on how cover crop management practices affect the abundance of moth pests in vineyards. Theoretically, cover crops that provide nectar could increase the longevity or fecundity of some parasitoids. Certain cover crops have been observed to host predators that could feed on moth larvae (e.g., lacewings) and adults (e.g., spiders); however, it is not known to what extent pest larvae are found in various cover crops. Several weed species are known to be alternate hosts for moth pests such as OLR and OT.

**Mealybugs**

Determining the role of cover crops in mealybug IPM is difficult because there are four mealybug species, each found in different grape growing regions and each with a different complex of natural enemies (Daane et al. 1996b). The four mealybug species are the grape (*Pseudococcus maritimus*), longtailed (*Pseudococcus longispinus*), obscure (*Pseudococcus viburni*), and vine (*Planococcus ficus*) mealybugs (plate 8-6). In California, each of these species has two or more generations per year, depending on temperature, and spend a part of their life cycle in the vineyard on the trunk, canes, leaves, or grapes. Economic damage results when egg sacs, larvae, or adults directly contaminate grape bunches or when mealybug excretion (honeydew) builds up on the leaves and bunches, resulting in the growth of sooty molds. As with moth pests, there have been no formal studies that investigated how cover crops or resident vegetation affects mealybugs or their natural enemies. For this reason, we can only speculate as to the most likely relationship.

**Predators of mealybugs.** There are some predators that specifically attack mealybugs. In most regions surveyed, one or two lady beetle species were found: the mealybug destroyer (*Cryptolaemus montrouzieri*) and *Hyperaspis* spp. (Daane et al. 1996a). Both of these beetles have larvae that resemble mealybug larvae, with white, waxy filaments on their abdomens. The adults also feed on mealybugs, and while they can kill other soft-bodied insects, they are considered mealybug specialists and typically do not attack other insect species in the field. Because these mealybug predators are relatively specific in prey selection, it is unlikely that any other insect or mite species in the cover crop serves as alternate prey. Furthermore, the mealybug destroyer spends most of its time on the vine, and it is doubtful that cover crops add an additional utilized habitat. Finally, whereas the adult mealybug destroyer will feed on honeydew, it must feed on mealybug eggs for maximum longevity and reproductive potential.

**Parasitoids of mealybugs.** Control of the grape mealybug has been largely attributed to the action of parasitoids (Bentley et al. forthcoming). In a recent survey, the most common parasitoids collected were *Acerophagus notativentris*, *Pseudaphycus angelicus* (plate 8-7), and *Zarhopalus corvinus* (Daane et al. 1996). Some of these parasitoids also attack the long-tailed mealybug and can provide adequate control unless disrupted by insecticide sprays. Importation programs are currently under way to find parasitoid controls for the obscure and vine mealybugs. Two parasitoid species (*Pseudaphycus flavidulus* and *Leptomastix epona*) were imported from Chile for the obscure mealybug, and 4 parasitoids (*Anagyrus pseudococci*, *Leptomastidea abnormalis*, *Cocci-doxenoidea peregrinus*, and *Leptomastix dactylopii*) were imported from Argentina, Spain, Israel, and Turkmenistan for the vine mealybug. These mealybug parasitoids are small (less than 0.2 inch [5 mm]) wasps that belong to the family Encyrtidae, and because of their similarities, they may be affected by cover crops in a similar manner. Although these
encyrstid wasps feed on honeydew for prolonged life, most host feed on mealybugs to maximize their egg production. In this way cover crops could provide a source of food via floral or extrafloral nectaries. However, mealybugs produce copious amounts of honeydew, which is a more likely source of carbohydrates for the parasitoids.

One aspect of cover crops that has not been fully investigated is whether mealybugs can feed on ground covers. In Central Coast wine vineyards and Southern California table grape vineyards, growers and researchers have observed obscure or vine mealybugs on the roots of some resident vegetation, but it is not known if this exacerbates mealybug problems.

Summary. There have been no formal studies on how cover crop management practices affect the abundance of mealybugs or their natural enemies. Some cover crops have been observed to host generalist predators (e.g., lacewings) that attack mealybugs. However, the more specialized mealybug predators (e.g., the mealybug destroyer) and parasitoids are not commonly found in the cover crop, and mealybugs do not readily move between the two habitats. Some ground vegetation has been observed to host the obscure and vine mealybugs. This alternate pest habitat may play a negative role in mealybug IPM because parasitoids effective against the obscure and vine mealybugs are not established in California.

Mites

Three species of spider mite can cause economic damage in vineyards: Pacific mite (Tetranychus pacificus, plate 8-8), Willamette mite (Eotetranychus willametti), and, rarely, twospotted spider mite (Tetranychus urticae). Mite feeding produces small yellow spots on grape leaves and at high densities can lead to a bronze discoloration or “leaf burn” and reduced photosynthesis (Flaherty et al. 1992). Mite abundance varies for each species depending on region and vineyard cultural practices.

Predators of mites. The above mites are attacked by several predators, including several predatory mites (Western predatory mite [Galendromus occidentalis, plate 8-9]; Metaseuilus mcgregori [observed in Arvin and Lodi]; Amblyseius californicus [observed in the Salinas Valley); and Euseius nr. hibisci ); six-spotted thrips (Scolothrips sexmaculatus); minute pirate bugs (Orius spp.); and the spider mite destroyer (Stethorus picipes). Twospotted spider mite is only infrequently a pest of grapes, so its presence on a cover crop can be beneficial if it serves as alternative prey for predatory mites. Zalom and Hanna (1992a) released twospotted mites on a vetch cover crop and succeeded in increasing the population of predatory mites there. The bur medics and clovers can also harbor the twospotted mite. However, the presence of twospotted spider mite on any cover crop is not guaranteed in any given year. Cover crops, especially grasses, can provide pollen to supplement the diet of some predatory mites (Kennett, Flaherty, and Hoffman 1979), although not the Western predatory mite. ‘Blando’ brome pollen, for example, has been shown to be a good food source for the Tulare predatory mite (Euseius tularensis) (Ouyang, Grafton-Caldwell, and Bugg 1992). Pollen can also support populations of tydeid mites, which are an important alternative food source for predatory mites. However, the grass cover crop must be allowed to flower to provide pollen. Most grasses grow back after a March mowing for frost protection, and, if not disturbed further, will flower in April or May. Appropriate grass cover crops for vineyards are discussed in chapter 2. No studies have been conducted to determine if the pollen from a grass cover crop leads to improved vineyard spider mite control because of greater predator activity.

Vine condition and mite abundance. Cover crops and resident vegetation have long been observed to dampen spider mite outbreaks (Flaherty et al. 1971). Properly managed ground covers should improve spider mite management by improving water infiltration, improving vine water status, and decreasing dust. Reduced-tillage programs include extending the management of the cover crop into June or July by periodic mowing or by managing permanent cover crops. Cover crops that respond well to mowing by regrowth, such as ‘Merced’ rye grain and berseem clover, can be maintained into July. Other covers are replaced by resident vegetation after spring mowing; this vegetation can also be maintained by periodic mowing. A cover crop that is disked under in March usually provides increased soil water penetration through mid-June, but thereafter the effect is diminished. A possible alternative strategy is to use a herbicide such as glyphosate on the cover crop or resident vegetation in late spring, thereby creating a “dead mulch” that will increase water infiltration through the soil but will not itself use any water. Some California perennial grasses, which go dormant in the summer, can be used to achieve this same effect.

Summary. Although there have been no formal
studies on the relationship between soil management and spider mite infestation, it is generally accepted that a well-managed cover crop can improve soil structure and water penetration and decrease dust, factors which are important to spider mite management. Some cover crops can harbor twospotted spider mite, which can serve as alternative prey for predatory mites. Grass cover crops could provide pollen for some predator mite species, but no formal studies exist to show that this helps control spider mites.

Minor Pests

Cover crops can have negative effects on some minor grape pests, notably false chinch bug (Nysius raphanus) and western flower thrips (Frankliniella occidentalis). False chinch bug can be found in significant numbers on a variety of cover crops (O'Keefe 1993) and on weeds such as wild mustard. If false chinch bug density is high on the ground covers, and they are mowed or allowed to dry up, false chinch bug will often migrate up to the vines. Their feeding is not usually significant on established vines but can be very damaging to young vines. In one study on the North Coast, more western flower thrips were trapped from a vetch-oat cover crop than from other ground covers, but this did not translate into higher damage to the grapevines (Varela et al. 1995).

Conclusions

The management of cover crops for vineyard IPM has been most thoroughly studied for leafhopper control. Cover crops were commonly associated with reduced leafhopper densities in the vineyards we studied, but because of wide seasonal variation in leafhopper numbers, cover crops only sporadically brought leafhopper populations below an acceptable economical threshold. Cover cropping by itself cannot be relied on for leafhopper control from one year to the next. Furthermore, the mechanisms involved are not clear, but the evidence points to lower leafhopper numbers because of reductions in vine vigor by the cover crop, and may also include occasional enhancement of spider populations.

It is popularly believed that biological controls in vineyards are enhanced because of the increased abundance and diversity of generalist predators on the cover crop. In our replicated studies we did not find a pattern of increased generalist predator abundance on the vines that corresponded to the presence of cover crops. Most often, cover cropping did not affect total numbers of spiders (the most common vineyard predators of leafhoppers) on vines. Cover cropping did, however, alter spider species composition at one site (table grapes) by increasing the density of the spider Trachelas. Whereas it is possible that the enhanced density of Trachelas was beneficial because they feed on leafhoppers, moths, and mealybugs, we do not know the contribution of Trachelas' enhancement to the overall control of these pests. Late-season leafhopper numbers were consistently lower with cover crops at the table grape site. In contrast, at a raisin vineyard site we found increased populations of cobweb and funnel web spiders with cover crops, but there was no corresponding decrease in leafhopper numbers. In all vineyards, other potential leafhopper predators such as whirling mites, big-eyed bugs, minute pirate bugs, and damsel bugs, as well as lacewings, were found at very low densities regardless of the cover crop and are not believed to be a significant factor in leafhopper pest management.

At three of our four study sites, cover crops or resident vegetation or both were maintained throughout the growing season. These were also the sites where cover crops affected vine condition by lowering brush weights, leaf water potential, or petiole nitrate and where leafhopper nymph densities were consistently lower with cover crops. At these sites, cover crops reduced vine vigor, and this likely contributed to a reduction in leafhopper numbers.

Although in theory, cover crops can provide alternate hosts or food sources for parasitoids of moth and mealybug pests, no formal studies on this have been conducted. Few formal studies have been conducted on cover crops and spider mites, but it is generally accepted that the beneficial effect of cover crops on soil condition, water infiltration, and dust removal can help boost vine tolerance to spider mite outbreaks.

The vineyard ecosystem is complex and many factors combine to influence both pest and natural enemy densities. Because natural pest control is an interwoven assemblage of migrating and resident pests and natural enemies, vineyard cultural practices, vineyard age, soil characteristics, and regional characteristics, it is difficult to predict how cover cropping will affect pest or natural enemy numbers. The annual fluctuation in leafhopper and spider
populations, which can be dramatic, often rendered insignificant the effect of the cover crop in terms of applied pest management. Overall, our studies show that cover crops and other floor vegetation can play a role in vineyard arthropod pest management, but they cannot be expected to provide complete control of any of the pests discussed. Properly managed cover crops should be considered as but one part of an overall IPM program.

Bibliography


