

PEST CONTROL

Cover crops and control of arthropod pests of agriculture

Robert L. Bugg

Cover crops can harbor both harmful and beneficial arthropods (1, 3). Damage to cover crops themselves is rarely of concern; more important is the possibility that pests harbored amid cover crops may disperse to adjoining cash crops [see Kennedy and Margolies (31) for a discussion of the dynamics of such mobile pests]. Here, I explore the roles that cover crops play in the life cycles and population dynamics of various arthropods and consider management tactics that may be useful for minimizing pest problems while maximizing beneficial arthropod activity. If through understanding these issues we can reduce the need for insecticides and acaricides, this could reduce the likelihood that these pesticides will contaminate surface water and groundwater.

Pests

Spider Mites. The two-spotted spider mite (*Tetranychus urticae*, Acari: Tetranychidae) can become abundant on senescing or drought-stressed cover crops of vetches (*Vicia* spp.) or clovers (*Trifolium* spp.), and can disperse to associated orchard trees, as Tedders et al. (54) have shown with pecan trees and an understory cover crop of arrowleaf clover (*Trifolium vesiculosum*). A similar phenomenon has been observed in California in an almond orchard with an understory cover crop of uniformly mid-season-maturing subterranean clover (*Trifolium subterraneum*) (Personal communication, Fred Thomas, Lohse Mill, Inc., Artois, California).

Flower Thrips. Flower thrips (*Frankliniella* spp.) are common on the inflorescences of various vetches (*Vicia* spp.); certain clovers, for example, rose clover (*Trifolium hirtum*)

and crimson clover (*Trifolium incarnatum*); and are especially abundant on low-alkaloid (sweet) varieties of narrow-leaved lupin (*Lupinus angustifolius*) (11). Flower thrips can damage certain stone fruits and grapes (37) if they attack during early fruit development. Flower thrips can also be important predators of spider mite eggs (25) and can serve as foods to certain predatory insects, including minute pirate bug, bigeyed bugs (25), and lady beetles (11).

Aphids. Certain aphids can be abundant on cool- or warm-season cover crops, and several of these can affect cash crops because of the damage they cause through feeding or through transmission of plant pathogens. Cowpea aphid (*Aphis craccivora*) is often abundant on cowpea (*Vigna unguiculata* ssp. *unguiculata*) and sesbania (*Sesbania exaltata*) during the summer (6) and during the winter and spring on common vetch (*Vicia sativa*) and hybrids that include this species as a parent (7, 11). Bean aphid (*Aphis fabae*) can attain high densities on fall- or spring-sown bell bean (*Vicia faba*) (9, 19). Pea aphid (*Acyrtosiphon pisum*) and blue alfalfa aphid (*Acyrtosiphon kondoi*) are common during late-winter and spring on various clovers, field peas (*Pisum sativum* var. *arvense*), and vetches (11).

Mustard (*Brassica* spp.) can be infested with turnip aphid (*Hyadaphis erysimi*), whereas cabbage aphid (*Brevicoryne brassicae*) and green peach aphid (*Myzus persicae*) attack various Brassicaceae, including mustard (*Brassica hirta*) and canola (*Brassica napus*) (11). Green peach aphid is an important vector of various viral pathogens of plants (18), but it is not clear to what extent the presence of brassicaceous cover crops could exacerbate this pest on associated cash crops.

Bird cherry-oat aphid (*Rhopalosiphum padi*) and other grain aphids can become abundant on cereal rye (*Secale*

Robert L. Bugg is information analyst, Sustainable Agriculture Research and Education Program, University of California, Davis, 95616.

cereale) and other grasses (7, 11).

Aphids on cover crops can serve as important foods for lady beetles and other beneficial insects (6, 7, 11).

In a young apple orchard in Oregon, Haley and Hogue (27) investigated the effects of various ground covers on apple aphid (*Aphis pomi*) and its predators. The trial compared four ground cover regimes: (1) fall cereal rye, herbicided in spring and summer; (2) a mixture of white clover and grass; (3) herbicided tree-row strips and grassed-in alleys; and (4) woven black-plastic strips in the tree row and grassed alleys. They initiated trial at the beginning of the second year of the orchard. The researchers found few aphidophagous insects of interest (e.g., the predatory mirids *Deraeocoris brevis* and *Campylomma verbasci*, the predatory midge *Aphidoletes aphidimyza*, lady beetles, hover flies, or lacewings) in the ground covers. In the first year of the study, leaf nitrogen (N) and aphid and predator densities were lower on trees with the white clover-grass mixture. These differences did not occur the second year. Terminal growth was particularly depressed for apple trees with understories of white clover and grass.

Leafhoppers. Researchers can associate several species of leafhoppers with leguminous cover crops, and some of these are damaging to cash crops as well. Several species in the genus *Empoasca* attack leguminous forages and vegetable crops in the western United States (18). Other species that infest legumes include *Graminella nigrifrons*, *Scaphytobius acutus*, *S. loricatus*, and *Paraphlepsius irroratus*. There is little information about how to manage these pests most effectively, but there is a suggestion that well-timed mowing can reduce densities of eggs and young nymphs, and that resistant crop cultivars may be available (18).

Mountain leafhopper (*Colladonus montanus*) is a vector of the mycoplasma-like organisms that cause buckskin disease (X-disease) of cherry; it can reproduce on cool-season *Medicago* spp. and *Trifolium* spp., which can harbor the pathogen (42). Thus, there is circumstantial evidence that cover crops of these groups should be used only with care, but there are no field studies showing increased damage to cherry orchards with leguminous cover crops. Apparently, a plant must survive at least a full year to be an effective reservoir of the pathogen, and this is atypical for annual clovers and cool-season medics.

Cover cropping in vineyards can apparently reduce the incidence of grape leafhopper (*Erythroneura elegantula*) and variegated leafhopper (*Erythroneura variabilis*), but the mechanism involved remains uncertain. Some researchers postulate enhanced biological control by predatory spiders (49), some propose possible changes in vine nutrition, and some cite possible microclimatic changes.

Leaf-footed bugs. Leaf-footed bugs are pests of various field, row, and orchard crops, and can disperse from cowpea and damage the kernels of associated pecan (20). In California, *Leptoglossus clypealis* can damage pistachio (44). In Georgia, researchers showed another species of leaf-footed bug (*Leptoglossus phyllopus*) to be abundant during spring on low-alkaloid strains of narrow-leafed lupin, but virtually absent from the other cool-season cover crops evaluated, including various Brassicaceae, rye, annual ryegrass (*Lolium*

multiflorum), clovers, vetches, and lentil (*Lens culinaris*) (11). *Leptoglossus phyllopus* can be abundant during the summer on buckwheat (*Fagopyrum esculentum*) (unpublished data, R. L. Bugg) and cowpea (20).

Plant Bugs. Tarnished plant bug (*Lygus lineolaris*) and other *Lygus* spp. can disperse from wild host plants, cover crops, or interplants and damage field, orchard, and row crops (18, 21, 22, 26, 33, 55). *Lygus hesperus* and *Calocoris norvegicus* can damage the developing nuts of pistachio (38, 44). On cover crops, *Lygus* spp. and other Miridae are mainly associated with inflorescences, extrafloral nectaries, and developing seed.

Fye (23) found that wheat planted as an orchard cover crop could contain abundant *Lygus*, which can cause catfacing to pears. *Lygus* spp. and *Calocoris norvegicus* can also be extremely abundant on various other cool-season cover crops, including mustards, bee phacelia (*Phacelia tanacetifolia*), burclover (*Medicago polymorpha*) and vetches, especially common vetch (*Vicia sativa*) and hybrids that have this species in their parentage (11, 12). Extrafloral nectaries aid in survival of *Lygus* nymphs (15) and nectariless cotton harbors lower densities of tarnished plant bug than do nectaried cultivars (47). Common vetch and its close relatives have stipular extrafloral nectaries, which may account for the extremely high densities of *Lygus* nymphs encountered on these plants (11, 12).

Mirid plant bugs, including tarnished plant bug, are very scarce on subterranean clovers, perhaps because the flowers lack nectar, bloom beneath the canopy, and because the developing embryos are implanted in the soil shortly after pollination (11, 12). Researchers have suggested several approaches to vegetational management to improve control of *Lygus* spp., including strip mowing of alfalfa (*Medicago sativa*) (52, 53), preemptive control of roadside weeds that serve as early-season hosts (22), use of diversionary roadside plantings (21), and simple avoidance of leguminous cover crops (18). The latter approach seems simplistic and at odds with the need for cover crops to sustain soil fertility. Perhaps the use of cover crops that harbor few *Lygus*, such as subterranean clovers, could serve as an alternative approach.

During the summer, *Lygus* spp. can be abundant on buckwheat (9). Crimson clover can temporarily harbor western box elder bug (*Leptocoris rubrolineatus*) after it disperses from box elder or maple; subterranean clover appears not to harbor this bug (Personal communication, M. Maltus, Fetzer Vineyards, Hopland, California.)

Stink Bugs. Various stink bugs (Pentatomidae) can damage nut crops (20, 38, 45). Stink bugs can occasionally be abundant during the winter and spring on burclover, and during the summer may reproduce heavily on cowpea, *Crotalaria* spp., or sesbania.

Ants. In California, two ant species are particularly damaging to almonds, pavement ant (*Tetramorium caespitum*) and southern fire ant (*Solenopsis xyloni*). These ants feed on nutmeats after the nuts have fallen to the ground, and were particularly damaging amid cover crops of brome grass (*Bromus mollis*), "Salin" strawberry clover (*Trifolium fragiferum*), and resident weedy vegetation, as compared with residual herbicide (4).

Various ants may also obtain honeydew from homopterous pests, for example, certain mealybugs, scale insects, and aphids, and protect them from natural enemies. Ants that have been observed to tend Homoptera in Californian agroecosystems include Argentine ant (*Iridomyrmex humilis*) (40) and various *Formica* spp. It is clear that such ants may also use cover crops as sources of Homoptera, nectar, and prey, but there is little work thus far to indicate how cover cropping affects the role of ants as protectors of agricultural pests.

Beneficial arthropods

Predatory Mites. Certain predatory mites are facultatively pollinivorous. For example, *Euseius* spp. (Acari: Phytoseiidae) are important biological control agents in Californian citrus and avocado groves (16, 17) and are known to subsist and even reproduce on diets of various pollens (59). Deposition of windblown pollen during late winter and early spring has been shown to be particularly important in hastening the seasonal buildup of populations of these mites (32). This group of predators can be important in the biological control of avocado brown mite (*Oligonychus punicae*), citrus thrips (*Scirtothrips citri*), citrus red mite (*Panonychus citri*), and scale crawlers (17). The principal groups of cover crops that provide wind-borne pollen are various annual and perennial grasses, and research is underway to evaluate the pollens of several of these plants for their suitability to *Euseius* spp. (personal communication, E. Grafton-Cardwell, University of California, Parlier, and P. Haney, University of California, Riverside). Observations in the San Joaquin Valley suggest that citrus groves that are cover-cropped with mixtures of Austrian winter pea, common and hairy vetches, and flowering oats (*Avena sativa*), which have wind-borne pollen, exhibit particularly high densities of *Euseius tularensis* (personal communication, P. Haney). Perhaps cover-cropping regimes can be designed to produce suitable pollens and at opportune times to promote the build-up and retention of high densities of these predators. Pollens are attractive foods (59), and if excessively abundant, might be expected to divert the predators from the target pests. Thus, mowing and other management approaches may prove to be important in reducing the availability of wind-borne pollen during periods of possible pest buildup.

Some researchers are exploring the possibility that certain predatory phytoseiid mites may move from understory vegetation into grapevines or fruit trees. To date, the studies do not show clear-cut enhancement of predator densities (personal communication, R. Hanna, University of California, Davis, and J. Nyrop, New York State Agricultural Experiment Station, Geneva).

Spiders. In Mississippi, Snodgrass and Stadelbacher (50) sampled, with pitfall traps in replicated plots, crimson clover, red clover (*Trifolium pratense*), white clover (*Trifolium repens*), ball clover (*Trifolium nigrescens*), subterranean clover, and winter vetch (*Vicia villosa*) grown in conjunction with tall fescue (*Festuca elatior*) or bermudagrass (*Cynodon dactylon*). During March, April, and May, densities of lycosid spiders or total spiders did not differ significantly among the different

types of vegetation. Riechert and Bishop (45) found that mulches of grass hay provided habitat to spiders, and thereby enhanced control of insect pests of vegetables. However, the addition of flowering buckwheat did not improve control over that obtained with mulch alone. Heidger and Nentwig (29) used leguminous cover crops of rape, lupins, and clover in an unsuccessful effort to improve biological control of wheat pests by a spider, *Dictyna arundinacea*.

Spiders (e.g., *Theridion* spp., Theridiidae) are believed particularly important in the suppression of grape leafhopper and variegated leafhopper in vineyards; some researchers believe that cover crops may be useful in enhancing control of leafhoppers in vineyards (49) and that this enhancement may be due in part to increased spider densities (3). Several replicated trials are now underway in California to test this idea (4, 7, 12).

Bigeyed bugs. Bigeyed bugs (*Geocoris* spp., Lygaeidae) are opportunistic predators of a wide range of insects and mites. They will also feed on nectar. They are especially important from May to mid-July when they are common on melon, okra, pepper, and squash plants (8, 14). These predators can also build up in cool-season cover crops, such as arrowleaf clover, berseem clover (*Trifolium alexandrinum*), and subterranean clovers, and may disperse to adjoining vegetable crops when the clovers die in early summer, as shown in Georgia (11, 13). Studies in California also indicate that high densities of *Geocoris* spp. can occur in leguminous cover crops and disperse during later spring and early summer (2).

Minute pirate bug. Minute pirate bug (*Orius tristicolor*) is an important predator of eggs and young larvae of corn earworm (*Heliothis zea*); beet armyworm (*Spodoptera exigua*); omnivorous leafroller (*Platynota stultana*); and other lepidopterous pests of field, row, and orchard crops. There is evidence that polycultures of various vegetable crops can harbor elevated densities of minute pirate bug (35). Adult and nymphal minute pirate bugs feed on thrips, pollen, and nectar, and often occur at high densities on plants with compound inflorescences. A close relative, the insidious flower bug (*Orius insidiosus*), has been shown, in Massachusetts, to become abundant amid cover crops of buckwheat or hairy vetch (9). In southern Georgia, this predator was particularly abundant on a low-alkaloid cultivars of narrow-leafed lupin, hairy vetch, and lentil (11).

Lady Beetles. In Washington, Fye (23) found that wheat grown as a cover crop in pear orchards led to a build-up of populations of convergent lady beetle (*Hippodamia convergens*) and *Coccinella transversoguttata* Richardsoni, and certain other generalist predators (*Geocoris*, *Nabis*, *Orius*, *Chrysopa* spp. and *Hemerobius* spp., and spiders) that attack pear psylla (*Psylla pyricola*). But the predators believed most important, *Anthocoris* spp. (Hemiptera: Anthocoridae) and *Deraeocoris* spp. (Hemiptera: Miridae), were relatively scarce. This study did not systematically evaluate cover crops prior to extensive use in growers' orchards.

Trujillo-Arriaga and Altieri (57) found that in Central Mexico, faba beans grown in tricultures with maize and squash provided extrafloral nectar that was fed upon by the lady beetles *Hippodamia convergens* and *H. koebelei*. This prob-

ably contributed to the observed greater densities of these lady beetles in tricultures than in maize monocultures. Densities of lady beetles appeared relatively low in all treatments, and inferential statistics were not presented.

Studies in southern Georgia have shown that cover crops can afford alternate prey and harbor various species of lady beetle, including convergent lady beetle (*Hippodamia convergens*), seven-spotted lady beetle (*Coccinella septempunctata*), and ash-gray lady beetle (*Olla v-nigrum*) (11). During the cool season in Georgian pecan orchards, an understory mixture of hairy vetch and cereal rye sustained lady beetles better than did mowed or unmowed resident vegetation (7). During the summer, understory plantings of sesbania provided bandedwinged whitefly (*Trialeurodes abutilonea*) and cowpea aphid that sustained convergent lady beetle and ash-gray lady beetle (6 and unpublished data, R. L. Bugg and J. D. Dutcher, University of Georgia, Tifton). However, there was no indication that use of winter or summer cover crops in pecan orchards led to improved biological control of pecan aphids (7). The lady beetles involved are highly mobile, and the experimental plots were relatively small. Analogous research in progress in Californian vineyards suggests similar patterns of predator build-up in cover crops but little difference in the vineyard canopy (7).

Hover Flies. Adult Syrphidae are principally flower visitors, and the morphology of the mouthparts suggests that certain species are predominantly nectarivorous, whereas others are pollinivorous (24). The larvae are maggots, and dietary habits vary among the diverse taxa, including mymecophily, fungivory, pollinivory, or feeding on monocotyledonous bulbs, decomposing vegetation, or dung. Larvae of some species are aphidophagous. Aphidophagous syrphids in America north of Mexico are mainly in the subfamily Syrphinae, and the following genera are encountered in many agroecosystems: *Allograpta*, *Eupeodes*, *Melanostoma*, *Metasyrphus*, *Scaeva*, *Sphaerophoria*, *Syrphus*, and *Toxomerus*. Nectar is probably important as an "energy food" to sustain the strong-flying hover flies. Pollen is important in sustaining ovariole development (46).

Flowering buckwheat (*Fagopyrum esculentum*), commonly used as a cover crop, is attractive to syrphid flies (6, 9, 40). In southern Georgia, Bugg and Dutcher (6) evaluated several prospective cover crops as sources of alternate prey for aphidophagous insects in the pecan agroecosystem. American jointvetch (*Aeschynomene americana*), cowpea, sesbania, and hairy indigo (*Indigofera hirsuta*) all supported cowpea aphid, whereas a sorghum x sudangrass (*Sorghum bicolor*) hybrid hosted corn leaf aphid (*Rhopalosiphum maidis*) and greenbug (*Schizaphis graminum*). Aphidophagous insects observed included syrphid flies (e.g., *Allograpta obliqua*, *Ocyrtamus fuscipennis*, *Ocyrtamus costatus*, *Pseudodoros clavatus*, *Sphaerophoria* spp., *Toxomerus boscii*, and *Toxomerus marginatus*). Sesbania appeared to be the most temporally consistent source of cowpea aphid. Per-plot densities of aphidophagous Syrphidae revealed significant differences on three of the 11 dates assessed, September 10, 14, and 29; sesbania featured the highest densities on all three dates.

Also in southern Georgia, Bugg et al. (11) assessed

aphidophagous Syrphidae in various cool-season cover crops. They observed *Allograpta obliqua*, *Syrphus* sp., *Eupeodes (Metasyrphus)* sp., and *Toxomerus marginata*. They saw particularly high densities of adult syrphids on arrowleaf clover, crimson clover, 'Cahaba White' vetch (*Vicia sativa* x *V. cordata*), lentil, hairy vetch, and narrow-leafed lupin.

Bugg and Ellis (9) evaluated five prospective cover crops in Massachusetts. Four taxa of aphidophagous hover flies were observed: *Allograpta obliqua*, *Sphaerophoria* spp., *Syrphus* spp., and *Toxomerus* spp. *Toxomerus* spp. represented more than 90% of the observations. Buckwheat (a nectar and pollen source) showed the highest densities of adult syrphids on three dates; hairy vetch, infested with pea aphid, did so on two dates (one tie).

Adult syrphids show a great tendency to accumulate in areas that are sheltered from the wind (36) and thus may be particularly active around hedgerows and windbreaks. Pollard (41) believed that shelter influenced syrphid oviposition, but that flowers did not. In that experiment, Pollard placed potted brussels sprout plants out in various habitats, then retrieved and inspected them for syrphid eggs. Adult syrphids were more abundant in areas with flowers. However, oviposition was depressed in unsheltered areas, regardless of whether flowers were available nearby. Pollard also believed that standing cereal grain could provide shelter to adjacent potted plants, and thereby enhance oviposition by syrphids (41). This raises the possibility that remnant strips of tall-statured cover crops, such as cereal rye, retained as windbreaks may enhance biological control by syrphids.

Sengonca and Frings (48) showed apparent enhancement of biological control in a 2-year, replicated study, involving bee phacelia (*Phacelia tanacetifolia*). This plant is an annual forb native to California and was introduced as a bee plant to Europe during the early 1900s. In the experiment, investigators grew bee phacelia in interior strips and in "islands" in conjunction with 239-square-yard plots of sugarbeet. Control plots featured monocultures of sugarbeet. Densities of bean aphid and eggs and larvae of aphidophagous hover flies were highest in control plots. On the other hand, sugarbeet yields were significantly higher, and adult syrphids (which feed on floral nectar and pollen of phacelia, and were presumably attracted thereby) were significantly more abundant in the plots with phacelia. Syrphids were credited with reducing the aphids in plots with phacelia. Aphidophagous syrphids observed included *Episyrphus balteatus*, *Metasyrphus corollae*, *Sphaerophoria scripta*, *Scaeva selenitica*, and *Melanostoma scalare*. In light of the small plot size and interplot distances, the practical significance of these results may be questionable. At the University of Southampton, England, S.E. Wratten and coworkers are using border strips of bee phacelia in efforts to enhance control by syrphids of aphids in wheat (5).

In California, Kloen and Altieri (34) compared monocultural broccoli with three schemes of intercropping with mustard (three planting dates for mustard: simultaneous with the broccoli, and 2 and 3 weeks after). There was no significant effect of cropping scheme on densities of aphids on broccoli or for syrphid larvae, but the ratios of syrphid larvae to aphids were significantly higher for broccoli with mustard sown 1

week later. This may have been due to attraction of adult syrphids by the flowering mustard.

Parasitic wasps. Parasitic wasps, including Braconidae, Chalcidoidea, Ichneumonidae, Scoliidae, and Tiphidae, are important in biological control of insect pests and may rely on honeydew or pollen and nectar in the adult stages. In Massachusetts, researchers observed twenty species of Ichneumonidae taking extrafloral nectar from faba beans from late September through late October (10). In southern Georgia, three species of Ichneumonidae were found feeding at the extrafloral nectaries of 'Vantage' and 'Cahaba White' vetches (11). For unknown reasons, few ichneumonids visit buckwheat flowers (9, 39)

Among the Chalcidoidea, members of the genus *Trichogramma* are especially important as egg parasites of lepidopterous pests. *Trichogramma* spp. are known to benefit from dietary honey (51, 56) or extrafloral nectar (56), and field studies in Texas suggest that the latter may be important in sustaining high rates of parasitization (56). There is at least one study suggesting that dietary pollen is not used by *T. platneri* (58). It is not clear whether nectar-bearing cover crops can be used to enhance performance of *Trichogramma* spp.

In Georgia, buckwheat flowers attracted two species of Scoliidae and three of Tiphidae (6). Members of these families are typically parasitic on the larvae of scarab beetles (Scarabaeidae).

Predatory wasps. Predatory wasps include both social and solitary species. The social species include paper wasps and yellow jackets (Vespidae), which attack many species of caterpillars. Solitary wasps of the Sphecidae attack various insects, including caterpillars, crickets, and weevils. Cover crops that attract many predatory wasps include buckwheat, cowpea, and white sweetclover (*Melilotus alba*). Eighteen types were obtained from buckwheat; 11 from annual white sweetclover (9). In Georgia, buckwheat flowers attracted nine species of Sphecidae, two of Eumenidae, and one of Vespidae (6). Also in Georgia, extrafloral nectar of cowpea attracted six types of Vespidae, four Pompilidae, and 10 Sphecidae (unpublished data, R. L. Bugg).

Management Issues

One of the first steps in managing a cover crop is to select the appropriate plant materials for the farming system of interest. Insect management does not exist in a vacuum. To optimize the role of cover crops in a farming system, producers must consider effects on soil fertility, weeds, diseases, and plant-parasitic nematodes. Other things being equal, a farmer could select cover crops that harbor many beneficial insects, but relatively few insects that likely would be pests on cash crops. For example, subterranean clovers harbor high densities of beneficial bigeyed bugs, *Geocoris* spp. (11, 13), but relatively few *Lygus* spp. (11, 12).

Cover crops can perform various functions, such as production of N or organic matter or protecting soil from erosion. Cultural methods are thus diverse. Grown for N, cover crops are typically plowed down at or near peak flowering. Mowing or chopping may be included in a management scheme.

When the goal is to supplement soil organic matter or arrest the leaching of nitrate-N, nonleguminous species are typically emphasized; an option for further increasing soil organic matter is to allow further maturation in order to increase lignin content prior to plowdown. However, some cover crops can become weeds if allowed to mature and reseed, for example, buckwheat, and 'Lana' woollypod vetch (*Vicia villosa* ssp. *dasycarpa*). This is a concern where cover crops are grown in rotation with field or row crops. On the other hand, in orchard or vineyard understories, such reseeding is usually desired.

When grown to prevent erosion, cover crops may be managed by some no-till or reduced-till method. These varied cultural practices can have implications for arthropods.

One definition suggested for the term weed is "a plant out of place." An analogous definition might serve for arthropod pest: "an arthropod out of place." In fact, some pests can actually be beneficial in some contexts, as they may attack and suppress other pests or serve as prey to beneficial arthropods.

In any event, potential pests are not necessarily problems so long as they are avoided during periods when cash crops are susceptible to their attack. These windows of vulnerability may be wide or narrow, depending on the nature of the crop-pest relationship. For example, during the blossoming and early fruit developmental stages of various fruit trees, these crops can be particularly susceptible to fruit scarring by flower thrips or catfacing by *Lygus* bugs.

For other pest-crop associations, windows of vulnerability may extend over much of the season. For example, kernel-feeding Hemiptera, such as leaf-footed bug and various stink bugs, can damage pecan or pistachio crops during most of the summer and autumn (20, 38). If artful management of cover crops can limit the dispersal to cash crops by various plant-feeding arthropods, producers can reduce pest problems.

Dispersal of pests to cash crops often occurs because cover crops mature, die, or otherwise become unsuitable hosts due to normal seasonal changes. Alternatively, drought stress, mowing, tillage, or herbicide applications can damage cover crops and drive pests into associated cash crops. If cover crops decline during windows of vulnerability, the danger of movement and subsequent damage will be heightened. There have been relatively few experiments on the subject, but it may be possible to manage insect movement by the following tactics:

1. Select cover crops that do not sustain high densities of significant pests of the associated cash crop.
2. Select cover crops that are more attractive to pests than the cash crop, and remain so by normal phenologies, during any windows of vulnerability for the cash crop.
3. Select cover crops that mature before the associated cash crop enters the window of vulnerability.
4. Mow or plow down a cover crop before it harbors significant densities of dispersive pests, or before the cash crop enters a window of vulnerability.
5. Postpone mowing or plowing under a cover crop until the associated cash crop is beyond the window of vulnerability.
6. Mow alternating strips and irrigate cover crops to ensure temporal continuity and extend the period of attractiveness of the cover crop later into the season; remnant strips may arrest

movement by dispersive pests, such as *Lygus* spp. Mowing plus irrigation can postpone maturation and lead to regrowth of many cover crops.

Clearly, some of these tactics are mutually exclusive; others may be complementary.

Cover crops also require special attention if they are to serve as field insectaries that support beneficial insects (9). During seasons when pests are scarce, supplementary resources, such as alternate prey or hosts (or in the case of *Euseius* spp., pollen), might be particularly important to beneficial arthropods. By contrast, complementary resources, such as nectar or honeydew, might be expected to be desirable whenever beneficial insects are active. As with *Lygus* spp., mowing also prompts dispersal of many predatory insects (43); tillage would probably do the same. Mowing reduces the ability of cover to support certain beneficial arthropods (28). Use of sickle-bar mowers appears a gentler alternative to flail mowing, but is not always feasible. Setting flail or rotary mowers at greater heights might permit better survival of beneficial insects (personal communication, John Freeman, Filmore, California). No comparative data have been published on the effects of different mowing techniques on survival of insects.

No-till approaches may conserve beneficial insects better than conventional tillage (30). Many predatory wasps are ground-nesting, and tillage would probably interfere with ongoing reproduction. On the other hand, ground-nesting predatory wasps often reside in disturbed areas, and superficial tillage could make available new potential nesting sites.

Timing of these practices may be important. For example, when used as green manure, buckwheat is typically plowed down after 7 to 10 days of flowering. By contrast, minute pirate bug requires about 20 days to produce a new generation. Mowing or plowing while most bugs are in the nondispersive nymphal stages would probably destroy most of them. On the other hand, hairy vetch takes longer to mature, and might produce more generations of minute pirate bug. However, it typically must be chopped prior to being incorporated as green manure. This would probably kill a large proportion of the associated minute pirate bug and lady beetles. Timing of mowing or tillage may be adjusted to allow maturation or dispersal of beneficial insects. Remnant strips of cover crops could provide habitat to beneficial insects.

Conclusion

Cover cropping may have impacts on beneficial and pest arthropods, and there is much interest among farmers in enhancing biological control. Much of the current use of cover crops in California orchards and vineyards appears intended to improve biological control of insect pests. However, the state of the art is characterized by interpolation, extrapolation, and speculation because there have been few definitive results from critical experiments. There is a clear need for large-scale, well-replicated studies in this field.

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Cover crop, nitrogen, and insect interactions

B. Warren Roberts and Bob Cartwright

Cover crops are an integral part of conservation tillage systems that have been proven effective at reducing soil erosion (6). Previous research has indicated that yields of crops grown under reduced tillage systems and utilizing cover crops can be similar to yields of crops grown under conventional tillage systems.

Knavel and Herron (1) showed that spring cabbage yields in Kentucky were reduced using no-till methods when compared with conventional tillage. In contrast, yields of fall cabbage increased with the use of no-till methods in Virginia (3). Morse and Seward (4) considered rye to be an effective mulch crop for no-till production of fall cabbage, and rye has been selected because it provides a quick soil cover in Oklahoma (5).

Crops grown with conservation tillage may require higher inputs of pesticides (7), but crop residues can also increase beneficial biological control agents that may reduce insect pests (2). Reduced tillage methods have been shown to lower certain insect pest populations on certain vegetable crops (8). But to date there has been little information published concerning interactions among cover crops, nitrogen (N), crop yields, and insects.

Materials and methods

We conducted studies at Lane, Oklahoma, in 1989 and 1990 with cabbage, sweet corn, and tomatoes to determine the effects of soil covers and N fertilization on crop yield, insect populations, and insect damage by the primary pests of each crop.

We formed raised beds, 3 feet wide on 6-foot centers, in the fall in preparation for a cash crop the following spring. In October 1988, 20-foot long plots were either seeded with rye (*Secale cereale L.*) or hairy vetch (*Vicia villosa Roth*) or were left as bare ground. In the spring of 1989, each soil cover treatment received each of four N rates (40, 80, 120, and 160 pounds/acre). We applied glyphosate to all plots prior to planting the cash crop.

In October 1989, plots similar to those of the previous year were either seeded with rye, covered with black plastic mulch, or left as bare ground. In the spring of 1990, we applied N at 30, 90, 150, 210, and 270 pounds/acre. We did not kill the rye with an herbicide, but instead allowed it to seed and die naturally. We planted cabbage, corn, and tomatoes into the covers during the spring of 1989 and 1990.

We surveyed each crop weekly or twice weekly for the presence of insect pests. In addition, we evaluated the quantity

and quality of the harvested commodity (fruit, heads, or ears) at the end of the season.

Results

With each crop, there was a positive yield response to increasing rates of N fertilizer. The response was linear with tomatoes and sweet corn. With cabbage, the response was linear in 1989 and quadratic in 1990, with the highest yield occurring at the 150 pounds/acre N rate (data not shown).

Tomatoes. Marketable yield of tomatoes was lower in the rye-covered plots than in the bare soil in 1990 (Table 1). In 1989, the same trend was noted, although the differences were not statistically significant. Two insect groups caused the majority of pest damage observed on tomatoes in our studies: stink bugs [green stink bug (*Acrosternum hilare*) and brown stink bug (*Euschistus servus*)] and tomato fruitworm (*Helicoverpa zea*). Damage by stink bugs was extremely heavy in 1989. In 1990, there was less stink bug damage but more fruitworm damage. The effects of ground cover were consistent in both years. Tomato fruitworm damage was lower on tomatoes grown in rye plots, and damage by stink bugs was greater in rye-covered tomato plots compared with tomatoes grown in bare ground (Table 2).

Sweet corn. In 1989, the marketable yield was lower in the rye-covered plots than in the bare-soil plots or the vetch-covered plots. In 1990, we noted the same trend, with yield in the rye-covered plots being lower than in the bare-soil or plastic-covered plots, although the differences were not statistically significant. Most insect damage was caused by the corn earworm (*H. zea*). While populations of corn earworm and the resulting damage to ears were high in 1989 and 1990, we did not observe significant effects of ground cover. It appears that oviposition by earworm moths is not affected by ground cover.

Table 1. Yield of cabbage, sweet corn, and tomatoes, as affected by soil cover during 2 years.

Soil Cover	Cabbage Yield		Corn Yield		Tomato Yield	
	1989	1990	1989	1990	1989	1990
	pounds/acre					
Bare soil	22,213a*	13,730b	11,177a	7,667a	33,144a	41,532a
Rye	17,920b	7,821c	8,126b	5,599a	31,518a	29,525b
Vetch	21,356a	-	11,611a	-	34,098a	-
Plastic	-	17,688a	-	7,136a	-	25,377b

*Means separation by Duncan MRT ($p = 0.05$). Means followed by the same letter within the same year and crop are not significantly different.

Table 2. Tomato damage by stink bug and fruitworm for 2 years, as affected by soil cover.

Soil Cover	Stink Bug Damage		Fruitworm Damage	
	1989*	1990†	1989†	1990†
Bare soil	3.3b‡	15.4c	9.5ab	19.4a
Rye	3.8a	33.6a	6.4b	10.9b
Vetch	3.4b	-	10.1a	-
Plastic	-	23.9b	-	23.3a

*1-5 rating: 1 = no damage, 5 = severe damage.

†Percent of culls caused by stink bug or fruitworm.

‡Means separation by Duncan MRT ($p = 0.05$). Means followed by the same letter within the same year and crop are not significantly different.

B. Warren Roberts and Bob Cartwright are assistant professors with the West Watkins Agricultural Research and Extension Center, Oklahoma State University, Lane, Oklahoma 74555.

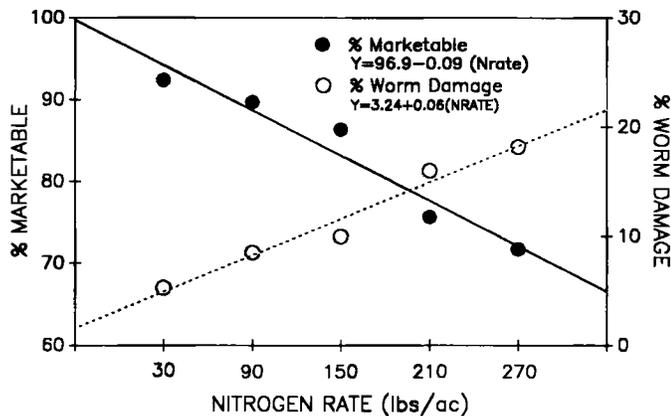


Figure 1. Relationship between N fertilization, percent marketable cabbage, and percent fruitworm damage.

Cabbage. In 1989, the yield from the rye-covered plots was lower than the yield from either the bare-soil plots or the vetch-covered plots. In 1990, the yield from the rye-covered plots was lower than the yield from the bare-soil plots, which was lower than the yield from the plastic-covered plots.

In 1989, cabbage loopers (*Trichoplusia ni*), thrips (>90% *Frankliniella fusca*), and turnip aphids (*Hyadaphis erysimi*) were the major pests observed on cabbage. Populations of cabbage loopers, thrips, and aphids were significantly lower on cabbage grown in rye-covered plots compared with cabbage grown in bare soil or vetch-covered plots. In 1990, we observed few aphids, and thrips populations were substantially lower than that observed in 1989. As a result of lower populations, we found no significant effects of soil cover on thrips or aphid populations. Diamondback moths (*Plutella xylostella*) were present as pests in 1990 but did not occur in large numbers and appeared not to be affected by ground cover. However, we observed fewer cabbage looper eggs and larvae on rye-covered plots compared with cabbage grown on black plastic or bare soil. Generally, it appears that cabbage grown in rye tends to have fewer insect pest numbers and reduced amounts of damage.

Populations of cabbage looper and aphids were positively related to increasing N levels in 1989 (data not shown). In 1990, we observed a strong relationship between N levels and damage caused by cabbage looper (Figure 1). The percentage of marketable heads declined with increasing N rates as a direct result of increased amounts of damage by lepidopterous larvae.

Summary

The results from 2 years of data with three crops indicates that marketable yields from crops grown on rye-covered plots will be lower than yields from bare-soil plots. The response of insects to cover crops varies with the insect in question. We observed the greatest change in pest populations, as a result of altering ground covers, on cabbage, especially with cabbage looper. On tomatoes, rye cover decreases tomato fruitworm damage but results in greater damage by stink bugs. Corn

earworm on sweet corn does not appear to be significantly affected by ground cover. In general, there were fewer insects and less insect damage on rye-covered plots. Nitrogen fertilization appears to have its greatest effect on cabbage looper and aphid populations on cabbage. Pest populations and damage on sweet corn and tomatoes appear not to be significantly affected by changes in N fertilization.

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