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Biological and cultural controls...

Nonpesticide alternatives can suppress crop pests

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Biological control has a long and rich history in California, beginning with the importation of the vedalia beetle for cottony cushion scale in 1889. *Above,* some of the UC pioneers of biological control and integrated pest management on an insect collection trip in Palm Canyon in 1948. From left to right: (top row) Huffaker, Fisher, Basinger; (middle row) Bartlett, Hagen, Smith, Sellers, Huges, Compere, Steinhaus; (bottom row) Flanders, Finney, Fleschner, Timberlake, Dietrick, DeBach. *Right,* cottony cushion scale was featured in a pest identification manual for California published in 1888.

Biological controls (the use of natural enemies) and cultural controls (the modification of cropping practices) provide valuable alternatives to organophosphate insecticides (OPs) for the suppression of major arthropod crop pests in California. We discuss the successes and limitations of these two approaches with regard to tree fruits and nuts, vines, and field and row crops. For example, a historic success story is that the cottony cushion scale remains innocuous in citrus production, more than 100 years after its successful suppression by the vedalia beetle. More recently, growers' use of groundcovers and road maintenance helps keep dust down on orchard roads to limit the buildup of web-spinning mites, and good vineyard management is now synonymous with cultural controls for grape pests. Although such alternatives may not always be as effective and predictable as conventional insecticide programs, recognition that partial suppression can greatly reduce the need for OPs will lead to the more widespread adoption of alternatives.

Biological and cultural controls can provide alternative strategies to pest management tactics that rely heavily on broad-spectrum, neurotoxic insecticides, particularly the organophosphates (OPs). Biological control suppresses pests via the action of their living natural enemies. Categories of natural enemies, in order of frequency of use in biological control, include: parasitoids (parasitic wasps and flies that require only a single host in which to complete their development); predators (insects, spiders and predatory mites that must consume many prey individuals to complete their development); pathogens (bacteria, fungi and viruses); parasites (soil-inhabiting entomopathogenic nematodes); and antagonists (less damaging competitors).

Three broad categories describe how natural enemies are used in biological control: classical biological control, augmentation and conservation. In classical biological control, host-specific natural enemies are imported from the exotic pest's region of origin. On average, a new invasive pest has arrived in California every 2 months during the past decade (Dowell 2002) and, with increasing global trade and travel, this rate seems likely to continue or even increase. In the best-case scenario, the imported natural enemy will establish and provide long-term suppression at low pest densities. A historic and stellar example is the 1889 importation to California of the vedalia beetle from Australia to control cottony cushion scale, which was devastating the citrus industry.

In the second approach, when natural enemies of either exotic or indigenous pests are unable to persist year-round or to build populations quickly enough to suppress pest damage, their numbers can be augmented through the periodic release of commercially produced natural enemies. The inoculation of small numbers of natural enemies can be used to improve colonization at critical periods for season-long pest suppression. Likewise, the inundation of large numbers of natural enemies can be used for immediate suppression, but often without a longer-lasting impact.

The third approach involves the conservation of natural enemy populations of both exotic and indigenous pests through habitat manipulation or the alteration of crop production practices. Natural enemies are often limited by the availability of essential resources such as nectar or overwintering sites, and the landscape within or surrounding a crop can have a major impact on the effectiveness of biological control among sites and regions. In addition, natural enemies often have a lower tolerance to many pesticides. As such, conservation tactics include habitat

The economic benefits of classical biological controls are evident from the multitude of historically important pests now held at low densities and all but forgotten.

enhancements for natural enemies and the use of selective pesticides.

Cultural controls include the various means by which the crop can be made less attractive, less available or less palatable to pests. The time frame for the effectiveness of cultural controls can range from a single harvest to the more long-term suppression of pest activity.

There are six key approaches to cultural control, presented here in order of frequency of use. Sanitation is the removal of residual populations of pests from crops, often during winter. Planting and harvesting dates can be altered to avoid coincidence with periods of high pest activity. Crop rotation, particularly effective against soil pests, displaces crops on an annual basis from pests with poor dispersal capabilities. Trap crops are used to attract colonizing pests into perimeter plantings where they can be readily destroyed by insecticide treatment or crop destruction. Diversification of the crops grown within and between fields can be used to reduce the attractiveness of a crop and the frequency of pest colonization. Nitrogen or irrigation levels can be manipulated to influence the susceptibility of a crop to pest damage.

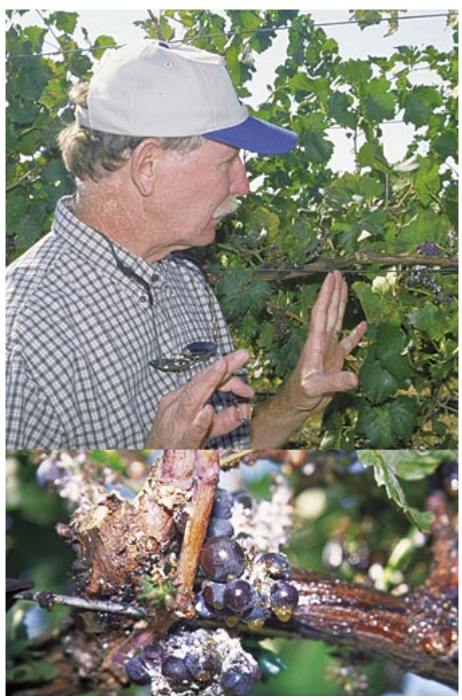
We discuss some of the successes and limitations of these biological and cultural practices in tree fruits and nuts, vines, and field and row crops, as potential alternatives to OP insecticides.

Successes in tree fruits and nuts

Classical biological control. There are numerous examples of successful biological control for the long-term suppression of exotic pests by imported natural enemies in tree fruits and nuts. The cottony cushion scale remains innocuous in citrus production, more than 100 years after its successful suppression by the vedalia beetle. Illustrating how consistent this control has been, flare-ups of cottony cushion scale occurred only after insect growth regulators applied to control California red scale caused the disruption of vedalia beetle pupation and egg hatch (Grafton-Cardwell and Gu 2003).

Other citrus pests — including California red scale and purple scale in coastal areas, woolly and bayberry whiteflies, and citrophilous, Comstock and longtailed mealybugs — have long been suppressed through the action of imported parasitoids and predators. The olive scale, once a ubiquitous and destructive pest, is seldom encountered in California olive groves due to the effective action of two complementary parasitoids, *Aphytis paramaculicornis* and *Coccophagoides utilis*. Similarly, walnut aphid was considered the most important pest of walnuts before the importation of the parasitoid *Trioxys pallidus* in 1969, and is now only an occasional problem when pesticides used against other pests disrupt the parasitoid.

The great advantage of classical biological control for tree fruits and nuts is that it can provide sustained control of exotic pests without the need for further intervention. The perennial nature of these crops, and their low level of seasonal disturbance for management and harvesting, provides a more favorable environment for natural enemy persistence and pest suppression. One drawback is that not all invasive pests of tree fruits and nuts have provided the same dramatic results. The best successes have occurred with indirect pests, such as aphids, scales and whitefly, which do not damage the harvestable part of the crop; successes against direct pests, such as fruit or nut borers, have been more limited. However, all exotic pests are potential targets for classical biological control, and even partial suppression can significantly reduce the frequency and extent to which OPs need to be used.



Photos: Larry L. Strand

In many crop systems, the success of natural enemies relies on the use of least-toxic or narrow-spectrum insecticides. *Top,* Walt Bentley of the UC Statewide Integrated Pest Management Program investigates the use of mating disruption for the vine mealybug, *bottom*.

Augmentation. The most effective program involving periodic releases of commercially produced natural enemies in tree fruit and nut crops is the use of the parasitoid *Aphytis melinus* for control of California red scale in citrus (Collier and Van Steenwyk 2004). Approximately 5,200 parasitoids are released per acre every 2 weeks from mid-February to mid-August to provide consistent reduction of red scale in the San Joaquin Valley. Augmentation of *A. melinus* has been a commercially viable program in citrus with costs comparable to the use of OPs, but it can be rendered ineffective by disruption from broad-spectrum pesticide sprays for thrips, soft scales or glassy-winged sharpshooter. In this regard, for coastal citrus the parasitoid *Metaphycus helvolus* has been released in combination with *A. melinus* to provide additional suppression of black scale.

Among other tree fruit and nut crops, experimental releases of the egg parasitoid *Trichogramma platneri* for the suppression of codling moth in pears and walnuts have shown that four weekly releases of 200,000 parasitized eggs per acre each generation can reduce damage by 60% for moderate populations of codling moth (Mills et al. 2000). In addition, releases of commercial predatory mites *(Galendromus helveolus* and *Neoseiulus californicus)* have proved effective against the persea mite in avocado. A minimum of 2,000 predatory mites must be released per tree when 50% of the leaves have one or more motile stages of the persea mite present (Hoddle 2002).

Conservation. Although cover crop management is considered important for the conservation of natural enemies in orchards, there is little clear evidence that natural enemies active on the orchard floor suppress pests in the orchard canopy. In contrast, the use of selective pesticides to preserve naturally occurring biological control has been the single most effective approach to conservation biological control in tree fruit and nuts. The majority of natural enemies are negatively affected by OPs and other neurotoxic insecticides, so switching to more selective products can often lead to a substantial reduction in damage due to secondary pests (see page 29). Without insecticide disruption, two-spotted and Pacific spider mites are under effective natural control in most deciduous tree fruit and nuts through the action of western predatory mites, other predaceous mites and predatory beetles *(Stethorus picipes)*.

Another example of effective naturally occurring biological control is that of citrus thrips in citrus orchards. The predatory mite *Euseius tularensis,* together with other generalist predators, often provide effective suppression of citrus thrips — particularly in Valencia, but also in navel oranges — unless disrupted by insecticide sprays. Similarly, the use of pheromone mating disruption to replace OP sprays for codling moth management in apples and pears in the Western region has led to substantial economic savings on treatments for secondary pests due to the enhanced activity of indigenous natural enemies (see page 16).

Cultural control. Sanitation is the most important form of cultural control in tree fruit and nuts. Sanitation of overwintered "mummy" nuts in the tree, by shaking or hand-poling, and on the ground, by disking or flail mowing, is of particular importance for suppression of navel orangeworm in almonds, pistachios and walnuts. In addition, harvesting as soon as possible after hull-split can significantly reduce nut damage. These two approaches, if used correctly, can often provide effective control. Similarly, the removal of remaining and rat-tail fruit (small, thin fruit resulting from secondary bloom that hang onto the trees into late summer) after harvest has been shown to reduce overwintering codling moth populations in pears.

Maintaining a groundcover and using water on roadways to reduce dusty conditions in orchards can also be very effective in reducing the buildup of web-spinning mites. In addition, the avoidance of water stress can prevent high population densities, as water stress leads to increased reproduction in mites.

Examples from vineyards

Classical biological control. Despite a 50-year history of research and development of biological control systems in California vineyards, there are few successful examples of imported natural enemies (Flaherty and Wilson 1999). However, the partial successes from vineyards provide some important insights for classical biological control.

In the 1950s, the wasp *Apanteles harrisinae* and the parasitic fly *Ametadoria misella* were imported to suppress the western grapeleaf skeletonizer. While neither parasitoid effectively reduced skeletonizer populations, nearly 40 years later, *A. misella* was shown to be an important vector of a virulent granulovirus, which is now part of effective biological control for skeletonizer. In the 1980s, egg parasitoids, which were originally identified as *Anagrus epos*, were imported from Arizona, New Mexico and Mexico to control the variegated grape leafhopper. A later taxonomic revision found that the imported parasitoids were a complex of closely related *Anagrus* species, each with slight differences in their geographic range, and none of which were *A. epos,* including the *Anagrus* commonly found in California vineyards (Triapitsyn 1998)!


Jack Kelly Clark

Some biological control agents can eat others, often referred to as "intraguild predation." Jay Rosenheim, *top,* UC Davis associate professor of entomology, showed that some predators such as the assassin bug, *bottom*, will feed on other predators.

In the 1990s, a parasitic wasp, *Pseudaphycus flavidulus*, was imported to control obscure mealybug in Central Coast vineyards. Although it can be an effective natural enemy, the invasive Argentine ant disrupts its potential impact. This example highlights the importance of effective competition from natural enemies after release (Rosenheim and Wilhoit 1993). Currently, one of California's larger biological control programs is being conducted for the glassy-winged sharpshooter, which vectors the bacteria that cause the devastating Pierce's disease. While egg parasitoids (*Gonotocerus* spp.) have been shown to kill more than 75% of the eggs deposited in the late season, significantly reducing overwintering populations, the level of control in vineyards may not be high enough since economic injury levels are set to near zero tolerance. Often, biological control agents do not provide the level of pest reduction needed when pests vector plant diseases in vineyards.

Augmentation. Predatory mites are released to control the Pacific spider mite in San Joaquin Valley vineyards, although release timing and rates have been problematic (Flaherty and Wilson 1999). One possible improvement, and an interesting concept in augmentation, is the combined release of predaceous mites along with less-damaging species of phytophagous mites in order to supply predators with an early-season prey. Although the parasitoid *Anagyrus pseudococci* was imported for the classical biological control of vine mealybug, its impact is limited by ant activity and the short period during which mealybugs are found in exposed locations on the vines. However, a combination of least-toxic ant control, using sugar or protein baits, and inoculative releases of *A. pseudococci* timed to the movement of mealybugs to exposed locations on the vine, has reduced mealybug damage (Daane et al. 2003).

Another example from integrated pest management (IPM) in vineyards is the importance of matching the augmented natural enemy to the targeted prey and release environment. Green lacewings are released for leafhopper control, but studies suggest that less than 30% pest reduction has been achieved (Daane et al. 1993). There are three reasons for the poor success. First, while green lacewings are considered generalist predators, leafhoppers are not a preferred host. Second, the release methods commonly used for lacewing eggs result not only in poor distribution, but also in high egg mortality. Third, released lacewings are often subject to a harsh environment, including mortality from other predators.

Conservation. Cover crops have been popularly used to reduce vineyard pests such as leafhoppers. Still, the beneficial role of cover crops with respect to natural enemies is not clear. It is likely that cover crops have a dual role, changing both the susceptibility of the vines to pests and the ability of the vineyard to support natural enemies, leading to a combined impact on pest densities (Costello and Daane 2003).

A classical example of conservation biological control from California vineyards is leafhopper control by *Anagrus* egg parasitoids. Vineyard leafhoppers overwinter as adults, while *Anagrus* parasitoids overwinter as larvae and must find alternate leafhopper hosts for the winter, such as the blackberry leafhopper or prune leafhopper (Flaherty and Wilson 1999). Blackberry or prune refuges have been planted near vineyards in order to increase parasitism levels, but in practice these refuges have not resulted in decreased leafhopper densities because of the small size of the refuge relative to the vineyard. A small blackberry or prune refuge will produce a correspondingly small number of blackberry or prune leafhoppers. *Anagrus* densities reach a peak in vineyards toward season's end, and these adult parasitoids will overwhelm leafhoppers in the refuge. The result is such a high percentage parasitism of blackberry or prune leafhopper eggs that their populations are often eliminated, thereby reducing the number of overwintering *Anagrus*. The refuge works, but in the wrong direction!

The judicious use of selective pesticides also conserves vineyard natural enemies. Even sulfur, which is approved for use in organic vineyards, can result in increased spider mite densities (Hanna et al. 1997). The most important recent advance in vineyard IPM is the identification and use of the vine mealybug sex pheromone (Millar et al. 2002). Properly monitoring for this new, invasive pest will reduce insecticide use.

Cultural control. Good vineyard management is now synonymous with cultural controls for vineyard pests. As the season begins, basal leaves can be removed to improve the control of powdery mildew, and this practice can also lower leafhopper densities. Throughout the season, dusty conditions and vine water stress are important components of spider mite control, as mentioned for other crop systems. At the opposite extreme, too much irrigation water and excessive vine vigor results in increased leafhopper densities (Daane et al. 1995). For these reasons, maintaining balanced vine vigor — either through the use of appropriate groundcovers, irrigation and fertilization practices, or cultivar selection — has become an essential part of vineyard pest management. At the end of the season, vines are cleaned of unharvested grape clusters, and this sanitation practice reduces omnivorous leafroller populations.

Phil Phillips

Jack Kelly Clark

In classical biological control, natural enemies are imported from the pest's native range, identified and screened in quarantine. *Top*, Serquei Triapitsyn, UC Riverside principal museum scientist, has traveled through the native range of the glassy-winged sharpshooter to identify new egg parasitoids, such as *Gonotocerus ashmeadi*, *bottom*, for the control of this invasive vineyard and citrus pest.

Field and row crop strategies

Classical biological control. In general, examples of success in the classical biological control of exotic pests in field and row crops are less common than in other cropping systems, in part due to a lower incidence of exotic pests in these crops. More importantly, the annual nature of these crops, their greater level of seasonal disturbance, and the highly dispersive nature of many of the associated pests are important barriers for the establishment and impact of introduced natural enemies. For example, despite the establishment of three parasitoids *(Eretmocerus emiratus*, *E. mundus* and *Encarsia sophia)* in California to combat the silverleaf whitefly, the highly migratory nature of this pest and its ability to readily colonize newly established fields has enabled it to escape effective parasitoid control.

In this regard, perennial field crops such as alfalfa have the greatest potential for success in the introduction of natural enemies for classical biological control. In California, for example, both alfalfa aphids and weevils have been partially controlled by introduced parasitoids (Summers 1998). Two different strains (previously considered separate species) of alfalfa weevils are present in California: the western alfalfa weevil (confined to cooler regions) and the Egyptian alfalfa weevil (found in warmer regions). Initial releases of the larval parasitoid *Bathyplectes curculionis* in the 1930s reduced western alfalfa weevil to almost undetectable levels in the mid-coastal region, but the parasitoid has not been effective in the warmer Central Valley where the Egyptian strain predominates.

Release of a second strain of *B. curculionis*, probably originating from Iran, extended control of western alfalfa weevil to the mountain valleys in Northern California. Subsequently, *Microctonus aethiopoides*, an adult parasitoid of the Egyptian alfalfa weevil, has also been established, although to date it has not achieved the effective level of control seen in the northern and eastern United States. In addition, the control of spotted alfalfa aphid in California has been achieved by the combined action of three imported parasitoid species *(Trioxys complanatus*, *Praon exsoletum* and *Aphelinus asychis)*, together with the use of aphid-resistant cultivars.

Augmentation. Although lady beetles, *Trichogramma* egg parasitoids and entomopathogenic nematodes have all been used on occasion, there are few examples of the successful use of commercially produced natural enemies in field and row crops in California. This is perhaps surprising, as the periodic release of natural enemies has often been considered the most suitable of the three approaches to biological control in annual cropping systems (Obrycki et al. 1997). Possible reasons for the lack of success include the high cost of commercial natural enemy production, the lack of data showing effectiveness and economic feasibility, and the misconception that mass-reared natural enemies can be used like insecticides.

Trichogramma releases for the control of fruitworms as part of an IPM program for insect pests in fresh-market tomatoes provides an illustrative example (Trumble and Alvarado-Rodriguez 1993). The releases of 247,000 *T. pretiosum* per acre per week over a period of 5 to 9 weeks in multiple plantings in Sinaloa, Mexico, reduced fruitworm populations by 80% to 90%, and fruit damage was often comparable to plots treated with conventional insecticides. However, despite the lower cost of *Trichogramma* production in Mexico and the substantial success shown by these pilot studies, *Trichogramma* releases have only been adopted by growers of processing rather than fresh-market tomatoes, and there has been no adoption of this approach in California. Clearly crop value, control costs, the predictability of control and recognition of the value of partial success all play an important role in the likelihood of adoption of augmentative biological control.

Conservation. Dr. Ken Hagen was hired in 1951 as the first supervised control entomologist in California to monitor pest-to-parasitoid ratios for alfalfa caterpillar, thereby taking advantage of the control provided by an indigenous natural enemy *(Cotesia medicaginis)* and minimizing the need for insecticide treatments. The importance of indigenous predators and parasitoids as natural controls for other alfalfa pests, including aphids and beet and western yellow-striped armyworm, has subsequently led to the recommendation of strip or border cuts for harvesting to maintain refuges for natural enemies (Summers 1998). The perennial nature of alfalfa facilitates the maintenance and enhancement of natural enemy activity, and the use of effective monitoring techniques to minimizing the need for insecticide intervention is a key element of conservation biological control.

With respect to annual crops, the delays inherent in the colonization of crops by natural enemies each season often allow early-colonizing pests to escape natural enemy suppression. Encouraging early colonization to generate predation pressure ahead of the normal colonization of a crop by pests, a form of preemptive biological control, is intuitively appealing and has met with some success (Summers 1998). Shelter strips within fields and perimeter plantings are known to encourage early natural-enemy activity in field crops such as wheat, and the use of adult food sprays to attract green lacewing adults has provided promising preliminary results in cotton and sugar beet. In addition to the encouragement of early colonization, the use of nectar-bearing plants as perimeter plantings has proved valuable in restoring limited adult food supplies for both predators and parasitoids in a number of field crops, a good example being the use of alyssum to encourage syrphids as aphid predators in Central Coast lettuce.

David Rosen

Jack Kelly Clark

The invasive Argentine ant, *bottom (tending scale),* disrupts biological control agents of aphids, scales and mealybugs. UC researchers are developing programs that use small amounts of toxic insecticides mixed with sugar bait to control ants in citrus and vineyards. *Top,* Phil Phillips, Ventura County IPM advisor, tests a commercial liquid-bait station.

Cultural control. Because most field and row crops are annual systems requiring extensive manipulation for planting and harvesting, cultural controls can readily be incorporated for pest management. For example, sanitation, planting and harvesting schedules, and variety selection are integral to the effective suppression of silverleaf whitefly in cotton (UC IPM 2003b). Sanitation is used to remove crop residues and weeds within and around the crop and prevent early whitefly colonization. It is also essential that vegetables, melons and alfalfa, which can generate substantial whitefly populations, be harvested on as short a growing cycle as possible in cotton production areas.

Finally, the early termination of the cotton crop itself, the use of smooth-leaved Acala rather than Pima varieties, and the prevention of regrowth after harvest can also help to suppress whitefly populations. Although cotton is not a favored host of Lygus bugs, migration into cotton from surrounding weeds or crops, particularly alfalfa, can also be a problem. However, Lygus migrations can be minimized through regional cooperation, staggering the harvest of alfalfa fields in an area, leaving alfalfa strips within harvested fields, or using trap crops, all of which ensure that sufficient attractive alfalfa remains in the area to reduce Lygus bug migration to nearby cotton.

Other field crops in which cultural controls have been of particular importance in California are alfalfa (Summers 1998) and artichoke (UC IPM 2003a).

Effective alternatives for OPs

Biological and cultural controls have proven to be effective alternatives to OPs for some major agricultural pests. Classical biological control remains one of the best solutions for the control of newly invasive as well as long-established exotic pests. The advantages are clear — long-term pest suppression without the need for toxic pesticides. Once well established in a crop system, however, effective natural enemies are too often overlooked. Growers are naturally concerned with pests that are currently causing crop damage, and are often unaware of those pests that are present in the crop system but held in check by the continued success of introduced biological control agents. In this manner, the importance and activity of many introduced biological control agents are poorly marketed in comparison to insecticides that have a more visible treatment-and-effect relationship.

A recent example of the "invisible" action of an introduced biological control agent was provided by the flare-ups of cottony cushion scale caused by disruption of vedalia beetle activity following the use of insect growth regulators for control of California red scale. Nonetheless, all successful classical biological controls will, eventually, be overlooked as alternatives to insecticides unless disruption occurs, as the very attributes that result in pest suppression also lead to the reduced or even forgotten importance of the target pest. Further, we suggest that the economic benefits of classical biological controls are evident from the multitude of historically important pests now held at low densities and all but forgotten as key pests in the crop system.

Cultural controls can be effective in reducing the susceptibility of all crops — but in particular field and row crops — to damage by indigenous pests, and conservation and augmentative biological controls appear best suited for use in perennial crops. Cultural controls like augmentation and conservation require direct action and economic analysis by the farm manager. For this reason, their use is more often directly weighed against the cost and effectiveness of insecticides. In our opinion, the adoption of many biological and cultural controls then rests in managerial decisions based on intangible elements of the crop system.

For example, crops marketed as organic have a limited range of chemical controls available and, therefore, rely more heavily on biological and cultural controls for sustained pest management. In addition, farm size, time period before harvest and potential for crop damage will also influence decisions regarding the use of biological and cultural controls, which often require more extensive monitoring of the crop and often have a delayed action in the suppression of pest damage. Finally, perhaps the most obvious intangible element is a grower's personal decision on how to best manage their land, and protect and market their crop.

Can the practice of biological and cultural controls be increased? Their impact and use vary among targeted pest species and crops. Their use is dependent on numerous interrelated components: effectiveness, cost, practicality (how easily can they be used), compatibility with other pest programs and legislative restrictions on currently registered insecticides. The development and implementation of new biological and cultural controls are driven by need, which in itself often appears to be driven by the availability of effective and environmentally safe pesticides.

Still, the application of biological or cultural controls necessitates sufficient background research and demonstrations of efficacy, frequently requires greater monitoring by pest control advisors, and often faces a problem of compatibility between natural enemies and pesticide use within a crop. In addition, more widespread adoption of biological and cultural controls will require greater investment in research, broader recognition of the importance of multiple tactics and the value of partial suppression, and the development of more selective insecticides that can be used when other tactics fail. Although the current new generation of insecticides shows low mammalian toxicity, in many cases they remain incompatible with natural enemies, suggesting that new priorities need to be incorporated into the development of future products.

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