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Update on Biological Control and the Challenges Growers Face

by Michael P. Parrella and Edwin Lewis

Biological control is employed as an integral component of IPM programs in commercial ornamental production. Given the current emphasis on sustainable production systems, one would expect that the use of biological control in greenhouses and nurseries would be increasing. However, there is concern that this is not the case. Here, we explore the advantages of biological control and the challenges growers must overcome in implementing and maintaining a successful program. We also present the current status of natural enemies for controlling important pests in floriculture and nursery production.

Editor's Note

We regretfully announce that this is the last issue of *UCNFA News*. In this newsletter, we commemorate the retirements of UC Cooperative Extension Farm Advisors Steve Tjosvold and Jim Bethke, along with Cooperative Extension Specialist Richard Evans. These people have made valuable contributions to the floriculture and nursery industry, in addition to regularly contributing to this newsletter (Steve, has provided leadership for the newsletter as co-editor). The first issue of *UCNFA News* — formerly called *CORF News* — was published in the fall of 1997. Michael Parrella — then associate dean of the College of Agricultural and Environmental Sciences — was instrumental in getting administrative support from the Department of Plant Sciences and establishing UCNFA. It therefore seems fitting that he is the lead author of our last feature article for this issue, which is on biological control (Michael Parrella is currently dean of agriculture at the University of Idaho). This isn't a final farewell, however, because Steve Tjosvold will be launching a nursery production blog for UCNFA as an emeritus farm advisor. Look for it to come out in August.

◆ Julie Newman, Co-Editor

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Factors Favoring the Use of Biological Control

Biological control uses living organisms to reduce pest populations. Because biological control reduces pesticide use, is highly selective, and is self-perpetuating, there are several major advantages, as described below. Moreover, an entire industry has developed to produce, disseminate, and aid in the adoption of natural enemies.

Reduces pesticide use. When biological control is implemented into an IPM program there is less reliance on pesticides for managing pest populations. This may help address problems with pesticide resistance and lessen the negative impact on overall plant quality that can occur with repeated applications of pesticides. Biological control may also be a simpler option for growers facing increasing rules and regulations governing pesticide use.

Fits into sustainable/organic practices. Biological control is a highly selective control measure that is considered an important technology for sustainable agriculture because it minimizes the negative impact on the environment and improves workers safety while maintaining the economic viability of crop production. There is a general movement in the ornamental production industry toward sustainability promulgated by consumers of plant products and a new generation of growers who are more concerned about pesticide use and its potential non-target effects than previous generations. Third-party certification of sustainable practices (e.g., [GLOBAL G.A.P.](#)) is required by some retailers of ornamental crops due to increased demand for safe, eco-friendly products.

Cost effective. Studies comparing costs in the greenhouse/nursery are limited but have shown that biological control is cost competitive — especially compared to the cost of some of the newer pesticides — and can be as effective as chemical control. Moreover, in some cases, products grown using biological control under sustainable/organic practices command a higher price. Advances in the use of banker plants and new [mechanical applicators for natural enemy release](#) have the potential to make biological control even more self-perpetuating and economical. A year-round production system can be implemented to permit natural enemies to establish

and move from crop to crop, which also reduces costs.

Natural enemies and support services are widely available. It is estimated that there are over 200 commercially available natural enemies used for biological control, and the number of biopesticide products are increasing. Although few natural enemies are sold through mainstream suppliers of agricultural products that are convenient for one-stop shopping, they are readily available from distributors that specialize in supplying natural enemies and from insectaries. Research and support from the university/cooperative extension has been reduced due to budget costs and limited grant support, but private consultants employed by commercial insectaries regularly visit growers. They have been instrumental in increasing adoption and moving biological control forward in this industry.

Biological Control Challenges

Despite the advantages, the use of biological control in ornamental crops in the United States and Europe is limited and is not increasing. Some of the factors listed in this section have made biological control in floriculture and nursery crops more complicated than for other commodities. There are many hurdles growers must surmount to make biological control work.

Aesthetics. Floriculture and nursery products are grown almost exclusively for aesthetic value and must be of very high quality (few pests and/or their damage) when the crop goes to market. Even incidental pests that pose little threat to the crop and/or the presence of natural enemies may cause retailers to reject a shipment.

Invasive Species. The intense use of pesticides needed to satisfy quarantine requirements for invasive species creates an environment that is also lethal to arthropod natural enemies. In addition, growers who must spend sizable amounts on insecticide treatments to meet quarantine requirements are less likely to spend more money on biological control agents. To date, no natural enemies have been approved for meeting quarantine requirements for any invasive pest in the United States. With a new invasive pest every 60 days in California, and with plant material moving within the state and across the

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country, the quarantine requirements are more restrictive than almost anywhere else in the world. Additionally, restrictions governing the international movement of natural enemies has limited the number of new natural enemies that can be used in biological control programs.

Large number of crop groups and cultivars.

Many different groups of ornamental crops are produced (e.g., bedding plants, cut flowers, seed production, foliage plants), and most nurseries produce many species and/or cultivars of plants. Pests and their natural enemies may each have specific responses to different plants or cultivars, and their interactions become more complicated as the diversity of plants increases. Recommendations must be tailored for each crop grouping and for specific crops. For example, in general, biological control on short-term crops such as bedding plants is more difficult because biological control agents rarely work as fast as chemicals.

Pest complex includes multiple pest species.

Multiple pests attack the many different crops typically grown in nurseries. Growers who specialize in a specific crop frequently manage multiple pests that attack their crop simultaneously. The more pests that must be controlled with biological agents, the more difficult it becomes because several different species of natural enemies must be released, significantly increasing costs (as opposed to one broad-spectrum pesticide that may kill all pests after one spray). Multiple natural enemies may interfere with one another through competition and/or intraguild predation.

Pesticides may not be compatible. For destructive pests in the pest complex that cannot be controlled with natural enemies (e.g., *Lygus* spp.) there is little choice but to use pesticides and these generally disrupt biological control. Broad-spectrum pesticides with long residual toxicity are especially harmful to natural enemies. However, some of the newer, more specific pesticides (i.e., insect growth regulators; entomopathogens) and pesticides with short residual toxicity have the potential to integrate effectively with the use of natural enemies. (Editor's note: see [UC IPM Pest Management Guidelines for Biological Control](#) Table 1 for a list of compatible pesticides).

Natural enemies may be adversely affected by environmental conditions. Temperature affects the

development of arthropod biocontrol agents and can limit their activity. Short day length can limit the efficiency of visual predators. Many beneficial species stop reproducing under short day length or prolonged cool conditions (e.g., *Aphidoletes aphidimyza*) and cannot be used at certain times of the year without supplemental light and/or heating.

Pest migration into the greenhouse/nursery.

When an agricultural field is harvested near a greenhouse or nursery, a surge of pests often moves into the ornamental crops. Such a large influx is hard to manage with biological control, even with advanced warning/monitoring systems in place. However, nurseries that produce crops in greenhouses can screen them to prevent immigration of pests.

Biological Control of Important Pests

In this section, we describe the present status of biological control of some of the most important pests of ornamental crops grown in commercial greenhouses, flower fields, and nurseries. Table 1 summarizes the natural enemies that have a proven track record in providing control efficacy or have research that supports their use.

Aphids

Hymenopteran parasitoids. The genus *Aphidius* contains many species that provide biological control of aphids (fig. 1). *A. colemani* appears to be the most effective of commercially available species, although limited research on biological control of aphids has been done in ornamental crops. This parasitoid can attack a wide range of aphid species and is capable of dispersing across a floriculture greenhouse in search of prey. For this reason, it is often the parasitoid of choice to use in a banker plant system, although hyperparasitoids can disrupt control. (Editor's note: banker plant maintenance, aphid density, and banker plant rate are also important factors affecting aphid control using *A. colemani* banker plants; see [van Driesche et al. 2008](#)).

Predators. Several predators are available commercially or naturally migrate into ornamental crops (e.g., the predatory midge *Aphidoletes aphidimyza*, ladybeetles, minute pirate bugs, and hover flies). However, few growers of ornamental crops make

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use of any of these predators in formal programs of aphid control because a high population of aphids develops on the plants prior to successful biological control, and the resulting cast skins and honeydew are unacceptable. The use of lacewings in biological control programs in the greenhouse and nursery is limited and few scientific studies have documented their success on ornamental crops.

Entomopathogenic fungi. *Isaria* (= *Paecilomyces*) *fumosoroseus*, is a microbial insecticide sold under the name PFR-97 20% WDG. This product is registered for all greenhouse ornamental plants to control aphids and several other arthropods. *Beauveria bassiana* can also be used (see whiteflies).



Fig. 1. Adult *Aphidius* parasite searching out and stinging pea aphids. Photo: J.K. Clark, Courtesy UC IPM.

Caterpillar Pests

Parasitoids, including tachinid flies and parasitic wasps, attack moth larvae and eggs of pest species (e.g., beet armyworm, yellowstriped army worm, variegated cutworm, light brown apple moth, European pepper moth). Although they reduce pest populations, larval parasitoids do not kill their hosts immediately; thus parasitized larvae may continue to feed through the last instar and may still damage crops. Applications of *Bacillus thuringiensis* (Bt) products (fig. 2) to control caterpillar pests will not harm parasitoids. Although it is an invasive pest species in California, requiring that plant material be completely clean when shipped, the European pepper moth (*Duponchelia. Fovealis*) has been effectively con-

trolled using *Steinernema. carpocapsae* in the Netherlands. Generalist predators that are commercially available, such as the soil-dwelling predatory mite *Hypoaspis* (= *Stratiolaelaps*) *miles* and the rove beetle *Atheta coriaria*, have also been effective in controlling this pest. Thus these natural enemies could possibly be effective on other caterpillar pests that are not invasive species in greenhouses and nurseries.



Fig. 2. This caterpillar (cabbage looper larva) died from infection by *Bacillus thuringiensis* (Bt). This naturally occurring insect pathogen is commercially available as a highly selective insecticide that kills only caterpillars and will not harm parasitoids that attack moth larvae and eggs. Photo: J.K. Clark, Courtesy UC IPM.

Fungus Gnats, Shore Flies, and Moth Flies

To control infestations of fungus gnats in greenhouses, commercial insectaries generally recommend the use of multiple natural enemies (bacteria, EPNs, predatory mites, and predatory beetles), presumably because no single species can provide acceptable control.

Predatory mites. *Hypoaspis miles* can provide good control of fungus gnat larvae (fig. 3). In more long-term crops, only an inoculative release of these predators is needed because they will reproduce and continue to build up in the crop. Many growers release this mite on a prophylactic basis, knowing it will establish in the soil and build up populations before pests become a problem in the crop. These preda-

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tors do not impact shore flies and moth flies because of the aquatic/semi-aquatic environment in which these pests live.



Fig. 3. Adult *Hypoaspis miles* predatory mite. Photo: J.K. Clark, Courtesy UC IPM.

Predatory insects. Rove beetle adults, *Athea coriaria*, are commercially available, but they are rarely used, probably because of the limited amount of data supporting their performance. There is some concern over whether this predator can be used successfully with predatory mites because it will eat them, but the two are often recommended for use together. At greenhouse temperatures, both *A. coriaria* and *H. miles* take 18–20 days to develop from egg to adult, and the adult beetles are relatively long-lived, surviving for months in the greenhouse. The hunter fly, *Coenosia attenuata*, has moved into many greenhouses (where pesticide sprays are reduced), and they can be seen aggressively feeding on fungus gnat or shore fly adults. (Editor's note: the hunter fly is not commercially available. See [Wainwright-Evans 2009](#) for more information about this common native predator.)

Entomopathogenic nematodes. EPNs also successfully control fungus gnats, but they are not very effective against shore flies and have not been tested against moth flies. The advantage of EPNs is that they reproduce by infecting fungus gnats. Thus they can become established in green-

houses and provide control over fairly long periods; also, they are transported by adult flies from one pot to another. The most effective species is *Steinernema feltiae*, probably because it is a better foraging nematode than *S. carpocapsae*.

Microbial insecticides. *Bacillus thuringiensis* subspecies *israelensis*, which is available commercially, will control all these pests because it is toxic to most *Diptera*. Several trials have shown acceptable levels of control when the material is applied as a drench to pots.

Leafminers

Hymenopteran parasitoids. *Diglyphus* spp. wasps (fig. 4) are natural enemies that can be used to manage leafminer species within the genus *Liriomyza*. Growers who produce gerbera cut flowers commonly use *D. isaea* for leafminer control. Initially released when the plants are young and when leafminers are first observed, this natural enemy gradually builds up and can provide control through the life of this two-year crop.



Fig. 4. Adult female *Diglyphus* sp. on chrysanthemum. The female adult stings host larva to paralyze it, then she lays one or more eggs on the late instar leafminer larva. Photo: J.K. Clark, Courtesy UC IPM.

Because *D. isaea* is expensive (see [example of *Diglyphus* costs](#)), growers routinely collect these parasitoids once the numbers build up in the crop with a small vacuum and move them into adjacent crops. *D. isaea* is generally considered to be more effective in warmer greenhouse conditions, so it is often recom-

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mended that they be supplemented with the release of *Dacnusa sibirica* during the winter. Biological control of leafminers in gerbera can be disrupted by pests such as *Lygus* bugs, broad mites, and mealybugs that can require the application of pesticides to prevent crop damage.

Entomopathogenic nematodes. EPNs such as *Steinernema feltiae* have the advantage of being able to infect the insects while they are inside the leaves, and there is evidence that they may be compatible with parasitoids, but their poor survival on the surface of leaves limits their effectiveness. Efforts are ongoing to formulate nematodes in a way that protects them from desiccation and other adverse environmental effects. This may improve their performance, especially in greenhouses, where the relative humidity is usually high.

Mites

Twospotted spider mite. Predatory mites can be used to control twospotted spider mite (TSSM) in bedding plants and greenhouses. Several species are commercially available, including *Phytoseiulus persimilis*, *Neoseiulus* (= *Amblyseius*) *californicus*, and *Metaseiulus* (= *Typhlodromus*) *occidentalis*. In comparing the relative efficacy of these mite species in controlling TSSM, *P. persimilis* (fig. 5) is clearly a top predator and is regularly used in ornamental greenhouses because it is capable of rapidly reducing large mite populations. However, this predatory mite species does not disperse well and is unable to persist in the greenhouse for long periods; thus, regular releases of this mite are required. In contrast, *M. occidentalis* can regulate spider mite populations at relatively low densities and for longer periods, so a single inoculative release of these predators may suffice (*M. occidentalis* in a rose greenhouse was reported to last more than two years). However, *N. californicus*, which is more widely used in greenhouses today, is generally considered to be better than *M. occidentalis* for TSSM biological control. Of course, the issue of pesticide compatibility with these predatory mites is critical to their long-term survival.

Thrips

Hymenopteran parasitoids. The commercially available parasitoid *Thripobius semiluteus* is specific to the greenhouse thrips and can be an effective biological control agent (fig. 6). Given the gregarious nature of this thrips and its regular use of copious amounts of anal fluid in defense against predation and parasitism, few other natural enemies can provide effective control.



Fig. 5. *Phytoseiulus persimilis* eating a twospotted spider mite (TSSM) egg. A TSSM nymph and more eggs are to its left. This predatory mite specializes in feeding on web-spinning tetranychids. *P. persimilis* has unique setae on its dorsal shield that enable it to move through strands of webbing, resulting in rapid increase in predator populations. Photo: J.K. Clark.



Fig. 6. Healthy greenhouse thrips nymphs, and black nymphs parasitized by *Thripobius semiluteus*. Photo: J.K. Clark, Courtesy UC IPM.

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Predatory mites. Several predator species, including *Amblyseius swirskii*, *Neoseiulus* (= *Amblyseius*) *cucumeris* and *Hypoaspis miles*, can attack and kill western flower thrips (*H. miles* feeds on thrips pupae that drop from the plant to the soil). However, the western flower thrips uses anal fluid defensively, and this can be a good deterrent against predatory mites. Thus large numbers of predatory mites must be present on the plant so that they can overcome larger thrips by the simultaneous attack of two or more mites on each thrips. This can be accomplished by releasing these mites in sachets (see [photo of sachet](#)) and allowing the predators to move onto plants over time. When there are few options for thrips control, growers may use one sachet per plant, which will guarantee large numbers for thrips control. Mini-sachets have been developed to try to keep costs down when using this technique.

Predatory insects. *Orius* spp. (minute pirate bug), which are available commercially, are rarely used in floriculture/nursery, primarily because they are unable to keep thrips numbers low enough to satisfy aesthetic demands.

Entomopathogens. EPNs in the genus *Heterorhabditis* have been used to control western flower thrips with mixed results. They are applied to the potting medium at a high rate (400 per cm²) to infect the pre-pupal and pupal stages of the thrips. Even at this application rate, which makes the nematodes very expensive, they seldom cause more than 50% mortality. Combinations of predatory mites and nematodes can achieve greater control of thrips. The presence of mites on the plant cause more second instar thrips to fall to the soil to pupate, where they are susceptible to nematode attack. The use of the entomopathogenic fungus *Beauveria bassiana* (see whiteflies) has also been successful when thrips populations are low.

Weevils

Entomopathogens. EPNs have been the most effective biological control agent against the larvae of root weevil pests such as black vine weevil and Diaprepes root weevil (fig. 7). Products containing *Heterorhabditis* spp. or *Steinernema* spp. provide levels of control acceptable to growers. The nematodes' ability to establish populations by reproducing inside their hosts is especially effective in crops with long

developmental periods, like most woody ornamentals. Because the weevils are highly susceptible to infection by these nematodes, the cost of treatment is competitive with the most commonly used chemical insecticides for these insects, imidacloprid and bifenthrin. The entomopathogenic fungus *Metarhizium anisopliae* is effective against a number of root weevil species. Currently, there are several companies that produce this entomopathogen as a biopesticide.



Fig. 7. The top photo shows a *Diaprepes* root weevil killed by entomopathogenic nematodes. Photo: R. Duncan., E. Grafton-Cardwell, and I. Jackson. The bottom photo shows pupae (above) and larvae (below) of black vine weevil; the brown ones are infected with the parasitic nematodes, *Steinernema feltiae*. Photo: J.K. Clark.

Whiteflies

Hymenopteran parasitoids. Whiteflies in the genera *Trialeurodes* and *Bemisia* can be controlled through releases of *Encarsia formosa* (fig. 8) and *Eretmocerus eremicus*. If mixed whitefly species are

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present, some commercial insectaries will combine parasitoid species on a single release card (e.g., *Encermix*). There are no commercially available parasitoids for the iris whitefly, so growers often resort to pesticides when this whitefly appears in any significant numbers.



Fig. 8. In the upper photo, *Encarsia formosa* is parasitizing a greenhouse whitefly nymph. The lower photo shows a greenhouse whitefly pupa (right), empty pupal case (left), and black pupa parasitized by *Encarsia formosa* (center). Black parasitized pupae are collected and glued onto cards that are commercially available; these cards are attached to plants for biological control. *Photos: J.K. Clark.*

Predatory mites. The advent of the *Amblyseius swirskii*, which feeds on eggs and very early instars, is a promising addition to biological control in the greenhouse. Many growers make use of this predator to control both whiteflies and thrips. Although *A. swirskii*

will also feed on spider mites, it has clear preference for the immature stages of whiteflies and thrips.

Entomopathogenic fungi. A mycoinsecticide containing spores of the fungus *Beauveria bassiana* has been developed commercially by BioWorks Inc. for control of whiteflies and other soft-bodied insects; one product is for use on conventional crops (BotaniGard) and another is approved for organic production (Mycotrol O). *Isaria fumosoroseus* is also available commercially (Certis USA) for control of whitefly and several other arthropods for greenhouse use. These microbial insecticide products can be applied to foliage with existing equipment used to apply any foliar pesticide. However, they are not compatible with chemical fungicides and are negatively impacted by several botanical products that have fungicidal activity. While efficacy can be very good, insect mortality will generally be slower than what would be expected from chemical pesticides, and adult whiteflies are not affected by these applications. These mycoinsecticide products are generally considered to be compatible with most natural enemies, although timing the release of natural enemies after spraying may be critical and is host-dependent.

Biological Control May Not Work on All Pests

Natural enemies are available for other pests but there is limited data supporting efficacy. Biological control of the broad mite is very difficult, although the use of predatory mites such as *Amblyseius swirskii* and *Neoseiulus cucumeris* may help control the pest. Early presence and damage from these mites is difficult to detect on floriculture crops, so growers often have little choice but to spray acaricides. Soil-dwelling predatory mites (*Hypoaspis* spp.) have been claimed to suppress or regulate bulb mite populations, and one study found that *A. (Neoseiulus) barkeri* had potential to control bulb mites on amaryllis. However, there are no specific guidelines for how to use these predatory mites that are based on practical field trials.

There are also no effective biological control agents for mealybugs attacking ornamental crops in the greenhouse or nursery. Although the mealybug destroyer, *Cryptolaemus montrouzieri* is available commercially and is often recommended, adults are rarely recovered after release. However, the commercial availability of [mealybug destroyer larvae](#)

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may be the breakthrough that is needed for biological control of mealybugs. This predator, however, is not effective on long-tailed mealybug. *C. montrouzieri* requires cottony egg masses for egg-laying; long-tailed mealybugs do not have cottony egg masses.

Natural enemies for scale insects are commercially available, including lady beetles, larvae of green lacewings, and several parasitoids such as *Aphytis melinus* for California red scale and *Metaphycus helvolus* for brown soft scale and hemispherical scale. However, although these natural enemies are often recommended, biological control will not necessarily prevent significant scale infestations, and there are no published research studies to support their use in ornamental production.

Table 1. Commercially available natural enemies of floriculture and nursery pests with evidence of efficacy

Target Pests Effectively Controlled	Natural Enemy Type	Natural Enemy
aphids	Hymenopteran parasitoid entomopathogenic fungi (microbial pesticides)	<i>Aphidius colemani</i> <i>Beauveria bassiana</i> , <i>Isaria fumosoroseus</i>
caterpillar pests	microbial pesticide	<i>Bacillus thuringiensis</i> (Bt) (may be combined with parasitoids)
fungus gnats	predatory mite entomopathogenic nematodes microbial pesticide	<i>Hypoaspis miles</i> <i>Steinernema feltiae</i> <i>Bacillus thuringiensis</i> ssp. <i>israelensis</i>
leafminers	Hymenopteran parasitoids	<i>Diglyphus isaea</i> , <i>Dacnusa sibirica</i>
spider mites	predatory mites	<i>Metaseiulus occidentalis</i> , <i>Neoseiulus californicus</i> , <i>Phytoseiulus persimilis</i>
thrips	Hymenopteran parasitoid predatory mites entomopathogenic nematode combined with predatory mites entomopathogenic fungus (microbial pesticide)	<i>Thripobius semiluteus</i> (for greenhouse thrips) <i>Amblyseius swirskii</i> , <i>Neoseiulus cucumeris</i> , <i>Hypoaspis miles</i> <i>Heterorhabditis</i> spp. + predatory mites <i>Beauveria bassiana</i> (low populations)
weevils	entomopathogenic nematodes entomopathogenic fungus (microbial pesticide)	<i>Heterorhabditis</i> spp., <i>Steinernema</i> spp. <i>Metarhizium anisopliae</i>
whiteflies	Hymenopteran parasitoids Predatory mite entomopathogenic fungi (microbial pesticides)	<i>Encarsia formosa</i> , <i>Eretmocerus eremicus</i> <i>Amblyseius swirskii</i> <i>Beauveria bassiana</i> , <i>Isaria fumosoroseus</i>

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We thank the Entomological Society of America for permission to use this material. Please refer to the original article for more information about biological control and a list of references.

SCIENCE TO THE GROWER: Clearing the air

by Richard Evans

Indoor air pollution can be a significant problem. The more time we spend indoors, the greater the chance of negative health effects. In 2001, average Americans spent 87% of their time indoors (Klepeis and others 2001). That percentage undoubtedly is higher now that we spend much of our time sitting around staring at our Internet-connected devices. Our building materials, furniture, appliances, and consumer products introduce lots of volatile organic compounds into the air. Some of these compounds have been linked to negative health effects, like eye irritation, headaches, and nausea. Some have even been identified as potential carcinogens and mutagens.

Studies of the ability of plants to improve indoor air quality began to appear in the 1980s, soon after the introduction of energy-efficient homes that had low ventilation rates and high concentrations of pollutants like volatile organic compounds. Researchers found that potted plants, such as golden pothos (*Scindapsus aureus*), nephthytis (*Syngonium podophyllum*), and spider plant (*Chlorophytum elatum* var. *vittatum*), could remove formaldehyde from indoor air (Wolverton and others 1984 and 1989). I remember reading that report. I was skeptical, because it seemed unlikely to me that indoor plants could achieve much air filtration while they sit passively on a credenza.

But the idea hasn't gone away. New studies keep appearing. Given the potential for a health angle that might boost plant sales, I decided to take a more serious look. What kind of plants are most effective at removing pollutants? How many are needed?

The quest to identify species that are particularly effective at removing pollutants has yielded inconsistent results. An Australian group (Orwell and others 2004) tested seven common houseplant species in chambers spiked with benzene and found that *Dracaena deremensis* removed the pollutant more effectively than other species in the period immediately after exposure. After luxuriating a while in the benzene-laden air, however, differences in the ability of species to remove benzene were not so clear. In fact, the substrate in which the plants were grown eventually removed volatile compounds just as well as the plants did. Researchers at the University of

Georgia (Yang and others 2009) screened 28 indoor plant species by putting them in gas-tight jars and exposing them to five volatile aromatic compounds. Five species, among them asparagus fern (*Asparagus densiflorus*) and English ivy (*Hedera helix*), excelled at removing all five pollutants. Other species, such as weeping fig (*Ficus benjamina*), removed some volatiles, but not all. *Dracaena*, on the other hand, was relatively ineffective at volatile removal.

A year later, a Korean research group (Kim and others 2010) evaluated 86 species that spanned five categories: ferns, woody foliage plants, herbaceous foliage plants, Korean native plants, and herbs. The plants were placed in airtight containers and tested for their ability to remove formaldehyde from the air. Ferns and herbs had the highest removal rates, but variation among plants in the groups was substantial and the study's authors concluded weakly that "certain species have the potential to improve interior environments."

The inconsistent results with different species spurred further work aimed at finding a connection between pollutant removal and the leaf waxes, hairs, stomates, and other attributes of foliage. However, much of that work is of questionable value because the experiments were poorly done, or experimental conditions unrealistic, or both (Cruz and others 2014). Nearly all of the studies employed closed chambers, in which the plants served as a passive system for pollutant removal. Since air exchange was low, or nonexistent, these chambers are a far cry from the rooms we inhabit for 87% of our time. When air exchange is accounted for in these systems, pollutant removal by potted plants is negligible. Girman and others (2009) calculated that one would need to cram 680 plants into a 1500 sq. ft. house — a plant density similar to that of a commercial greenhouse! — to achieve the level of pollutant removal reported in Wolverton's work.

Horticulturists working with engineers have developed more effective approaches to air biofiltration, such as botanical biofilters. The general idea is to force air through a vertical wall of plants growing in a highly porous substrate. Experimental results have been promising. Torpy and others (2018), for example, tested the ability of a free-standing biofiltration

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wall, on which 63 individual foliage plants were grown, to remove methyl ethyl ketone (also known as 2-butanone) in a single pass through the filter. They reported an impressive 57% removal efficiency in a system that achieved 1.7 room air changes per hour. Botanical biofilters generally outperform biofilters that comprise the substrate and microbes alone (Pettit and others 2017), and plant foliage and roots contribute less to biofilter air flow resistance than the substrate does (Irga and others, 2017). However, questions about the relative contribution of plants to pollutant removal, and the potential for differences in removal efficiency among plant species and growth habits, remain unresolved.

There are other unresolved questions, too. Botanical biofilters introduce a lot of moisture into the air, so relative humidity can be elevated to uncomfortable levels. The microbial populations in substrates vary, even in response to air composition (Russell and others 2014), and there is a potential for introduction of pathogenic microbes, such as *Legionella*. Spores released into the room from microbes in the walls could be allergens, or could encourage mold development. Cost-benefit studies are also needed, including an assessment of the maintenance costs. For now, the best solution to removing air pollutants may be using a mechanical ventilation system.



A green wall at the children's museum in Kitchener, Ontario, Canada (THEMUSEUM). Although green walls may remove air pollutants, further research studies are needed before recommendations can be made regarding their use in biofiltration. Photo: M. Rehemtulla.

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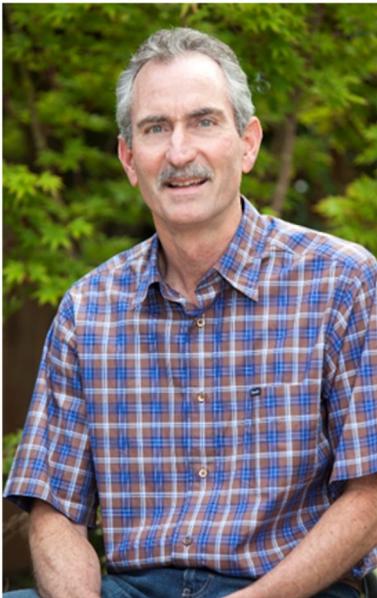
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CAMPUS AND COUNTY NEWS: Three retirements in nursery and floriculture programs

by Julie Newman

We bid farewell to three University of California Agriculture and Natural Resources (UC ANR) academic staff members who had focused programs in ornamental production — two farm advisors (Steven Tjosvold, James Bethke) and one extension specialist (Richard Evans). Their careers have advanced the commercial floriculture and nursery production industry with combined experience that stretched over 100 years!

Steven Tjosvold



Steven (Steve) Tjosvold concluded a 38-year career with UC ANR on June 28 as environmental horticulture farm advisor in Santa Cruz and Monterey counties. The emphasis of Tjosvold's program was floriculture and nursery production, but he also worked with the turf and landscape industries and provided leadership for Santa Cruz County's Master Gardner program. He is internationally respected in the scientific community and lauded by nursery growers for his years of research and extension activities contributing to the knowledge of the biology and management of *Phytophthora ramorum* (sudden oak death).

Tjosvold received an M.S. degree in environmental horticulture from UC Davis in 1980 and began his career with UC Cooperative Extension as a farm advisor intern in Alameda, Orange, and San Bernardino counties. Upon completion of his internship he joined the UC Cooperative Extension Santa Cruz County office in 1983 and developed a cross-county program with Monterey County.

Tjosvold's early career focused on the management of nursery and landscape plant diseases (e.g., damping off, powdery mildew, *Heterosporium* leaf spot, rust, pitch canker, fusarium wilt) and insect problems (e.g., borers, thrips, blue gum psyllid, spider mites), as well as methods to improve water use and postharvest handling in nursery crops. In addition, Tjosvold helped to establish the use of scouting in ornamental

production by working with other farm advisors to document effectiveness statewide. He was also one of the original founders of CORF, which eventually became UCNFA.

In the mid-1990s, many tanoaks and coast live oaks started dying in central and coastal California due to *Phytophthora ramorum*. Although this disease was previously only considered to be a problem in forests in North America, it began showing up in nurseries, including Santa Cruz County, where *P. ramorum* was officially detected on rhododendron plants in 2001. Quarantine regulations for this invasive species seriously impacted nursery growers. As a result, a critical focus of Tjosvold's research and extension program was dedicated to understanding the biology of this pathogen and managing the spread of this disease, which helped to mitigate economic losses. Light brown apple moth — another invasive pest that economically impacted the nursery industry — also became an integral part of Tjosvold's research and extension program. He was instrumental in developing monitoring methods, pheromone mating disruption, chemical control, and guidelines for managing this pest in nurseries.

During his career Tjosvold wrote or contributed to 94 scientific peer-reviewed publications and 234 industry publications. He served as editor/co-editor for *UCNFA News*; he also had a regular column ("Regional Report for Santa Cruz/Monterey Counties") and contributed to numerous feature articles in *UCNFA News* and its predecessor, *CORF News*. He received many awards for his research and education efforts in Cooperative Extension, including the 2015 Western Extension Directors Association Award of Excellence for contributions to a team effort that addressed sudden oak death, 2012 California Association of Nurseries and Garden Center Award for Outstanding Research, 2008 Western Extension Directors' Award of Excellence for contributions to a team effort of the Farm Water Quality Planning Project, UC ANR Distinguished Service Award for Outstand-

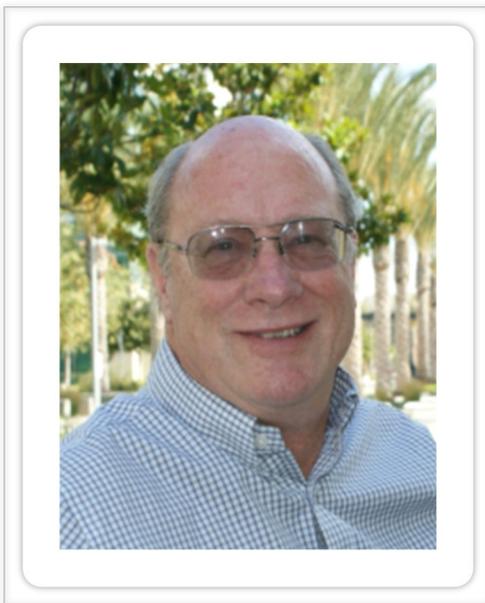
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ing Team Work (1997, 2004, 2006), and the 2004 UC ANR Distinguished Service Award for Outstanding Extension.

As an emeritus, Tjosvold plans to launch a blog for UCNFA that will help to replace the loss of the newsletter due to retirements, and he will be available locally for focused educational projects and consultation. He is avid about fly fishing and hiking — he hopes to do lots more of it in the future.

James Bethke



James (Jim) Bethke retired last January, wrapping up a distinguished 37-year career with UC — 12+ years with UC ANR and 25 years with the Department of Entomology, UC Riverside. He is highly regarded for his expertise in the integrated pest management of pests of commercial floriculture and nursery crops.

Bethke grew up in Milwaukee, WI and showed an early interest in the insect world. His youth pastimes were turning over boards and rocks in yards and checking outdoor lights for new and interesting bugs. He collected jars full of insect specimens to study at home.

Bethke received an M.S. degree in entomology in 1985 from UC Riverside. He worked as an undergraduate lab assistant and as a graduate research assistant for Dr. Michael Parrella on leafminer pests on ornamental crops. Upon graduation, he continued working in the Department of Entomology as a staff research associate in Dr. Richard Redak's lab, focusing on research involving pest management of commercial floricultural and ornamental plants and supervising other lab staff.

In July 2005, Bethke joined the UC Cooperative Extension San Diego County office as the floriculture and nursery farm advisor, initially as a split appointment with the entomology department at UC Riverside. His extension program in both San Diego and Riverside counties continued to emphasize the integrated pest management of major pests of floriculture and nursery production. Bethke was highly active in helping the ornamental production industry address the serious impacts of invasive pests through research and extension, as well as collaboration with regulators, growers, and other scientists on advisory committees that set policy on invasive pests (e.g., Diaprepes root weevil, European pepper moth, gold-spotted oak borer, light brown apple moth, polyphagous shot hole borer, Q-biotype whitefly). In addition, Bethke took the reins as UC Cooperative Extension, San Diego county director in 2012.

During his career, Bethke has written or contributed to over 800 publications which include 62 peer-reviewed publications (39 in scholarly journal articles, 16 of which were senior author publications). He was a regular contributor to *UCNFA News* with two columns: "Insect Hot Topics" (which focused on new and invasive pests) and "Regional Report for San Diego/Riverside Counties," along with writing feature articles and contributing to the "CDFA Nursery Advisory Report." He has been a frequently invited speaker and has given over 600 presentations. His research and education efforts in Cooperative Extension have been recognized by UC ANR and the nursery and agricultural industries with significant awards, including the 2014 California Association of Nurseries and Garden Centers Outstanding Research Award, 2013 California Association of Pest Control Advisers Outstanding Contribution to Agriculture, 2013 San Diego County Flower and Plant Association Outstanding Person of the Year Award, 2011 San Diego County Agricultural Commission Certificate of Excellence, and the 2011 UC ANR Outstanding New Academic Distinguished Service Award.

Bethke is a member of the Entomological Society of America (ESA), Entomological Association of Southern

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California, Pesticide Applicators Professional Association (PAPA), American Society of Horticultural Science (ASHS), and an affiliate member of the San Diego County Flower and Plant Association and the California Association of Pest Control Advisers (CAPCA). He is also the Science Advisor to the Center for Applied Horticulture Research and for the California Citrus Nursery Board.

Bethke plans to spend considerable time outdoors during his retirement fishing, camping, hiking and collecting more specimens for his vast collection of insects and other arthropods.

Richard Evans



Richard Evans retired June 30 after 32 years of service as Cooperative Extension specialist in nursery crop production at UC Davis. He received his PhD in Plant Physiology at UC Davis and shortly thereafter joined the department of Environmental Horticulture (which is now part of the department of Plant Sciences) in 1986. In addition to his responsibilities as extension specialist, Evans also regularly taught two undergraduate courses (“Management of Container Media,” “Principles and Practices of Plant Propagation”) and one graduate course (“Principles of Horticulture and Agronomy”), along with supervising many graduate students over the years.

Evans’s research has focused primarily on identifying nutrient and water requirements of greenhouse and nursery crops. His research group determined the nitrogen, phosphorus, potassium, and water uptake of nearly 100 ornamental crops, with the goal of providing commercial growers with information needed to use fertilizer and water more efficiently. Among the significant findings arising from that work was a description of the spatial and temporal separation of nitrogen assimilation in greenhouse rose crops. Evans’s work with students led to the discovery that rose nitrogen uptake is highest when shoot growth rate is lowest; they quantified the redistribution of stored nutrients in rose plants in response to management practices. These and related studies formed the foundation of an Extension program aimed at improving fertilizer and water management in ornamental crop production.

Throughout his career Evans has been a strong advocate for programs aimed at field workers rather than farm owners alone. He was instrumental in developing hands-on irrigation training in Spanish and English for greenhouse and field irrigators, and he participated in award-winning Extension programs that helped California crop producers meet Federal water quality standards.

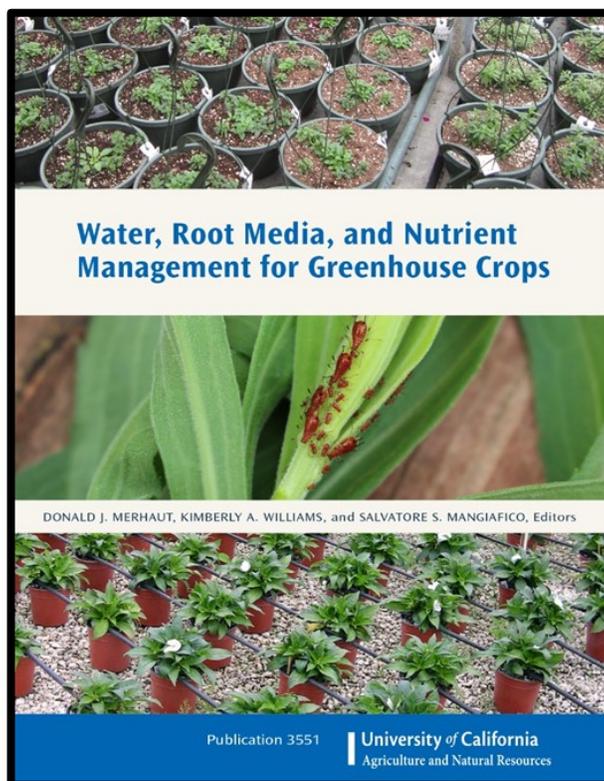
During his career, Evans contributed to over 70 peer-reviewed publications. He had a regular column in *UCNFA News* (“Science to the Grower”) in which he presented grower-friendly literature reviews of topics related to the ornamental production industry that showcased his characteristic dry humor and wit. He received several significant awards for his research and extension efforts, including a Western Extension Directors’ Award of Excellence, a UC ANR Distinguished Service Award, an Allan Armitage Leadership Award from the Association of Specialty Cut Flower Growers, and an American Society for Horticultural Science Outstanding Publication award in Floriculture and Nursery Production.

As an emeritus, Evans will continue as the major professor for a graduate student and as faculty advisor for the Horticulture and Agronomy Graduate Group, along with working to complete some ongoing research projects. His retirement plans include providing daycare for his 3-year-old grandson and 7-year-old granddaughter and partnering with his wife in her food safety consulting business. He also plans to spend lots of time playing guitar and accordion.

New Publication from Agriculture and Natural Resources

by Donald J. Merhaut

Water, Root Media, and Nutrient Management for Greenhouse Crops



A new user-friendly, practical reference book for the greenhouse and nursery industries will be released by the University of California Agriculture and Natural Resources (UC ANR) in the fall of 2018. *Water, Root Media, and Nutrient Management for Greenhouse Crops* is for large and small greenhouse producers of containerized crops throughout the United States and all climates of North America. It provides a thorough overview of plant nutrition, root media, and water quality, making it an ideal user manual for both the greenhouse and nursery industries. Books can be purchased at 1-800-994-8849 or 530-400-0725. For online orders, go to anrcatalog.ucanr.edu.

The editors are Drs. Donald J. Merhaut, Kimberly A. Williams, and Salvatore S. Mangiafico. Dr. Merhaut is an associate Extension specialist for nursery and floriculture crops at the University of California, Riverside. Dr. Williams is professor of horticulture at Kansas State University, and Dr. Mangiafico is an associate professor at Rutgers. Together, they worked with 20 other national and international academics and industry leaders to formulate this comprehensive guide in greenhouse crop management.

Greenhouse production was originally associated with floriculture crops, specialty crops such as houseplants, and “out-of-season” vegetable production. The last comprehensive book to focus on the water and nutrient aspects of greenhouse production in the United States was *Water, Media, and Nutrition for Greenhouse Crops*, edited by David W. Reed and published in 1996. Since that time, many aspects of greenhouse production have changed: new marketing trends have emerged such as organic production; improved and more efficient production technologies have been introduced; and new laws and regulations have been developed and implemented related to environmental sustainability and food safety. These changes have motivated growers to have a comprehensive understanding of greenhouse management.

The book is sectioned into three main topics: water, root media, and fertilizer. Chapter 1 provides an overview of these three topics and the importance of understanding and integrating all three components when formulating a sound and cohesive horticultural plan for the nursery that is sustainable and profitable. Within each book section, details are provided on the proper use of water, media, or fertilizer and tailoring these inputs to meet the specific needs of a production facility. Instructions are also included in each section on how to monitor the water, media, or fertilizer status of the crop and general crop health, and how to correct problems that may arise in production.

The editors would like to thank all the authors and UC ANR Publications (especially Ann Senuta and Stephen Barnett). Much credit goes to Kimberly Williams, who developed the original content and has been the visionary guide for this book since its inception. The editors dedicate this book to the growers and greenhouse managers across North America who daily accomplish the complex and challenging work of producing crops in protected environments that beautify and feed our world.

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