The IPM Practitioner

Monitoring the Field of Pest Management

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Special Pheromone Issue

Pheromones and Attractants for Invasive Pests

By William Quarles

The U.S. is being overrun by invasive pests. A partial list is the brown marmorated stinkbug (BMSB), *Halyomorpha halys*; the spotted lanternfly, *Lycorma delicatula*; spotted wing drosophila (SWD), *Drosophila suzukii*; and the emerald ash borer (EAB), *Agrilus planipennis*. Because they are exotic pests, they do not have effective natural enemies in North America. Management is either frequent pesticide sprays or a patchwork quilt of IPM methods.

Pheromones and attractants are the key to IPM management. Pheromones are used for monitoring, mass trapping, and attract and kill technology. In many cases, pheromone management leads to pesticide reduction. Pheromone management also has great versatility. The invasive exotics described here range from a voracious bug that eats fruits and vegetables, to a sap sucking planthopper, to a destructive fruit fly, to a lethal tree borer. This article is an update of pheromone management methods for these invasive pests (Herms and McCullough 2014; Leskey and Nielsen 2018).

Courtesy B. Butler, Northeastern IPM Center, StopBMSB.org

The black pyramid trap, shown here, can be used to monitor populations of the brown marmorated stink bug, *Halyomorpha halys*. Bugs are attracted by aggregation pheromones at the top of the pyramid.

Brown Marmorated Stinkbug

The brown marmorated stink bug (BMSB), *Halyomorpha halys*, is an invasive species native to China, Japan, and Korea. It invaded Pennsylvania in the 1990s and has now spread to more than 41 states. It attacks more than 170 different plant species, and prefers to eat many of the same foods as humans, especially beans, garden vegetables, and tree fruit. It is a threat to commercial agriculture, landscape ornamentals, and backyard gardens. It is also a structural pest, as large populations invade houses, trying to overwinter (BMSB 2020; Lee et al. 2013; Inkley 2012; Quarles 2014). Biology of BMSB can be found in Quarles (2014).

Conventional management of the pest with pesticide sprays is difficult. The bugs are resistant to many insecticides. Also, killing all the bugs in a field may not control the damage, as infestations move in waves across a landscape. The bugs go back and forth between crops, and a field free of bugs is soon invaded again (Leskey and Nielson 2018).

Pheromones are essential to IPM management. Black pyramid traps baited with pheromones are useful monitoring tools, and they are commercially available (see Resources), Larger traps give better results than small ones, and placement on the ground is more effective than in a tree canopy (Leskey et al. 2012). Black pyramid traps catch more bugs, but sticky traps can often give satisfactory monitoring results. Sticky traps are more economical and are easy to use (Weber et al. 2017).

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Update

Aggregation Pheromones

Aggregation pheromones are used in BMSB monitoring traps. The first commercial pheromone was MDT (methyl decatrienoate), which was isolated from the related stinkbug, *Plautia stali*. The USDA then isolated the true aggregation pheromone secreted by BMSB males. MDT combined with the true aggregation pheromone is attractive to all BSMB adults and nymphs. The pheromone is used to monitor early season populations, establish economic thresholds for IPM, implement mass trapping, and produce attract and kill formulations. Though the natural pheromone is optically active, BMSB is relatively insensitive to ratios of the isomers. Since concentrations in the mixture do not have to be rigorously controlled, economic production of an effective synthetic pheromone is possible (Quarles 2014; Weber et al. 2020).

Leskey et al. (2012) baited apple trees with BMSB aggregation pheromones to reduce pesticide applications. Nine trees in a border row were baited with pheromones, then pesticides were used to destroy the bugs attracted to the pheromones. Using baited perimeter apple trees in a similar attract and kill approach, Morrison et al. (2016) were able to reduce applied insecticides by 97% (Weber et al. 2017).

IPM Programs

BMSB is concentrated in the North Atlantic states. But it has recently invaded the South and California. It has grown fond of California almonds. In addition to pheromone techniques, biocontrols and exclusion have potential. One of the most successful biological controls, the samurai wasp, *Trissocolus japonicus*, an egg parasitoid, was found reproducing in the wild in the United States. Since this Japanese wasp is already in the U.S., it can be released without the time consuming quarantines needed for many imported biological controls (Leskey and Nielsen 2018).

Northeastern IPM Center, StopBMSB.org

Adult *Halyomorpha halys*

Spotted Lanternfly

The spotted lanternfly is a voracious plant hopper that feeds on plant sap. It has a wide host range but has done extensive damage to apples, stone fruit and grapes. Its feeding can kill shade trees. Especially at risk are tree of heaven, maple, black walnut and willow. Like the brown marmorated stinkbug, it was first found in Pennsylvania. Since 2014, it has spread to several adjacent states. There is a high risk of widespread infestation because it lays large numbers of eggs and hitchhikes on automobiles and trains. Since tree of heaven is its primary host, it could thrive in California vineyards, where there are many nearby tree of heaven plantings (Urban 2019). Biology of spotted lanternfly can be found in Dara et al. (2015).

Trapping with attractants can be used to monitor for spotted lanternfly and reduce populations. It is naturally attracted to tree of heaven, and one strategy is to install a sticky band around the trunk of the trees. Sticky bands are controversial, but protective barriers can be constructed that prevent trapping of non-target wildlife. Attraction is increased by using a lure, and methyl salicylate is the best lure found so far (Cooperband et al. 2019).

Update

Spotted Wing Drosophila

Spotted wing drosophila (SWD), *Drosophila suzukii*, is a tiny fruit fly that is native to China. Unlike most fruit flies, it lays its eggs in intact fruit, ruining the crop. Yield losses of 20-40% have been seen in cherries, blueberries, raspberries, cranberries and strawberries. It has become a pest because of quick reproduction times, lack of effective biocontrols, increased winter survival due to global warming, and quick dispersal from fruit shipments (Bolda et al. 2010; Quarles 2015). Biology of SWD can be found in Quarles (2015).

Insecticide application is the major control method. Monitoring allows timing of insecticide applications, often leading to a reduction in pesticide use (Quarles 2015).

Pheromones are not commercially available for SWD, so fermenting fruit volatiles are most often used in monitoring. The most common trap is a clear plastic cup with a small amount of apple cider vinegar containing a drop of detergent. This trap is often used by backyard gardeners (Quarles 2015).

The spotted lanternfly, *Lycorma delicatula*, is a voracious plant hopper that can attack many different plants. There is a high risk of widespread damage to vineyards, apples, and stone fruits.

Early Detection

The purpose of monitoring adult flies is early detection. Early detection is critical so that control methods can be applied before eggs are laid in the developing fruit. A strongly attractive bait is needed to draw in pests from low populations. Addition of wine to apple cider draws more flies than cider alone. Fermenting yeast baits are also strongly attractive (Quarles 2015).

Synthetic baits are available (see Resources). One good synthetic bait is a mixture of acetic acid, acetoin, methionol, and ethanol. Addition of ethyl acetate to make a 5-component bait attracts larger numbers of flies (Cha et al. 2017; Larson et al. 2020). Adult fly catches with synthetic baits suspended over unscented drowning solution correlate best with larval infestation rates (Quarles 2015; Cha et al. 2014).

This is a male spotted wing drosophila (SWD), *Drosophila suzukii*. It can be identified by the spots near the tips of each wing. Females lay eggs in ripe, intact fruit, causing major damage to crops.

Traps must be balanced between attracting large numbers of flies and selectivity. If the bait is not selective, the labor of fly identification is increased. Synthetic baits are usually more selective than fermenting baits. Trécé offers a choice of synthetic lures, either a lure that emphasizes attraction of large numbers, or a more selective lure that concentrates captures of SWD. The synthetic lures capture flies 2.5 weeks earlier than natural baits and last 4-6 weeks (Trece 2020) (see Resources).

Update

Type of Trap

Red or black traps catch more flies than white or clear ones (Basoalto et al. 2013). When the same lure was used in cherries and raspberries, Kirkpatrick et al. (2018) found that more flies were caught by red panel sticky traps than liquid baits.

A new dry lure and trap has been developed recently. It is more convenient to use than the liquid traps, and performance is marked by a controlled release dispenser releasing attractants at a constant rate (Larson et al. 2020).

Pesticide Reduction

Spies et al. (2019) investigated alternatives to total field sprays. They found that either spraying or mass trapping border rows was more effective than spraying alternate rows in blueberry.

An attract and kill technology has been commercially developed (see Resources). It is a sprayable bait with the active ingredient of spinosad. It has the advantage of less impact on bees and beneficials than broad spectrum pesticide sprays (Klick et al. 2019). Organic growers have turned to exclusion methods, protecting the crops with netting of 0.98 mm (0.04 in) mesh size (Lee et al. 2011). (see Resources)

Courtesy Trécé

Pherocon SWD Monitoring Trap

Emerald Ash Borer

The emerald ash borer (EAB) was first seen in Detroit, MI in 2002. Since then, it has killed millions of U.S. ash trees in more than 35 states. Infestations are mostly in the East, but it has also been found in Colorado. The EAB is native to China, Korea, and Japan. but is apparently not a pest in Asia (Herms and McCullough 2014).

Containment may be impossible. The situation is so hopeless that the USDA is removing quarantine restrictions and is just concentrating on pest management. All 8.7 billion U.S. ash trees may be eventually killed, except those in Montana, North and South Dakota, Minnesota and other states with very cold winters (DeSantis et al. 2013). Black ash is especially vulnerable. The situation is reminiscent of Dutch elm disease and chestnut blight. Costs of removing and replacing ash trees in just four Midwestern states has been estimated at $26 billion (Herms and McCullough 2014).

Life Cycle

Adult EAB is an emerald green beetle with a one or two year life cycle. Metallic copper colored adults emerge during the summer months, starting in May leaving 2-3 mm, D-shaped exit holes. Adults live 3-6 weeks and feed on ash leaves. They must feed on ash leaves for about 10 days before mating and egg laying.

Mated females lay 40-70 eggs in bark cracks and crevices. Eggs are preferably deposited in the upper canopy and hatch within two weeks. Eggs are about 1 mm, ivory to light green. Eggs hatch into wormlike larvae that bore into the tree, feeding in serpentine galleries that eventually girdle the tree and prevent nutrient distribution, killing the tree (Herms and McCullough 2014; Wang et al. 2010).

Monitoring EAB

The first visual sign of EAB infestation is canopy dieback. By this

Photo courtesy USDA/APHIS

Adult emerald ash borer, *Agrilus planipennis*

time, the tree has been infested for 3-8 years and is essentially dead. Monitoring and early detection is important because urban trees can be saved by injections of emamectin benzoate or neem (McKenzie et al. 2010). Neonicotinoids can also be used, but are less effective than emamectin and might impact populations of bees and beneficials (McCollough et al. 2011). EAB preferentially attacks stressed trees, so intentionally girdled trees can be used as traps to detect when EAB is

Photo courtesy USDA Forest Service

Multifunnel traps are convenient to use and are effective at low population densities.

in an area (Herms and McCullough 2014).

If girdled trees are not used for detection, attractants and traps are deployed. Attractants include the sex pheromone (3Z)-dodecen-12-olide (abbreviated as (3Z)-lactone). Both sexes secrete this macrocylic lactone, but females release 10x as much as males (Bartelt et al. 2007). Traps are also baited with manuka oil, phoebe oil, and the ash leaf volatile, (3Z)-hexenol (Crook et al. 2012; Crook et al. 2014).

Trap Types

Common traps are green or purple prism traps, double decker traps, and multifunnel traps. A prism trap is composed of three equal sized plastic panels (60 by 40 cm; 24 by 16 inches) made into a triangular trap. Triangular panels are covered with glue, and the standard trap is about 60 cm (24 inches) long. Prism traps are usually hung in the ash tree canopy (Herms and McCullough 2014; Poland et al. 2019).

Double decker traps are made of two prism traps stacked together on a pole. The pole can be positioned near trees. Some studies have shown that double deckers with one green and one purple trap catch more beetles than two traps of the same color (Poland et al. 2019). McCullough and Poland (2017) give detailed instructions for making double decker traps.

Multifunnel traps are just a stack of funnels with a collector cup. Funnel traps are hung in the tree canopy. Traps with larger numbers of funnels catch more beetles (Francese et al. 2013a). Multifunnel traps are commercially available (see Resources).

Key to success is detection of EAB at low population densities. Trapping effectiveness is a complicated function of trap type, trap color, lure, placement, sun exposure, infestation levels in a tree, and general EAB population levels (Poland et al. 2019). At low population densities either funnel traps or double decker traps are the most effective. Funnel traps have the advantage that no glue is needed, since slippery coatings prevent the beetles from escaping (Francese et al. 2013b).

Biocontrol

Some biocontrols can be effective for EAB. The best larval parasitoids introduced from China are *Spathius galinae* (33-49% parasitism rate) or *Tetrastichus planipennisi* (30-85% parasitism rate). *T. planipennisi* is only effective in saplings and very small trees. *S. galinae* can attack EAB in trees up to 50 cm (20 in) diameter. The problem with biocontrols is that they work slowly. EAB has had time to spread before the parasitoids were released. Parasitoids might help protect new plantings (Duan et al. 2019; Yang et al. 2013; Johnson et al. 2016).


Photo courtesy USDA Forest Service

Double decker traps are effective at low population densities.


Photo courtesy USDA/APHIS

The purple prism trap is used to monitor EAB populations.

Conclusion

The U.S. has been invaded by exotic pests. The major control method is pesticide applications. Pheromones and attractants as part of an IPM program can reduce pesticides. Pheromone monitoring gives early warning, and leads to sprays only when needed. Pheromones and attractants can also be used in mass trapping, perimeter sprays, and attract and kill methods that can also reduce pesticide applications.

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Update

Resources

Brown Marmorated Stink Bug (BSMB)

BMSB Lures—Trécé Inc., PO Box 129, Adair, OK 74330; 866-785-1313, trece.com; Arbico Organics, 800-827-2847, arbico-organics.com

Black Pyramid Trap (Dead Inn™)—AgBio Inc, 9915 Raleigh St., Westminister, CO 80031; 303-469-9221, agbio-inc.com

BMSB Sticky Trap—Trécé, see above

Spotted Wing Drosophila (SWD)

Exclusion Netting—(ProtekNet), Dubois Agrinovation, 478 Notre Dame, CP 3550, St. Remi, Quebec, Canada J0L 2L0; 450-454-3961, duboisag.com; Harmony Farm Supply, PO Box 460, Graton, CA 95444; 707-823-9125; harmony-farm.com

SWD Lures—Trécé (Pherocon Dual™), see above

SWD Lures—Scentry Biologicals, 610 Central Avenue, Billings, MT 59102, 800-735-5323, scentry.com; Arbico, see above

SWD Monitoring Trap—Trécé, see above

Attract and Kill for SWD—Isca Technologies, 1230 W. Spring St., Riverside, CA 92507; 951-686-5008, iscatech.com

Emerald Ash Borer (EAB)

EAB Lures—Synergy Semiochemicals Corp., 7572 Progress Way, Delta, BC V4G1E9, 604-454-1122, semiochemical.com

Green funnel traps—AgBio, see above

Purple or Green Prism Traps—See Synergy above

Double Decker Traps—See McCullough and Poland 2017

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A Cure for Huanglongbing?

By William Quarles

Photo courtesy of Michael E. Rogers

Shown here is an adult Asian citrus psyllid, *Diaphorina citri*. Both adults and nymphs can transmit the huanglongbing pathogen.

Huanglongbing (HLB) or yellow dragon is one of the most serious citrus diseases worldwide. The disease is called yellow dragon because yellow shoots with asymmetrically blotched yellow leaves are the first symptoms. As the disease develops, small, green, misshapen fruit with bitter juice drop prematurely, dramatically reducing yield. Because of effects on fruit, yellow dragon is also called citrus greening. The disease in the U.S. is caused by the bacterium *Candidatus* Liberibacter asiaticus (Las). Within 3-5 years or so infected trees start to die, and currently there is no cure (Grafton-Cardwell 2013; Bové 2006; Quarles 2013).

The bacterium is spread from tree to tree by feeding of the Asian citrus psyllid, *Diaphorina citri*. Feeding damage of the psyllid can be managed, but growers "may apply as many as 6 to 15 foliar and 1 to 2 systemic treatments per year from five chemical classes in an effort to slow the speed of HLB" (Grafton-Cardwell et al. 2013). Frequent pesticide use is having a detrimental effect on bees and other beneficial insects (Grafton-Cardwell et al. 2008). Far fewer pesticides would be needed if there was a treatment that directly killed the pathogen.

Professor Hailing Jin of the University of California Riverside has found a possible cure for yellow dragon. To find the cure, she studied Australian finger limes, *Citrus australasica*, that are resistant to huanglongbing. During this work, Jin isolated the genes that give finger limes their immunity.

One of the isolated genes produces a simple peptide that kills the huanglongbing pathogen. Jin has tested the peptide in citrus over the course of two years. According to Jin, pathogenic huanglongbing bacteria are drastically reduced, and citrus leaves appear healthy again after only a few months of treatment (Bernstein 2020).

Since Australian finger limes have been safely consumed for hundreds of years, the natural peptide in the limes has a proven track record for low to no toxicity. The peptide can withstand temperatures of at least 130°F (54.4°C), and it can be applied either as a foliage spray or by injection. It moves systemically through plants and remains stable in the field. The peptide can also produce induced immunity in citrus, making it possible to "vaccinate" young citrus plants against the disease (Bernstein 2020).

According to Jin, the peptide has low cost, which is important, as the treatment must be applied several times each year. The peptide will be commercialized by Invaio under a license from UC Riverside. According to Jules Bernstein of UC Riverside, commercialization of the product will take at least a year (Bernstein 2020a).

Antimicrobial Peptides

Antimicrobial peptides like the one discovered by Jin occur in a wide range of organisms from bacteria to humans. They are short, generally positively charged peptides, usually containing 10-50 amino acids. Some are able to kill microbial pathogens directly, and others help activate host immune systems. More than 2000 antimicrobial peptides have been discovered (Mahlapuu et al. 2016).

Antimicrobial peptides have been studied by other researchers as a treatment for huanglongbing. UC Berkeley scientists identified two peptides associated with *Candidatus* Liberibacter spp. that trigger a citrus immune response (Chen et al 2020).

Shami et al. (2013) found that ethanolic and peptide extracts of a mixture of four Australian plants: lemon myrtle, *Backhousia citriodora*; billy goat plum, *Terminalia ferdinandiana*; Australian wheat grass sprouts, *Lophopyrum ponticum*, and Australian finger limes, *Citrus australasica* had antibacterial actions.

Organic Production

Professor Jin's discovery is important because there are few options for organic production of citrus affected by huanglongbing. Since the peptide is a non-synthetic product produced by Australian finger limes, it could be used in organic agriculture if production and the formulation met organic requirements.

Caution

So far, the only published information about efficacy of the peptide are press releases by UC Riverside and the Invaio corporation. Jin's efficacy studies with the peptide have not yet been published in a peer reviewed journal. According to Jin, "We just submitted the paper, which takes several months or even a year to get it published" (Jin 2020).

The peptide has been tested in greenhouse and limited field trials. How well it will work under many different field and climate conditions with several different citrus cultivars is a question to be answered over the year or so it takes to develop the product for commercial use.

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Pyrethroids and Poverty

By William Quarles

A landmark paper in epidemiology was published in December 2019 in *JAMA Internal Medicine*. Wei Bao and researchers at the University of Iowa used the NHANES, a survey of the National Center for Health Statistics, as a research source to measure the health effects of pyrethroid exposure in the U.S. NHANES is thought to be a representative sample of the U.S. population.

Since urine samples had been collected for the population, the pyrethroid pesticide exposure was detected by measuring amounts of the pyrethroid metabolite 3-phenoxybenzoic acid. The metabolite is a biomarker, the greater the pyrethroid exposure, the greater the amounts of the metabolite. Many papers have been published on the epidemiology of pesticides, some of them relying on surveys and recall to establish exposure. Biomarkers are the gold standard and represent solid research.

The researchers included a sample of 2116 adults. There were 1145 females and 971 males. Race was represented, as 11.3% were black, 14.7% Hispanic, 68.4% non-Hispanic white, and 5.6% other. The average age at the start of the experiment was 42.6. Researchers followed adverse health effects in the sample over the course of about 14 years. The median interval was 14.3 years.

The researchers then sought correlations between pyrethroid exposure and adverse health effects. They found that about 70% of the population had been exposed to pyrethroids, mostly permethrin and cypermethrin. Those with the greatest exposure were three times more likely to die of cardiovascular disease than those with low exposure. Those with the greatest exposure were also 1.56 times more likely to die of any cause.

Epidemiology research can only establish correlations, not causation. There is always a possibility that something associated with pyrethroid exposure may be a contributing factor to the adverse biological effects. The researchers controlled for "age, sex, race/ethnicity, socioeconomic status, dietary and lifestyle factors, body mass index, and urinary creatinine levels."

Nonetheless, the authors cautioned about the possibility of residual confounding: "we could not rule out the residual confounding by unmeasured or unrecognized factors." Moreover, the authors stated that "further studies are needed to replicate the findings and detetermine the underlying mechanisms."

Pyrethroids are the backbone of the pest control industry. This paper has received wide attention and discussion in the research community and industry with some criticism from other epidemiologists and even the *New York Times*. No one has been able to find fault with the methodology. Major criticism has been that the sample considered was young (mean age 42.6 years), and excess heart attacks in a population that young from a chemical agent is unusual.

It is possible that pyrethroids may be more toxic than we thought, and other experiments should be designed to explore this possibility. The researchers controlled for socioeconomic status, but that may not have adequately controlled for location and substandard housing. Several studies have found a correlation between zip code and health. People who live in substandard housing, with poor access to medical care, and exposed to unhealthy air pollution levels are more likely to show adverse health effects than those who live in a better neighborhood. Substandard housing draws roaches, bedbugs and other problems. Since improved housing through structural changes and exclusion are often not economically possible, the alternative is often application of pesticides.

Whatever the confounding factors, this study suggests it would be prudent for us to avoid exposure to pyrethroids and other pesticides whenever possible.

Bao, W., B. Liu, D.W. Simonsen et al. 2019. Association between exposure to pyrethroid pesticides and risk of all-cause and cause-specific mortality in the general US adult population. *JAMA Internal Medicine* Published online December 30, 2019.

Conference Notes

ESA Special Pheromone Report

By Joel Grossman

This Special Pheromone Report from the ESA was selected from among 2,885 presentations at the Nov. 17-20, 2019 Entomological Society of America (ESA) Annual Meeting in St. Louis, Missouri. The next ESA annual meeting is Nov. 15-18, 2020 in Orlando, Florida. For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org). Note: The 2020 ESA meeting in Orlando will be a virtual meeting online.

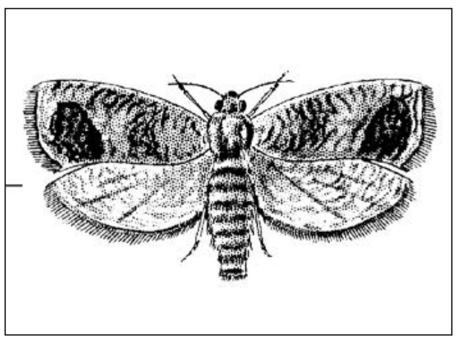
Pheromones Boost Orchard Biocontrol

"Pheromones have become the foundation of pest management programs in apple, pear and stone fruit orchards, and have allowed biological control to become feasible," said Marcia Anderson (US EPA, 2777 Crystal Dr, Arlington, VA 2220; anderson.marcia@epa.gov). Being biopesticides, pheromones have a less costly path to EPA registration, which has helped in terms of cost effectiveness for both passive- and active-release pheromone dispensers. Pheromones used for monitoring provide decision-making data, and help target pest hot spots. Monitoring traps typically have cardboard or plastic devices with pheromone emitters and sticky surfaces to capture male moths. Traps for monitoring are best placed in orchards prior to adult pest arrival, and checked daily until first pest arrival; then weekly to observe fluctuations in pest populations.

Mating Disruption

Mating disruption with pheromones reduces the need for pesticide sprays, thereby slowing development of pesticide resistance. Mating disruption also means no residue or groundwater contamination problems; fewer worker reentry issues; wildlife safety; and minimal risk to applicators and consumers. Biocontrol benefits, because mating disruption does not kill natural enemies; which means no additional pesticide sprays are needed to combat secondary pest outbreaks.

Mating disruption choices include pheromone-impregnated polymer spirals, ropes, dispensers, tubes and spray dispersing systems. "Wires, clips and circular twin tubes facilitate installation," said Anderson. "Larger product reservoirs provide residual activity up to 140 days. Single application of some products may suppress mating for most or all of the growing season." Application rates vary widely, from 2 to 400 dispensers per acre (0.4 ha).



Codling moth, *Cydia pomonella*

Walnut Mating Disruption

Three pheromone mating disruption technologies able to reduce codling moth, *Cydia pomonella*, damage in northern California walnuts to under 0.5% are spurring wider adoption in IPM programs, said Emily Symmes (Univ California, 2279-B Del Oro Ave, Oroville, CA 95965; ejsymmes@ucanr.edu). CIDETRAK® CMDA COMBO™ MESO™ (Trécé Inc, Adair, OK) devices combine codling moth pheromone, codlemone (8E,10E-dodecadien-1-ol), and pear ester, ethyl (2E,4Z)-deca-2,4-dienoate) a natural plant fragrance. CIDETRAK® is effective at high and low rates. In small orchards, CIDETRAK® can cut walnut damage by half.

Isomate® CM Mist (Pacific Biocontrol Corp, Vancouver, WA) dispensers placed in the upper tree canopy can be programmed to meter pheromone release rates (e.g. 50% or 100%). Isomate works best in larger orchards, or where there are blocks of contiguous trees. The CheckMate® Puffer® CM-O (Suterra USA, Bend, OR) meters out puffs of aerosol for mating disruption, and is also best in larger orchards.

All three walnut pheromone mating disruption products produce trap shutdown, a measure of effectiveness; when no male moths are caught in monitoring traps baited with female pheromone lures. Reduction of codling moth walnut damage below 0.5% is spurring wider adoption of mating disruption technologies by California walnut growers.

Codling Moth Mass Trapping Blend

In Washington State and the USA Pacific Northwest, where codling moth, *Cydia pomonella*, damage to commercial apples has to be under 3%, pheromones are one of the few options for organic growers, said Benjamin Jaffe (Univ Wisconsin, 1630 Linden Dr, Madison, WI 53706; bjaffe2@wisc.edu). Codling moth, which spread from Europe to the USA in the 1700s, has two flights per year (May-July) in Washington State, with each female laying up to 100 eggs. Codling moth pheromone (codlemone), which attracts male moths, is useful for monitoring and mating disruption. However, 80% of conventional apple acreage in Washington State relies on organophosphate insecticides for codling moth control. Organic apple growers, who have few other options, are big users of codling moth pheromone mating disruption.

Conference Notes

Mating disruption is less applicable in small orchards (<4 acres or 1.6 ha) with high codling moth populations and insecticide resistance. However, Attract & Trap (A&T) has proven useful in these situations, and can even be scaled down for use on individual trees. Attract & Trap utilizes a 3-component codling moth lure attracting both males and females. The A&T lure is formulated with pear ester, ethyl (2E, 4Z)-deca-2,4-dienoate, a kairomone released by ripe fruit; acetic acid, produced by microbial fermentation of fruit sugars or ethanol; and n-butyl sulfide.

This is "a more effective mass-trapping paradigm," because removal of females has a larger impact on reducing pest population growth than removing males with codlemone, said Jaffe. From 2014 to 2017, mass trapping near Wapato, WA used 50 A&T traps per acre (0.4 ha) in paired 4-acre (1.6-ha) plots within larger apple orchards where codling moth damage was previously over 30%. Not only did A&T reduce codling moth populations in small orchards, but apple damage was at about the 3% commercially acceptable level.

A&T was also tested on widely-separated, individual unmanaged apple trees, which are common around homes in Washington state. Damage reduction was statistically significant, from 60% down to 50%, "but not great," said Jaffe. The problem with only one trap per tree was that homeowner trees suffered heavy damage on the side opposite the trap. Individual trees had only six female codling moths during the 13-week season, versus 35-70 in small orchards, "which is why A&T worked better in small orchards than on individual trees." Nonetheless, since homeowners' individual trees are a source of orchard infestation in Washington state, any reduction is welcomed. Jaffe is currently employed creating an analogous program for Wisconsin apples.

Dogwood Borer Mating Disruption

Dogwood borer, *Synanthedon scitula*, a problem in the Mid-Atlantic and northern states such as New York, girdles outside tree edges, causing reduced vigor, stunting and longer-term tree death in high-density commercial apple orchards and nurseries, said Peter Jentsch (Cornell Univ, Highland, NY 12528; pjj5@cornell.edu). Adult male dogwood borer seasonal emergence is monitored by hanging tent traps with female pheromone lures in trees. Degree-day models help time egg hatch and base of tree treatments. Dogwood borer frass (excrement) and cankering are found at tree bases, which are treated with chlorpyrifos. However, California has already canceled chlorpyrifos registration, and New York is in the process of doing the same. Reduced risk pesticides (e.g. indoxacarb, chlorantraniliprole, fenpropathrin) require more precise timing and multiple tree base applications. IPM also includes using B-9 and Geneva rootstocks, which are less prone to adventitious growth at the tree base.

Another alternative is mating disruption, which involves flooding orchards with excessive quantities of female pheromones to confuse males. Pheromone mating disruption was tested at the Schoonmaker orchard in NY: 1) CIDETRAK® MESO™ @ 32 traps/acre (80 traps/ha); 2) CIDETRAK(® MESO™ @ 96 traps/acre (240 traps/ha); 3) chlorpyrifos (Lorsban® trunk treatment. Pheromone mating disruption with 32 traps/acre (80 traps/ha) was better than 96 traps/acre (240 traps/ha) or chlorpyrifos tree base applications.

Wisconsin Cranberry Mating Disruption

Wisconsin produces 60% of the USA cranberry crop, mostly in the south, where conservation-minded growers drive their tractors on the beds surrounding the cranberry marshes to avoid compaction, said Elissa Chasen (Univ Wisconsin, 1575 Linden Dr, Madison, WI 53706; elissa.chasen@usda.gov). Sex pheromones are commercially available for the three major moth pests: Sparganothis fruitworm, *Sparganothis sulfureana* (Tortricidae), which has displaced cranberry fruitworm, *Acrobasis vaccinii* (Pyralidae), as the major pest; and blackheaded fireworm, *Rhopobota naevana* (Tortricidae). Mating disruption floods the air with female moth sex pheromones to confuse males. Growers have been experimenting with pheromone delivery systems; including guns, booms to reach across marshes and UAVs (unmanned aerial vehicles).

In central WI, where *S. sulfureana* is the major concern, growers achieved mating disruption success using a micro-encapsulated carrier (Trécé Inc, Adair, OK), provided the pheromone was applied before heavy rains set in. The standard practice is two separate applications, beginning at the start of moth flights. At six cranberry marshes in north and central WI, growers applied a second pheromone application three weeks after the first. By week four, one week after the second application, fruitworms declined to zero. Cranberry fruit damage was reduced 75%, versus 50% with other mating disruption technologies, such as SPLAT (ISCA Global, Riverside, CA).

Sugar Beet Root Maggot Pheromone

Sugar beet root maggot, *Tetanops myopaeformis*, is a major USA and Canadian sugar beet, *Beta vulgaris*, pest whose larval root feeding "can cause substantial losses in tonnage and sugar yield," said Erik Wenninger (Univ Idaho, 3806 N 3600 E, Moscow, ID 83341; erikw@uidaho.edu). IPM programs can utilize sugar beet root maggot aggregation pheromone, a blend of 9 volatile compounds, to improve monitoring and economic thresholds; and for mass trapping and attract-and-kill. Synthetic (R)-(-)-2-nonanol is as effective as the natural aggregation pheromone blend, but costs $90/gram ($255/oz); as it is expensive for chemistry labs to purify or separate the (R) and (S) isomers (mirror-image molecules). Fortunately, a blend of (R) and (S) isomers costing 65 cents/gram ($1.84/oz) is as effective as the (R) isomer alone or the natural blend.

Impregnating cotton dental wick lures with the (R)- and (S)-(-)-2-nonanol aggregation pheromone blend improves the unbaited orange sticky stake traps beet growers currently use for monitoring and timing treatments. Adult root maggot flies normally prefer orange and black and avoid white, but adding the aggregation pheromone makes white attractive. Male and female flies are both attracted to the aggregation pheromone, though the bias is male. An IPM program at the Amalgamated Sugar Company changes out traps three times per week. But many beet growers are also going back to formulating attract-and-kill and mass traps with sugar beet juice, a practice abandoned when newer insecticides appeared.

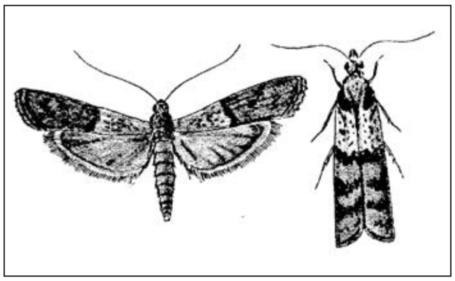
Indian Meal Moth

Indian meal moth (IMM), *Plodia interpunctella*, is "one of the most serious stored product pests around the world," attacking coffee beans, birdseed, powdered milk, chocolates, fruits, nuts and grains. It "got its name since it was found on a meal made of Indian corn or maize in United States," said Xiaodan Pan (Rutgers, 96 Lipman Dr, New Brunswick, NJ 08901; xiaodan.pan@rutgers.edu). "IMM do not feed on intact coffee beans and do not cause direct damage. But the larvae on coffee bean bags and the silk they produce cause customer complaints. The cost to monitor and control IMM populations per coffee bean warehouse is tens of thousands of dollars each year."

New Jersey warehouses receive coffee beans from 30 countries, sometimes infested on arrival. "Mating disruption is very effective in reducing IMM numbers," suppressing IMM reproduction in 2019, said Pan. CIDETRAK® IMM dispensers (Trécé Inc, Adair, OK) were placed throughout two New Jersey coffee warehouses in April and September of 2019. The mating disruption active ingredient, 3.2% (9Z, 12E)-9,12-tetradecadien-1-yl acetate, is also used in monitoring traps.

Monitoring Traps

Pheromone monitoring traps (Pro-Pest Pheronet; J.F. Oakes LLC) were replaced every four weeks or when over 50 IMM adults were trapped in warm seasons; every eight weeks in winter. "IMM first appeared in monitoring traps in mid-May 2019," said Pan. "There are two IMM peaks on both pheromone and sticky traps. The first one may be from overwintering IMM, and the second peak may be from bags newly received in summer. Also there were much more IMM activity during second peak." Sticky traps, which capture more females than pheromone traps, indicated more female IMM in August and September, versus early summer. Steaming and double-sided tape on warehouse walls killed IMM larvae, preventing movement up the wall. Sticky traps placed on warehouse floors identified infested pallets, which were shunted into large freezers constructed from modified trailers.



Indianmeal moth, *Plodia interpunctella*

Freezing

"Cold disinfestation often requires long exposure periods, measured in days," said Pan. "A better commercial freezer is needed to get more efficient in treating IMM with cold." In lab tests, two days at -10°C (14°F) or two hours at -15°C (5°F) produced 100% IMM larval mortality (Athanassiou et al, 2018). Killing all IMM life stages required below -20°C (-4°F), as 5th instar larvae are especially tough (cold tolerant). Coffee warehouse freezers, big containers capable of -30°C (-22°F), only went to -15°C (5°F) with heavy loads; so it required seven days to kill all IMM life stages on 175 150-lb (68-kg) coffee bags stacked on pallets. With fewer coffee bags, less freezer time is needed.

Disrupting Swede Midge Mating

Swede midge, *Contarinia nasturtii,* "causes drastic losses for Brassica crops such as broccoli and cauliflower in the northeastern United States and Canada," with organic growers losing 100% of broccoli and kale crops as the pest spreads through Ontario, Quebec, New Hampshire, Vermont, New York, Massachusetts, Wisconsin and Michigan, said Andrea Swan (Univ Vermont, 63 Carrigan Dr, Burlington, VT 05405; andrea.swan@uvm.edu). Scarred stems and puckered leaves reduce crop marketability; and one swede midge maggot can completely destroy one cauliflower or cabbage head.

A 2 mm (0.08 in) long fly in the family Cecidomyiidae with multiple overlapping generations, adult swede midge flies live 2-5 days after emerging from pupae in the soil. During her brief 2-5 day life, an adult female fly can lay over 100 eggs. Eggs are laid mostly on plant tips (meristems), where larvae are protected from sprays and feed for 1-3 weeks before dropping to the ground to pupate in the soil. Swede midges overwinter in the soil, sometimes for multiple years. There are no organic remedies. Conventional growers often start with systemic neonics when transplanting, then spray more pesticides as the crop develops; which destroys IPM programs for other cole crop pests. Hence, swede midge pheromone mating disruption interests both organic and conventional cole crop growers in Canada and the USA.

Conference Notes

Areawide Mating Disruption

"Management approaches are needed to prevent females from laying eggs on host plants, either by disrupting mating or adult activity," said Swan. "Some phytophagous insects will migrate to host plants before mating while others will mate at the site of emergence regardless of the absence of host plants." When unmated adult swede midges were caged with cauliflower (host plant), tomato (non-host), Swiss chard (non-host) and fake plants, they mated successfully regardless of presence or absence of host plants and then sought out host plants for egg laying. Thus, in contrast to some cropping systems, host plant volatiles which can interact with pheromones and even stimulate female pheromone production are not a factor with swede midge. This means swede midge mating disruption must extend beyond current cole crop fields and include fields previously in cole crop rotations (where emergence of swede midge adults from the soil is likely).

Microcontroller Monitoring and Mating Disruption

"Microcontroller systems are increasing in use as inexpensive methods to produce precisely timed acoustic and visual stimuli for insect trapping and mating disruption," and in lab tests have achieved 80% mating disruption of Asian citrus psyllid (ACP), *Diaphorina citri*, a vector of huanglongbing (HLB), which has cost Florida growers billions of dollars, said Richard Mankin (USDA-ARS, 1700 SW 23rd Dr, Gainesville, FL 32608; richard.mankin@ars.usda.gov). Microcontrollers can help sift through background "noise" for early detection of ACP male-initiated vibrational courtship calls and female responses (i.e. quick "duetting replies"). Detecting low population densities of ACP could prove quite useful to IPM programs.

Microcontrollers can also be used to mimic female ACP responses to male courting calls; useful in mating disruption. In IPM programs, microcontroller systems emitting "synthetically generated" female ACP response calls (multiple harmonics of 170-250 Hz wingbeat frequencies) can function as male traps for monitoring or population control.

Repellent Mold Mite Pheromones

Mold mites (ham mites), *Tyrophagus putrescentiae*, "one of the most devastating cosmopolitan arthropods of dry-cured hams," also infest semi-moist pet foods, cheese, dried mushrooms, corn, sorghum and other stored products, and as a fumigation alternative might be controlled using repellent pheromones, said Naomi Manu (Kansas State Univ, 123 W Waters Hall, Manhattan, KS 66506; nmanu30@k-state.edu). "Mites produce species-specific combinations of compounds." For example, "neral, geranial, and neryl formate can represent sex, alarm and aggregation pheromones." Mold mite volatiles such as neral, geranial, neryl formate and tridecane also function as kairomones.

"Mold mites tend to aggregate in food, however they disperse when one or a few of them are disturbed," said Manu. "Neryl formate was identified as the alarm pheromone in mold mites by Kuwhara, 1975." When presented with alarm pheromone, "mites move away from danger." In Petri dish experiments with treated filter paper, mold mites were repelled by crushed mite extracts and synthetic neryl formate. Filter paper barriers treated with alarm pheromone deterred mold mites from moving towards pieces of ham.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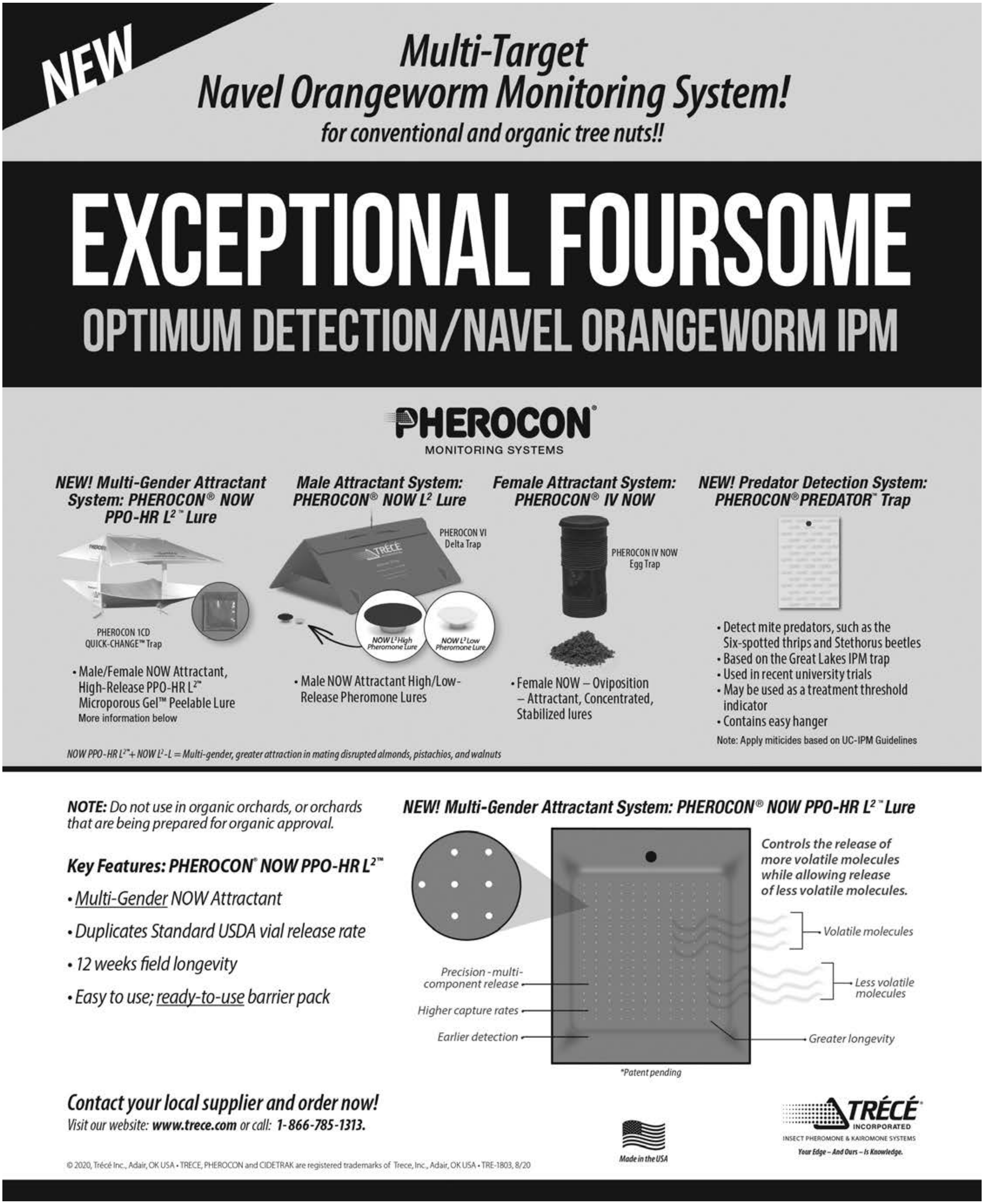
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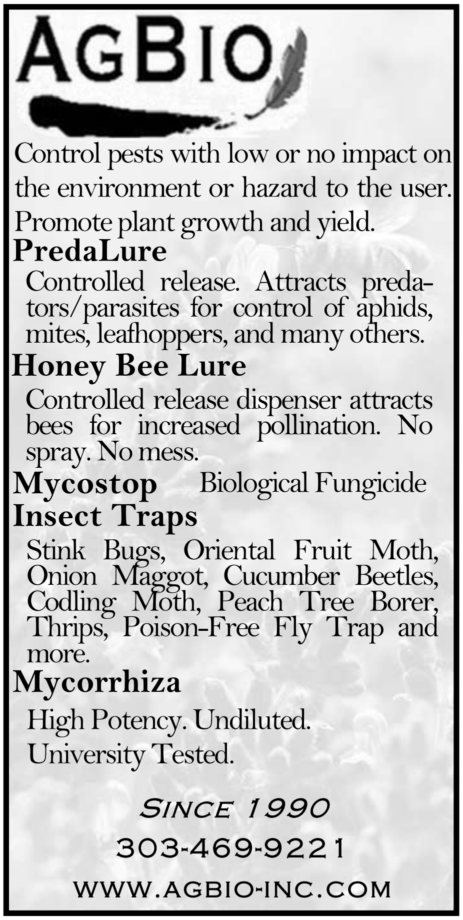
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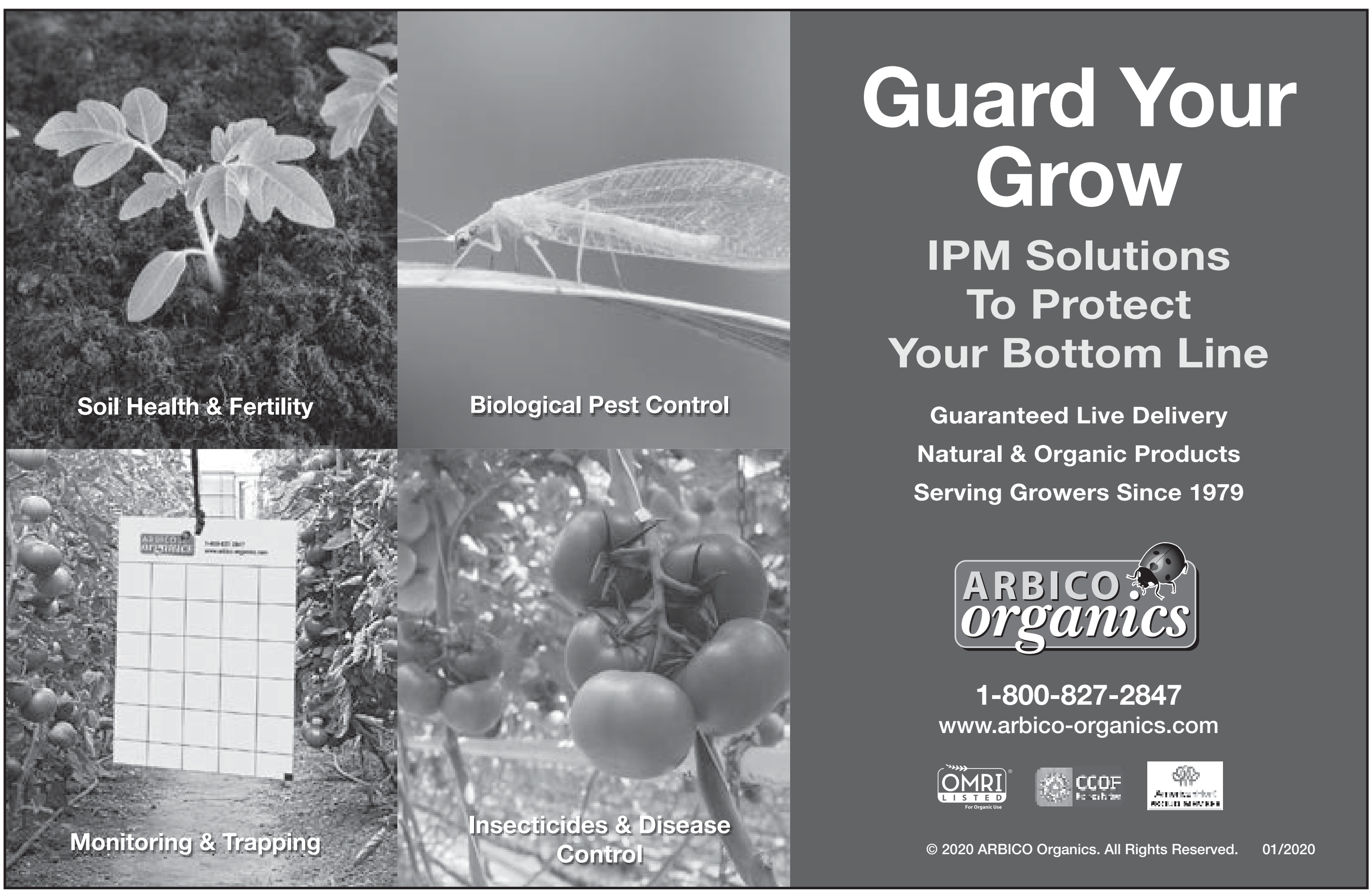
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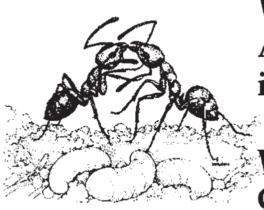

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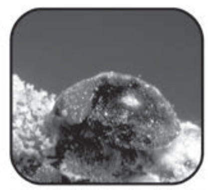

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