The IPM Practitioner
Monitoring the Field of Pest Management
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Mating Disruption for the Navel Orangeworm

By William Quarles

The navel orangeworm (NOW), *Amyelois transitella*, has been in the U.S. for about 100 years. It was initially a pest of oranges, but soon developed a taste for almonds, walnuts, and pistachios. It is now a key pest of those crops, and its importance has been increasing with global warming. NOW overwinters as larvae and pupae in unharvested nuts, and warmer winters have allowed larger numbers to survive. Rate of development also increases with temperature, leading to earlier crop infestations (Wade 1961; Haviland et al. 2021). (See Box A. Biology of the Navel Orangeworm.)

Mating disruption as part of an IPM program that includes sanitation, biocontrols, resistant cultivars, and early harvest can spare the bees and other beneficial insects found in almond and walnut orchards from NOW insecticide sprays. In almonds NOW mating disruption can, in some cases, replace some or all NOW sprays while maintaining good crop protection. Since most of the research is concentrated on almond production, that is the focus of this article (Wade 1961; Zalom et al. 1984; Wilson et al. 2020; Haviland et al. 2021).


USDA Photo by Peggy Greb

Shown here is a fifth instar larva of the navel orangeworm, *Amyelois transitella*, infesting a Nonpareil almond. Feeding damage ruins the almond, making it unmarketable.

Pest Damage

Infestations are concentrated in nuts approaching maturity or those previously damaged. Larvae feed directly on the kernels, making them unmarketable, reducing the price of the overall crop. Damage to almonds, *Prunus dulcis*, averaged 8% or more each year during the 1970s. Damage was reduced to an average of about 4% in the 1980s and 1990s due to strict orchard sanitation measures. An effort was made to remove infested unharvested almonds (mummies) from orchards (Higbee and Siegel 2009).

Discovery that NOW damage was associated with infections of the fungus *Aspergillus flavus* and production of carcinogenic aflatoxins led processors to demand damage thresholds less than 2%. The low damage thresholds required draconian sanitation measures (see below) and encouraged the development of NOW mating disruption (Palumbo et al. 2014; Higbee and Siegel 2009; Haviland et al. 2021).

Navel orangeworms overwinter as larvae and pupae in unharvested nuts (mummies) left on the trees and on the ground. Emerging adults lay eggs in April, usually on unharvested nuts (See Box A).

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The IPM Practitioner
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The *IPM Practitioner* is published six times per year by the **Bio-Integral Resource Center (BIRC)**, a non-profit corporation undertaking research and education in integrated pest management.

Update

In the middle of the summer the hull of the developing almond splits open. At this time almonds are most vulnerable to NOW damage. The hullsplit provides entrance to the developing larvae. Due to different maturity rates of different cultivars, damage can continue over a 3-month period after hullsplit occurs in early cultivars (Haviland et al. 2021).

There are about a million acres (405,000 ha) of almonds in California worth $5.5 billion/year. There are also about 350,000 acres (142,000 ha) of walnuts ($0.8 billion), and 264,000 acres (107,000 ha) of pistachios ($2.6 billion) (Wilson et al. 2020). NOW damage to almonds ranges from 1.2 to 2.4% of the one billion kg (2.2 billion lbs) harvested each year. This damage amounts to at least $75 million each year (Haviland et al. 2021).

Cultural and Biocontrol

Cultural methods include destroying unharvested nuts (mummies) on the trees, nuts on the ground, culls and nut waste products. Early harvest and resistant cultivars can help control the damage. Hard shell varieties are more resistant than soft shell almonds such as Nonpareil. Controlling codling moth, *Cydia pomonella*, helps control NOW, as NOW prefers nuts with previous damage (Wade 1961).

Tree mummies are nearly twice as likely to be infested as ground mummies. Strict sanitation measures of less than 0.2 mummies per tree (1 mummy per 5 trees) and less than four mummies on the ground near each tree are necessary to reach damage thresholds of less than 2% (Higbee and Siegel 2009).

Natural biocontrols found in the orchards include the parasitoids, *Perisierola breviceps* (Bethylidae), *Mesostanus gracilis* (Ichneumonidae), and *Bracon hebetor* (Braconidae). NOW adults and eggs are attacked by the mite *Blattisocius*, and black hunter thrips, *Leptothrips mali*, may eat eggs. Larvae are attacked by the fungus, *Beauveria bassiana* (Wade 1961).

The parasitoids *Bracon hebetor, Pentalitomastis plethoricus*, and especially *Goniozus legneri* are commercially available for navel orangeworm biocontrol. The latter two are imported species. Usefulness of biocontrol may be limited due to the very low damage thresholds required because of aflatoxin contamination. Biocontrols must be combined with other methods in an IPM program (BIRC 2015; Wilson et al. 2020; Haviland et al. 2021).

Insecticides

Insecticides are one component of conventional nut orchard management. Organophosphates such as chlorpyrifos were used almost exclusively until recently. For the last five years, there has been a concerted effort to ban organophosphates, and they have been replaced by generally more expensive pesticides. Bifenthrin, the IGR methoxyfenozide, and the insecticide chlorantraniliprole are used currently in conventional management. Organic farmers use spinosad and *Bacillus thuringiensis* (BT). Insecticide management should be discouraged because of its effects on the environment, development of secondary pests, and the eventual resistance problems. For instance, NOW is becoming resistant to bifenthrin (Wade 1961; Wilson et al. 2020; Haviland et al. 2021).

Typically, one spray is applied at hullsplit, and another about 2-3 weeks later. When pest pressure is high, an additional spray is applied in the spring when eggs are hatching (Haviland et al. 2019). Almonds flower in the spring, and bees are used for pollination. Any pesticides must be used with care during these times.

Pheromone Composition

The sex pheromone of NOW is emitted by females to attract males. It consists of three components: the aldehyde (11Z,13Z)-hexadecadienal (hereafter called hexadecadienal), the alcohol (11Z,13Z)-hexadeca-

Update

Box A. Biology of the Naval Orangeworm

The navel orangeworm came from Mexico in 1920 and was initially a pest of oranges. It was found in Southern California in 1942, but eventually dispersed throughout the state. It switched hosts from citrus to nuts and was found in California walnuts in 1946 (Wade 1961).

Life stages are eggs, 5-7 larval stages, pupae, and adults. Adults are silver gray and wings have a dark pattern of wavy lines. Wingspans are about an inch (23 mm) wide. Body length is up to half inch (12 mm). Eggs are about 1 mm in diameter. Egg color changes from white to orange as the insect develops. Hatching larvae are reddish orange, but color of later instars vary with the food source. Heads are a dark reddish brown. Dark brown pupae are a maximum half inch (12 mm) in length (Wade 1961).

Most mating occurs one to two days after adult emergence from the pupa. Mating is confined to early morning hours, and eggs are laid on or near nuts. Females average about 85 eggs, but can lay

USDA Photo by Peggy Greb

Adult navel orangeworm on a Nonpareil almond

as many as 244. Incubation period is determined mainly by temperature, and eggs hatch in about 5 days at an optimum temperature of 27.5°C (81.5°F)(Wade 1961).

Larval development is faster at higher temperatures, about 55 days at 25°C (77°F) and 43 days at 30°C (86°F). Most favorable humidity is 75-95%. Larvae develop faster on almond (42.8 days) than walnut (51.7 days). Development from egg to adult on almond is about 56 days (2 months). Adults live about 11 to 12 days, longest at 25°C (77°F) and 75% RH (Wade 1961).

Nuts damaged by weather or codling moths are prime targets. NOW can penetrate the shell of mature almonds, but walnuts are entered through the stem end. Larvae rasp the surface or bore into the nutmeat, ruining the nut with frass and webbing. The largest number of larvae found on one almond was 17 (Wade 1961).

NOW overwinters as larvae and pupae. Nuts left on the tree (mummies) or on the ground are a prime area of development. Survival is greater in tree nuts versus those on the ground. Soft shelled almonds are preferred by NOW. There are four moth flights. The first flight is from emerging overwintering moths. Eggs are found at the start of April. Developing almonds are infested by July, pistachios and walnuts are infested later (Wilson et al. 2020).

dien-1-ol, and a novel 23-carbon compound (3Z,6Z,9Z,12Z,15Z)-tricosapentaene. Addition of a fourth component, the alcohol (11E,13Z)-hexadecadien-1-ol gives greater attraction in some tests, but not in the field (Leal et al. 2005; Kanno et al. 2010; Higbee et al. 2017).

Hexadecadienal was the first component discovered, and was first used for mating disruption in the field by Landolt et al. (1981). It is an effective mating disruptant, but is not attractive to male moths in the field (Higbee et al. 2017). Though the 3-component mixture is more attractive, the commercial mating disruption pheromone is hexadecadienal because it is effective, readily available, and economical (Haviland et al. 2021).

Commercial Products

In general, pheromone mating disruption formulations range from microencapsulated pheromones sprayed over a large area, to pheromones embedded in plastic ropes or membranes applied to the crop by hand, to aerosol cans (puffers) with timed pheromone emissions. Hand-applied ropes or membranes slowly release pheromones by diffusion. Meso diffusion dispensers release pheromones more rapidly than other diffusion dispensers (Benelli et al. 2019; Haviland et al. 2021).

There are three aerosol (puffer) formulations and one diffusion dispenser (meso) formulation currently available for NOW mating disruption. Sprayable pheromones are available, but have had limited adoption. The navel orangeworm is sexually active for the last three hours of the night, and the puffers available have different timing programs. One product is timed for constant emission over a 12-hour period (Checkmate®). Another emits for a shorter period, but produces higher concentrations during the 3-hour activity period (Isomate®). A third puffer can be programmed to release pheromone at variable rates throughout the night (Semios®) (Wilson et al. 2020; Haviland et al. 2021).

Puffer Experiments

Shorey and Gerber (1996) showed that puffers or dispensers emitting hexadecadienal and deployed along the periphery of test plots provided effective mating disruption for NOW. Higbee and Burks

(2008) found that grid deployment was more effective.

Using a programmable puffer, Burks and Thomson (2019) found that mating suppression measured by pheromone monitoring traps increased with frequency of emission. Emissions over the last 4-6 hours each night gave the same results as a 12-hour program.

A study with pheromone monitoring traps in pistachios showed that stopping pheromone releases 1-2 hrs before the end of sexual activity was not detrimental to mating disruption. Thus, the mating disruption pheromone has a persistent effect on males (Burks and Thomson 2020). Puffers can produce NOW mating disruption effects up to 2 km (1.2 mi) away from a treated orchard. But there is no residual activity after 24 hours (Haviland et al. 2021; Burks and Thomson 2020).

Monitoring

Both pheromone and egg traps are used for monitoring NOW, but pheromone traps are more reliable. Egg traps are cylinders baited with almond meal that attract females. Pheromone attractants are deployed in wing traps and delta traps. Wing traps are more efficient than delta traps, but the latter is easier to use (Wilson et al. 2020).

When mating disruption is used, alternatives to pheromone traps must be found. Saturation of the air with pheromones makes it difficult for males to find monitoring traps. Phenyl propionate (PPO) or synthetic kairomone blends are used as alternate attractants. PPO is more attractive than the kairomone blend. Both sexes are captured by these attractants. PPO plus pheromone can be used as a trap attractant during mating disruption (Burks et al. 2020a; Wilson et al. 2020).

Efficacy

Puffers and meso dispensers are all effective for mating disruption. Choice depends on how well the pheromone integrates into other elements of a pest management program. For instance, Trécé has a combination meso dispenser effective for mating disruption both in codling moth and naval orangeworm. Since NOW often infests damaged nuts, reducing codling moth damage can potentially help reduce NOW damage (Wade 1961). (See Resources).

USDA Photo by John Beck

Almond hulls naturally split open as the nut matures on the tree, making infestation easier.

Reasons to Use NOW Disruptants

In almonds, growers usually apply two or three insecticide sprays starting at hullsplit. But in some cases, an additional spray is applied in the spring, when eggs are starting to hatch. The financial benefit of NOW mating disruption (MD) is “a linear function of NOW pressure.” Since costs of MD are constant, increased pest pressure leads to increased damage reduction at no additional cost. Addition of MD to a conventional program can lead to damage reduction up to 80%. In one study, increase in crop value was $370/ha ($150/acre) and the cost of MD was $313/ha ($127/acre)(Haviland et al. 2021).

NOW MD also allows growers to reduce or eliminate insecticide applications and still make a good profit. In one case, MD was used to replace two insecticide sprays, and the result was a net gain in crop value of $83.5/ha ($34/acre) (Haviland et al. 2021). Mating disruption is especially useful in organic production where choice of insecticide is limited.

Limitations of NOW Disruptants

A major limitation of mating disruption for NOW in almond orchards is immigration of already mated females from surrounding nut orchards. For instance, damage to almonds decreases with distance from pistachio orchards with minimal interactions at distances greater than 3 miles (5 km)(Higbee and Siegel 2009).

Because of the tendency of NOW to disperse, NOW mating disruption in orchards less than 40 acres (16 ha) is not recommended unless it is well isolated from other nut bearing orchards. Mating disruption is best when used in an areawide program (Wilson et al. 2020; Sappington and Burks 2014).

Comparison of Products

The efficacy and economics of NOW mating disruption have been quantitatively studied only in almonds. Puffers and meso dispensers gave similar protection. In an efficacy study of test plots in four orchards, total kg of damaged almonds with MD protection ranged from 38.2 to 45.4 kg/ha (34 lb/acre to 40.4 lb/acre). Almonds not protected by mating disruption showed 76.7 kg/ha (68.3 lb/acre) of damage. Standard deviations of measurements were large, and statistically, all treatments gave similar damage reduction, ranging from 41-50%. Average increase in crop value was $370/ha ($150/acre)(Haviland et al. 2021).

Damage varied with the cultivar. For almonds not protected by mating disruption, average damage was 1.7% for Nonpareil, 2.0% for Fritz, and 3.6% for Monterey.

Damage in almonds protected by mating disruption ranged from 0.8 to 1.5% in Nonpareil, 0.7 to 1.2% in Fritz, and 1.2 to 2.4% in Monterey (Haviland et al. 2021).

Self pollination of almonds leads to poor yields. Several different cultivars are typically planted to insure cross pollination. In a direct comparison study in 9 orchards, addition of mating disruption gave a 65.4% reduction in Nonpareil almond damage and a 78.3% damage reduction in pollinizer cultivars (Fritz and Monterey). The average damage reduction over all treated orchards and all cultivars was 70.2% (60.5 kg/ha damage untreated to 18.0 kg/ha with MD). Average increase of crop value was $357/ha ($145/acre) (Haviland et al. 2021).

Increased crop value exceeded the cost of mating disruption with a breakeven point of 0.86-1.06% almond damage. The 10-year average of almond damage in California is 1.35%, so generally mating disruption in almonds pays for itself and leads to increased profits (Haviland et al. 2021).

Organic Production

About 2% of California nut production is certified organic. Growers use cultural methods, biocontrol, early harvest, and resistant species. If sprays are needed, spinosad and *Bacillus thuringiensis* are applied (Wilson et al. 2020; Haviland et al. 2019).

The Trécé Cidetrak® NOW Meso formulation is certified for organic production in almonds, figs, pistachios and walnuts. The Cidetrak® CDMA for codling moth and the Cidetrak NOW Meso combination formulation is also certified for organic production. Among the aerosols, Semios® NOW Eco is approved for organic production (Trécé 2017; Semios 2018).

Conclusion

Addition of mating disruption to an IPM program can lead to decreased NOW damage and increased profits. In almonds, mating disruption can in some cases replace some or all NOW insecticide sprays, leading to good crop protection and good profits. Insecticide reduction has positive environmental effects, protecting workers from exposure and leading to fewer impacts on beneficial insects. Mating disruption is especially useful in organic production, helping growers to meet the strict damage thresholds required by processors.

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Resources

Checkmate® NOW Ace Puffer, Suterra,20950 NE Talus Place, Bend, OR 97701; 1-866-326-6737; suterra.com

Cidetrak® NOW Meso (organic formulation), Trécé, PO Box 129, Adair, OK 74330; 866-785-1313; trece.com

Isomate® Mist NOW Puffer, Pacific Biocontrol, 14615 NE 13th Court, Suite A, Vancouver, WA 98685; 360-571-2247; pacificbiocontrol.com

Semios® NOW Eco (organic formulation), Semios Bio Technologies, 480-887 Great Northern Way, Vancouver, BC V5T 4T5 Canada; 1-604-229-2044; semios.com

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Update

Pesticides and Soil

By William Quarles

Each gram of soil contains millions of microbes and invertebrates that regulate soil health and affect plant growth, soil structure, soil fertility, and even greenhouse gases. Pesticide effects on soil organisms have been generally ignored by regulators. But neonicotinoid pesticides have drawn attention to pesticide soil contamination. Neonicotinoid seed treatments leave more than 90% of the active ingredient in the soil. Neonicotinoids are persistent and residues can build up in soil (Goulson 2013).

Pesticide applications especially in corn and soybeans have generally increased since the introduction of GMO crops. Glyphosate applied to Roundup Ready GMO crops can change the microbial distribution in the soil. Plant disease problems are increasing, and there was a 10-fold increase in the percentage of soybean acres treated by fungicides between 1994 and 2015, and a 20-fold increase in insecticides (Wolmarans and Swart 2014; Babujia et al. 2016; Quarles 2017). Effect of pesticides on soil microbes is reviewed by Puglisi (2012).

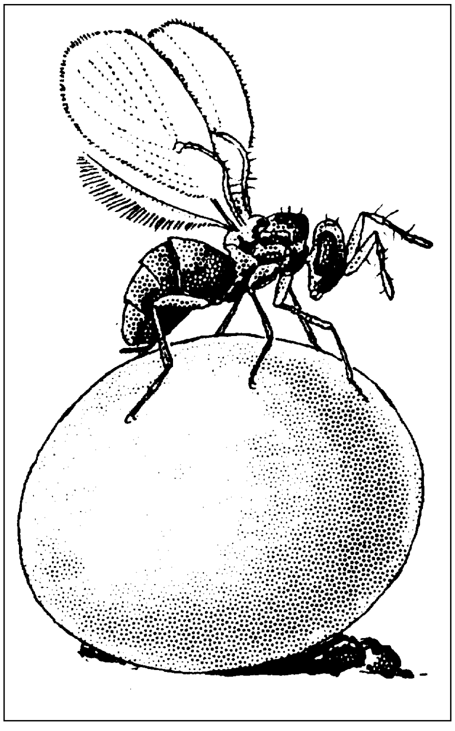
Effects on Soil Invertebrates

Tara Gunstone and coworkers at the Center for Biological Diversity have just published a massive review on the effects of pesticides on soil invertebrates. They reviewed about 400 published studies and more than 2800 experiments, involving more than 275 species or types of soil organisms and 284 different pesticides or pesticide mixtures. About 70% of the time, soil pesticides caused harm to soil invertebrates. Factors measured included mortality, abundance, biomass, behavior, reproduction, structural changes, biochemical markers and others. Harmful changes most often seen were structural changes (97.2%), biochemical changes (85.4%), reproduction (78%), and mortality (75%) (Gunstone et al. 2021; Donley and Gunstone 2021).

Most Harm

Both laboratory and field experiments were reviewed. Most of the studies reviewed were on insecticides, followed by herbicides, fungicides, and pesticide mixtures. Greatest negative effects from combined pesticides were on earthworms (78.6%), potworms (80.6%), groundnesting bees (77.8%), and parasitic wasps (78.9%).

Insecticides took a toll on earthworms (84.2%), millipedes and centipedes (83.3%), woodlice (80.7%), beetles (79.3%), groundnesting bees (81.8%), and parasitic wasps (78.6%). Surprisingly, there were also significant effects on earthworms from fungicides (77.7%) and herbicides (71.7%).



Greatest soil pesticide harm was to earthworms, groundnesting bees, and parasitoids such as *Trichogramma* sp. shown here.

Parasitic wasps were affected by herbicides (100%) and fungicides (50%). Potworms were more affected by herbicides (87.8%) and fungicides (83.1%) than insecticides (71.1%). Beetles were most affected by neonicotinoids (91.5%) and least affected by pyrethroids (50%).

Bumblebees showed less overall harm than other insects studied. According to Gunstone et al. (2021), most of the bumblebee studies reviewed were field studies that generally show less pesticide harm than laboratory studies. But insecticides and especially neonicotinoids "negatively affected about 50-60% of the bumble bee tested parameters."

Regulatory Impacts

The EPA currently uses the honey bee, *Apis mellifera*, to assess pesticide damage to invertebrates. It is good that honey bees are protected, but the bulk of soil invertebrates are not considered in regulation. Groundnesting bees, parasitic wasps and others are clearly impacted, but are not considered.

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Update

Forever Chemicals

By William Quarles

Forever chemicals are not easily degraded by normal biological processes. As a result, they have very long half lives in the environment. These substances are generally chlorinated or fluorinated hydrocarbons that were released into the environment without proper screening and with little or no thought about the consequences (Rachel Carson 1962).

One of the first forever chemicals was DDT. DDT (dichloro-diphenyl-trichloroethane) is a chlorinated carbon insecticide. During World War II, it was hailed as a miracle, reducing insectborne diseases at low cost. Around 1.35 billion tons, about 7.5 pounds per person, were applied in the U.S. before the publication of Rachel Carson's *Silent Spring* (Arnold 2021).

DDT is fat soluble and accumulates in the food chain. DDT led to a number of environmental problems, such as production of thin shelled eggs that decimated bird populations. Public opinion led to a ban on DDT in 1972. But effects of DDT are lingering, and we all have DDT in our bloodstream (Rachel Carson 1962; CDC 2009).

Effects Linger for Generations

New research shows that the toxic effects of DDT are transcending generations. Daughters of women exposed to larger amounts of DDT while pregnant have shown a greater incidence of breast cancer. Female grandchildren of these women are also showing measurable adverse effects, such as obesity and early onset of their periods (Arnold 2021). The grandchildren are too young to have manifested breast cancer, but the researchers conclude, "ancestral exposure to environmental chemicals, banned decades ago, may lead to the development of earlier menarche and obesity, which are established risk factors for cancer and cardiometabolic diseases" (Cirillo et al. 2021).

Perfluoro Organic Compounds

Perfluoro organic compounds such as PFAS (perfluoroalkyl substances), PFOA (perfluorooctanoic acids), and PFOS (perfluorooctane sulfonates) are water soluble, but some of the long chain compounds can bioaccumulate. PFOS and PFOA can persist in the human body (CDC 2018).

These substances were used as non-stick coatings for frying pans and as fire retardant chemicals. EPA standards for drinking water are less than 70 ppt or 70 ng/liter. [A nanogram (ng) is one-billionth of a gram.] (CDC 2018).

A Harvard study shows that about six million people are exposed to drinking water with PFAS levels above the toxic threshold (70 ng/liter). About 75% of the contamination occurs in 13 industrial states, including California. Drinking water systems in the Central Valley of California and around San Diego exceed the 70 ng limit. Very large concentrations are found in Arizona and Pennsylvania (Hu et al. 2016).

PFAS occurs both in groundwater and surface water. Wastewater treatment plants do not reduce it, and biosolids from these plants can contaminate crops when they are applied to soil. It can be removed from drinking water sources by carbon filtration and reverse osmosis, but these processes are expensive. Home water filters remove some, but not all of PFAS (Hu et al. 2016).

More than 97% of Americans have PFAS in their bodies. Levels are typically about 5 ppb. According to the molecule, half life can range from 2-9 years (CDC 2018). Perfluoro organic compounds cross from the mother's bloodstream into the placenta, resulting in lower birth weights, reduced gestational times and other problems. They pass to the infant during breast feeding (CDC 2018).

PFAS is a possible carcinogen and endocrine disruptor. Health problems in humans have been associated with accidental exposures. They include higher cholesterol, liver problems, and testicular cancer. Perfluoro compounds also depress the immune system and may result in lower antibody production from vaccines. A recent study has shown that higher body concentrations of PFBA correlate with more serious symptoms of Covid-19 (CDC 2018; Grandjean et al. 2020).

Editors generally prefer articles where positive solutions are proposed. The positive solution here is to stop releasing forever chemicals, and clean them up as best we can. Mitigation of these problems will be very difficult, and very expensive. We hope that the lessons learned from these mistakes will prevent similar problems in the future.

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IPM News

Glyphosate Sales to Stop

On March 20, 2015 IARC (International Agency for Research on Cancer) found that glyphosate was a probable human carcinogen. Since then, there have been several lawsuits against Monsanto involving settlements of billions of dollars.

Monsanto-Bayer announced July 29, 2021 that it will end U.S residential sales of glyphosate in 2023. The company will switch to formulations that rely on alternative active ingredients in order to "manage litigation risk and not because of any safety concerns." Sales of glyphosate will continue in the agricultural market.

Center for Food Safety Press Release, July 29, 2021.

Ticks and Vegetation

The strategy for ticks is to be where they are not. Daniel Mathisson and coworkers at Columbia University have reviewed the literature on tick distribution as a function of vegetation type. The blacklegged tick, *Ixodes scapularis*, which carries Lyme disease, anaplasmosis, ehrlichiosis, babesiosis and others is found primarily in closed canopy forests and dense vegetation. Deciduous forests are preferred to conifers, and leaf litter encourages these ticks. It is found less in grasslands or old agricultural fields.

The American dog tick, *Dermacentor variabilis*, carries Rocky Mountain spotted fever and tularemia. It is found mostly in grasses and open canopy fields. The lone star tick, *Amblyomma americanum*, carries many diseases and is "a habitat generalist without consistent associations with particular types of vegetation." Habitat associated with the Asian longhorned tick, *Haemaphysalis longicornis*, has not been well determined, but it likely prefers grasslands.

These are broad generalizations that are supported by publications. But the safest strategy is to be aware of your surroundings. Tick encounters are sometimes found in unexpected places.

Mathisson, D.C., S.M. Kross, M.I. Palmer et al. 2021. Effect of vegetation on the abundance of tick vectors in the Northeastern United States: a review of the literature. *J. Med. Entomol.* June 3, 2021.

Wolbachia Infected Mosquitos

Aedes aegypti mosquitoes transmit dengue and other diseases. Infection of the mosquito with the *wMel* strain of the bacterium *Wolbachia pipientis* blocks infection of the mosquito with dengue, reducing disease transmission.

Wolbachia infected mosquitoes were released in Indonesia in 12 areas. Clinical infections of dengue were monitored in these areas and compared to 12 areas where only wild type *A. aegypti* were present.

People in areas with *Wolbachia* infected mosquitoes had about 77% protection against clinical dengue infections. Protection against serious illness and hospitalization was about 86%.

Utarini, A., C. Indriani, R.A. Ahmad et al. 2021. Efficacy of *Wolbachia*-infected mosquito deployments for control of dengue. *New Engl. J. Med.* 384:2177-2186.

Bed Bugs and Repellents

Repellents are part of an IPM program for bed bugs, *Cimex lectularius*. Part of the problem of finding repellents is finding the proper tests to evaluate them. Cinnamon oil, icaridin, DEET, permethrin and margosa oil are potential bed bug repellents.

Researchers invented laboratory tests to measure repellent effects for simulated bed bug harborages and for bed bugs seeking a blood meal. DEET, cinnamon oil, and icaridin repelled 99% of the bed bugs from the simulated harborage for at least 24 hours.

The second test simulated conditions of bed bug feeding. Bed bugs were attracted by carbon dioxide to cross treated filter papers. DEET showed 97% repellency. Other repellents were much less effective. The researchers conclude that it is harder to repel bed bugs from a blood meal than from harborage.

Kruger, A., E. Schmolz, A. V. Pan. 2021. Methods for testing repellents against bed bugs. *J. Econ. Entomol.* 114(1):265-273.

Rosemary Repels Thrips

The repellent effects of rosemary, *Rosemary officinalis*, were studied on three species of thrips; western flower thrips, *Frankliniella occidentalis*; flower thrips, *F. intonsa*; and melon thrips, *Thrips palmi*. Rosemary leaves repelled the thrips in Y olfactometer bioassays. In cage tests, "the presence of rosemary plants significantly reduced settlement of females of the three thrips species, and eggs laid by *F. occidentalis* females on target host plants."

Both males and females were repelled by rosemary leaves. Of the 47 chemical components of rosemary oil, alpha-pinene and eucalyptol were the best repellents. Alpha-pinene only repelled *F. occidentalis* and *F. intonsa*, eucalyptol repelled all three species.

Li, X-W., Z.-J. Zhang, M. Hafeez et al. 2021. *Rosmarinus officinalis* a promising repellent plant for thrips management. *J. Econ. Entomol.* 114(1):131-141.

Rain Gardens Stop Microparticle Pollution

Rain gardens are composed of vegetation planted especially to filter pollution from stormwater in urban areas. In addition to vegetation, rain gardens may have engineered soil, organic matter, and mulch. They are placed in a depression and act as a trap to remove metals, chemical pollutants, and nutrients from stormwater.

Researchers in the San Francisco Bay Area have found that rain gardens can also remove plastic and rubber microparticle pollution from urban stormwater runoff.

Runoff contained rubbery fragments and fibers with concentrations ranging from 1.1 to 24.6 particles per liter. Plastics were the most common type of particle found, mostly concentrated in the smallest size fraction, 125-355 micrometers.

One particular rain garden in El Cerrito, California was monitored during three storms. The rain garden removed 96% of "anthropogenic debris on average and 100% of black rubbery fragments."

Werbowski, L.M., A. N. Gilbreath, K. Munno et al. 2021. Urban stormwater runoff: a major pathway for anthropogenic particles, black rubbery fragments, and other types of microplastics to urban receiving waters. *ACS EST Water* 1:1420-1428.

Organic Produce Has Fewer Pesticide Residues

Organic farming is less reliant on pesticides, concentrating on management strategies that encourage biocontrols and maintain healthy soil. But some pesticides are allowed. Biopesticides are the crop protection chemicals most often used. These "pose minimal risk to human health and the environment."

Using published databases, the authors were able to compare pesticide use on conventional farms with that on nearby organic farms. Paradoxically, organic farms actually used more fungicide (0.92 kg/ha) than conventional farms (0.56 kg/ha). Synthetic fungicides used on conventional farms are more potent and less is applied than the copper oxide and *Burkholderia* sp. used on organic farms.

Synthetic insecticides are also generally more potent than organic insecticides. Organic farms applied 0.56 kg/ha of insecticide, while conventional farms applied 0.16 kg/ha. But conventional farms applied much more herbicide. The entire acreage of conventional tomatoes was treated about 2.5 times using 17 different herbicides. About 0.02% of organic tomato acreage was treated with alternative herbicides such as fatty acids.

A big difference was residues. Pesticide residues were found about 11 times more often on samples of conventional tomatoes. For apples, residues were found 274 times more often on samples of conventional apples. About 62% of organic apple samples had no residues, only 0.83% of conventional had no residues.

Benbrook, C., S. Kegley and B. Baker. 2021. Organic farming lessens reliance on pesticides and promotes public health by lowering dietary risks. *Agronomy* 11:1266.

IPCC Report on Climate

The Intergovernmental Panel on Climate Change (IPCC) has just released a report on climate change. There are more than 1300 pages of grim predictions. The report summarizes effects that will occur with a 1.5°C (2.7°F) average increase in world temperatures, and projects consequences if temperatures rise above that.

There are no surprises. The increased ocean and land temperatures will cause extreme weather events such as heat waves, drought, extreme precipitation, and floods. Problems will be worse with each incremental increase in temperature. Effects will be greatest at midlatitudes where temperatures will increase by 3°C (5.4°F) if the worldwide average is 1.5°C.

We may be able to avoid the worst problems by keeping temperature increases below 1.5°C. To do this, we must reach net zero carbon dioxide emissions by 2050.

IPCC (Intergovernmental Panel on Climate Change). 2021. *Sixth Assessment Report (AR6) Climate Change: The Physical Science Basis.* World Health Organization (WHO). Geneva, Switzerland. Ipcc.ch. August 9, 2021.

Western Bean Cutworm in Quebec

Pests of crops, animals and people are likely to increase with global warming (see Global Warming Means More Pests IPMP 29(9/10)(2007)). The effects of global warming have been seen recently with the western bean cutworm, *Striacosta albicosta.*

The western bean cutworm is actually more of a corn pest than a bean pest. Its behavior is more like that of a corn earworm. Up to now, cold weather has kept it from overwintering in Quebec. The authors have observed the first overwintering of the pest in Quebec. Increased corn damage in Quebec will likely be the result.

Saguez, J., M. Neau, C. Rieux et. al. 2021. First evidence of western bean cutworm overwintering in the province of Québec (Canada). *J. Econ. Entomol.* 114(1):174-179.

Cinnamon Powder Stops Plant Disease

The authors tested the effects of aqueous sprays of cinnamon powder suspensions at concentrations of 0.5% and 1% on tomato plants in greenhouses and in the field. Symptoms of grey mold caused by *Botrytis cinerea* decreased. Mycelium growth was inhibited by 81.4% by the 1% spray.

The sprays significantly stimulated growth of the tomato plants, from 12.83 grams in the controls to 17.17 grams for plants treated with the sprays.

Kowalska, J., J. Tyburski, J. Krzyminska et al. 2020. Cinnamon powder: an in vitro and in vivo evaluation of antifungal and plant growth promoting activity. *Eur. J. Plant Pathol.* 156:237-243.

Conference Notes

ESA 2019 Meeting Highlights

By Joel Grossman

The 2020 ESA Conference was cancelled because of the coronavirus pandemic. These Conference Highlights were 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 October 31 to November 3, 2021 in Denver, CO. For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org).

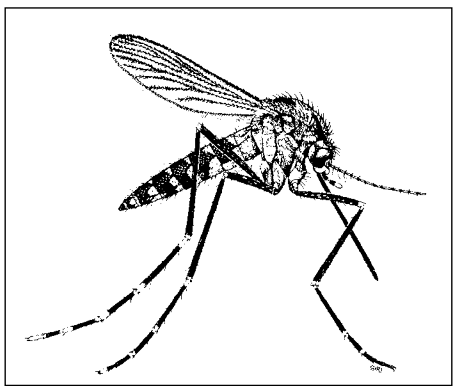
Hemp IGR Fights Flies

"Fayetteville State University has developed a hemp-based formulation (HDX)" that works like the insect growth regulator (IGR) methoprene to disrupt development of house flies, *Musca domestica*, and fruit flies, *Drosophila melanogaster*, said Marina Better (Fayetteville State Univ, 1200 Murchison Rd, Fayetteville, NC 28301; mbetter1@broncos.uncfsu.edu). "Previous studies found hemp to disrupt development in fruit flies, keeping the flies in a juvenile state and inhibiting normal development. Hemp has high concentrations of phytosterols and therefore, it was hypothesized that the HDX pesticide would disrupt development in houseflies similar to the juvenile hormone-III analog methoprene."

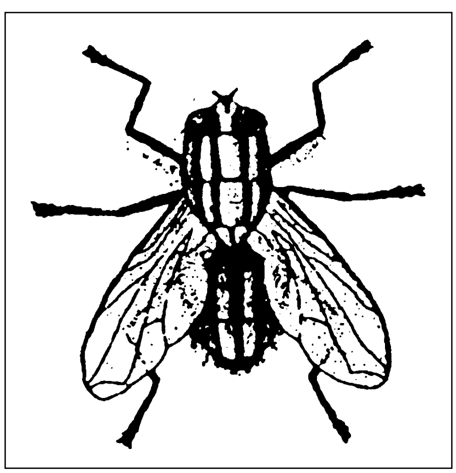
"When exposed to methoprene, fly larvae exhibited incredible growth in comparison with HDX-exposed larvae," said Better. "While larvae in both treatments exhibited developmental disruption, HDX was found to be more effective in increasing mortality in the flies." HDX is covered by patent 10,045,540.

Gut Level Mosquito IPM

The yellow fever mosquito responsible for Zika virus (ZIKV) and dengue virus (DENV) outbreaks on Guadeloupe Island, *Aedes aegypti*, varies in its ability to transmit these human pathogens depending upon which bacteria species the larvae feed on in their aquatic habitats, said Lyza Hery (Instit Pasteur, Morne Jolivière – 97139, Guadeloupe, France; lhery@pasteur-guadeloupe.fr). "The interactions between *Ae. aegypti*, its natural microbiota and arbovirus transmission are still poorly understood since most reports have focused on laboratory-based experiments," which do not mimic the indigenous bacteria communities (microbiomes) of natural aquatic habitats. In nature, mosquito larvae ingest bacteria sharing their aquatic habitat; these bacteria help shape the mosquito gut microbiota, which in turn influences the ability of adult females to transmit pathogens such as ZIKV and DENV.



An *Aedes* sp. mosquito



House fly, *Musca domestica*

The abilities of adult female *Ae. aegypti* to transmit DENV and ZIKV was compared when larvae where reared in aquatic habitats with "a natural bacterial microbiome" versus a more sterile aquatic laboratory environment. "We found that bacterial communities from aquatic habitats influenced the microbiome associated to the corresponding mosquitoes," said Hery. "The vector competence experiments conducted on local *Ae. aegypti* showed differences on DENV and ZIKV transmission according to the breeding-site water used." Ecological (e.g. microbial) breeding site variables affecting disease transmission by mosquito vectors may prove useful in public health IPM.

Natural Tick Contact Repellents

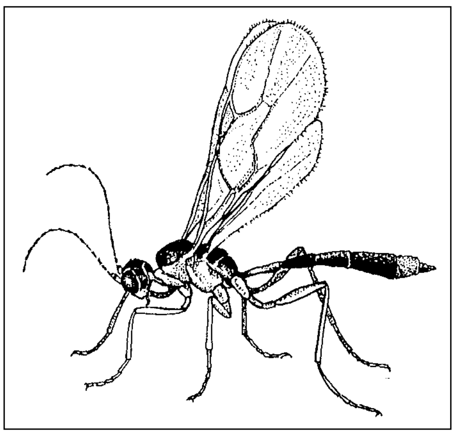
Many naturally-occurring terpene chemicals found in plant essential oils are better than DEET as contact repellents to protect against deer ticks, *Ixodes scapularis*, said Joel Coats (Iowa State Univ, 116 Insectary, Ames, IA 50011; jcoats@iastate.edu). Whole nutmeg oil is a "so-so" contact repellent. But 1-5% solutions of isolated nutmeg oil constituents such as myristicin and safrole are effective against hard ticks like American dog tick, *Dermacentor variabilis*. *I. scapularis* is more sensitive, so 0.5% (0.1 mg/cm2) solutions are sufficient. Isovaleric acid, a compound naturally occurring in many plants, is one among many "promising leads" for tick repellents. Commercial products already incorporate the botanical 2-undecanone, which is more effective than DEET, icaridin (picaridin) and IR3535. Products containing nootkatone and p-menthane-3,8-diol (PMD) from lemon eucalyptus also work well.

American dog tick, *Dermacentor variabilis*, a vector of Rocky Mountain spotted fever, tularemia and other diseases, is found all over the USA except the Rocky Mountains. It is a model hard tick for testing repellents derived from nutmeg, rosemary and the steam distillation of catnip and other plants, said Colin Wong (Iowa State Univ, 115 Insectary, Ames, IA 50011; cwong1@iastate.edu). "Our lab has already shown several plant oil extracts and specific chemical constituents that can repel ticks to the same degree as any of the current CDC recommended active ingredients including DEET." *D. variabilis*, whose bite can induce red meat allergy, is assessed by placement in open petri dishes with 5% botanical solutions on filter paper. Acetone, which evaporates to 0, is the control, and DEET is the positive control. Time elapsed for male and female ticks to cross onto treated filter paper and crawl out of their petri dishes is a measure of repellency.

"A number of monoterpenoids including limonene and linalool were significantly more repellent than DEET in our assay," said Wong. The best botanical repellent on the market is 2-undecanone, though p-menthane-3,8-diol (PMD) from lemon eucalyptus oil is also a good repellent. Nootkatone will likely soon have EPA approval. In general, essential oil components such as myristicin, safrole, nepetalactone (from catnip), limonene, camphor and p-cymene are better tick contact repellents than whole plant oils.

Drowning Ticks

Blacklegged deer tick, *Ixodes scapularis*, and lone star tick, *Amblyomma americanum*, are found in eastern USA woodlands that periodically flood (e.g. after heavy rainfall, riverbank overflowing), said Kaniya Sandoval (Eastern New Mexico Univ, ENMU 2880, Portales, NM 88130; kaniya.sandoval@enmu.edu). In flooding simulation experiments, 10 unfed adult male and female *I. scapularis* and *A. americanum* were immersed in water. Ticks responded to water immersion by clustering together. Tick survival was 100% (0% mortality) after 2-4 days underwater; after 7 days, tick mortality was 8-27%. After 14 days water immersion, tick mortality was almost 100% (one male deer tick survived). Thus, short-term flooding events (natural or IPM) lasting one week do not provide significant tick control; as it takes up to two weeks water immersion to approach 100% tick mortality.



An aphid parasitoid, *Aphidius sp.*

Banker Plant Economics Beat Neonics

Neonicotinoid drenches are used by 80% of surveyed Oklahoma greenhouse growers, primarily for bird cherry-oat aphid, *Rhopalosiphum padi*, whiteflies and fungus gnats, but banker plants and biocontrol are a more economical alternative, said Tracey Payton (Langston Univ, 1301 N Western Rd, Stillwater, OK 74075; ptracey@langston.edu). An imidacloprid (or dinotefuran) drench for 25,000 ft^2 (2,323 m^2) of growing space with 100,000 plants in 6 inch (15 cm) pots costs $2,500 per 16 week crop cycle, or $7,500 annually. Augmentative release of 1,500 *Aphidius colemani* parasitoids sprinkled as aphid mummies onto greenhouse plants every two weeks costs $88; which is $704 per 16-week crop cycle, or $2,112 annually.

Banker plants are maintained to grow aphids that in turn grow natural enemies such as *Aphidius colemani* that disperse throughout the greenhouse to provide sustainable aphid biocontrol at a one-time startup cost of $500-$700. Banker plants require two hours of maintenance per week, or $500 every 16 week cycle ($1,500/yr) at the prevailing Oklahoma $10/hour wage rate. Thus, growing your own natural enemies on banker plants is much cheaper than neonic drenches; and slightly cheaper than continuous purchase of aphid parasitoids for augmentative release every two weeks.

Bee and Butterfly Pesticide Impacts

"Neonicotinoids (thiamethoxam, clothianidin, imidacloprid) cause much greater toxicity in adult bees than monarchs, *Danaus plexippus*," in studies where monarch butterfly larvae eat insecticide-treated leaves, said Niranjana Krishnan (Iowa State Univ, 7 Genetics Bldg, Ames, IA 50011; nkrish@iastate.edu). In topical toxicity studies: "Pyrethroids cause similar toxicity in bees and monarchs, but organophosphates and neonicotinoids are much more toxic to bees." Among pyrethroids tested topically, naled was most toxic to butterfly larvae and fenthion was least toxic. Most of the research is on butterfly larvae, and there is a "paucity of neonicotinoid oral exposure studies on adult butterflies."

EPN Neonic Alternative

Wireworms, the larval stage of click beetles (Elateridae), can live 2-7 years in the soil and are significant pests of cereal crops, canola, pulses, wheat, cereals and potato in Montana and the Great Plains region, said Ramandeep Sandhi (Montana State Univ, 9546

Old Shelby Rd, Conrad, MT 59425; ramandeepkaursandhi@montana.edu). "Because of their cryptic behavior in soil, there are no effective control measures available," and "there is a dire need to develop an alternative wireworm management strategy." Neonic seed treatments are repellent but do not kill wireworms, delaying but not stopping the damage.

Sugarbeet wireworm, *Limonius californicus*, was the dominant pest species collected in 750 soil samples using a nylon stocking with water-soaked grain. The pest attacks germinating seeds, cuts down seedlings and burrows into potato tubers, plant stems and roots. Waxworm larvae, *Galleria* spp., added to sandy loam soil samples collected two strains of *Steinernema feltiae* and one strain of *Heterorhabditis bacteriophora*. In lab bioassays, these entomopathogenic nematodes (EPNs) killed 20-50% of *Galleria* larvae. *Steinernema carpocapsae* and *S. riobrave* caused 30-50% wireworm mortality, depending on the dose.

In the field, EPNs can be applied by: 1) squeezing a sponge with a water-soaked EPN solution; 2) by sprayer; 3) placement into holes poked in field soils. Surprisingly, non-native EPNs were more virulent than native EPNs. For field management of *L. californicus* in IPM programs, higher doses are recommended. *Steinernema carpocapsae* and *S. riobrave* provided up to 55% control of *L. californicus*; versus up to 25% with *S. feltiae*.

Organic Fertilizers

"Organic fertilizer may be a key component of effective pest control," because it "may enhance plant growth and inducible chemical defenses such as jasmonic acid (JA), salicylic acid (SA) and abscisic acid (ABA) more than synthetic fertilizers," said Elisabeth Oeller (Washington State Univ, PO Box 646382, Pullman, WA 99164; elisabeth.oeller@wsu.edu). "Synthetic fertilizers may increase uptake of free nitrogen (N) to plants, in turn making them more attractive to insect pests." In contrast, besides mineral nutrients, organic fertilizers may contain living organisms such as microbes, which play a role in stimulating plant growth and pest protection.

"Interactions between crop variety and nitrogen source could greatly impact not only the crop growth and yield but also the insect pest populations in the system," said Oeller. "Characterizing how pests respond to different fertilizers is thus critical for developing IPM programs" for pests such as cowpea aphid, *Aphis craccivora*, and *Lygus hesperus* on quinoa, *Chenopodium quinoa*, a popular South American Andes grain crop relatively new to North American markets. Pest population growth was quantified on two quinoa varieties, Titicaca and Cherry Vanilla, grown with synthetic nitrogen granules, organic chicken manure, or no fertilizer (control). Plant measurements (in caged and open field settings) included defense pathway phytohormones (JA, SA, ABA).

"Organically fertilized quinoa had the fewest aphids and *Lygus*," said Oeller. Plant variety was also important. *Lygus* survival and egg laying was lower on Cherry Vanilla than on Titicaca, possibly due to varietal differences in plant branching structure, flowering time and secondary metabolites such as saponins. Fertilizers reduced plant phytohormone levels, suggesting "trade-offs between plant growth and resistance to herbivory." Future IPM goals include evaluating fertilizer effects on natural enemies, saponin pest control effects, and alfalfa as a *Lygus* trap crop.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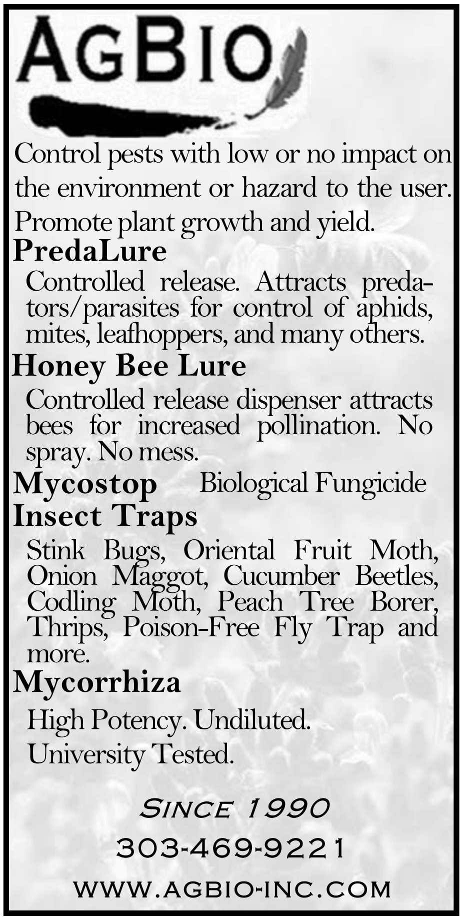
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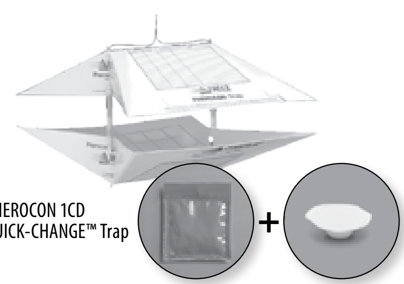

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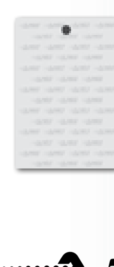

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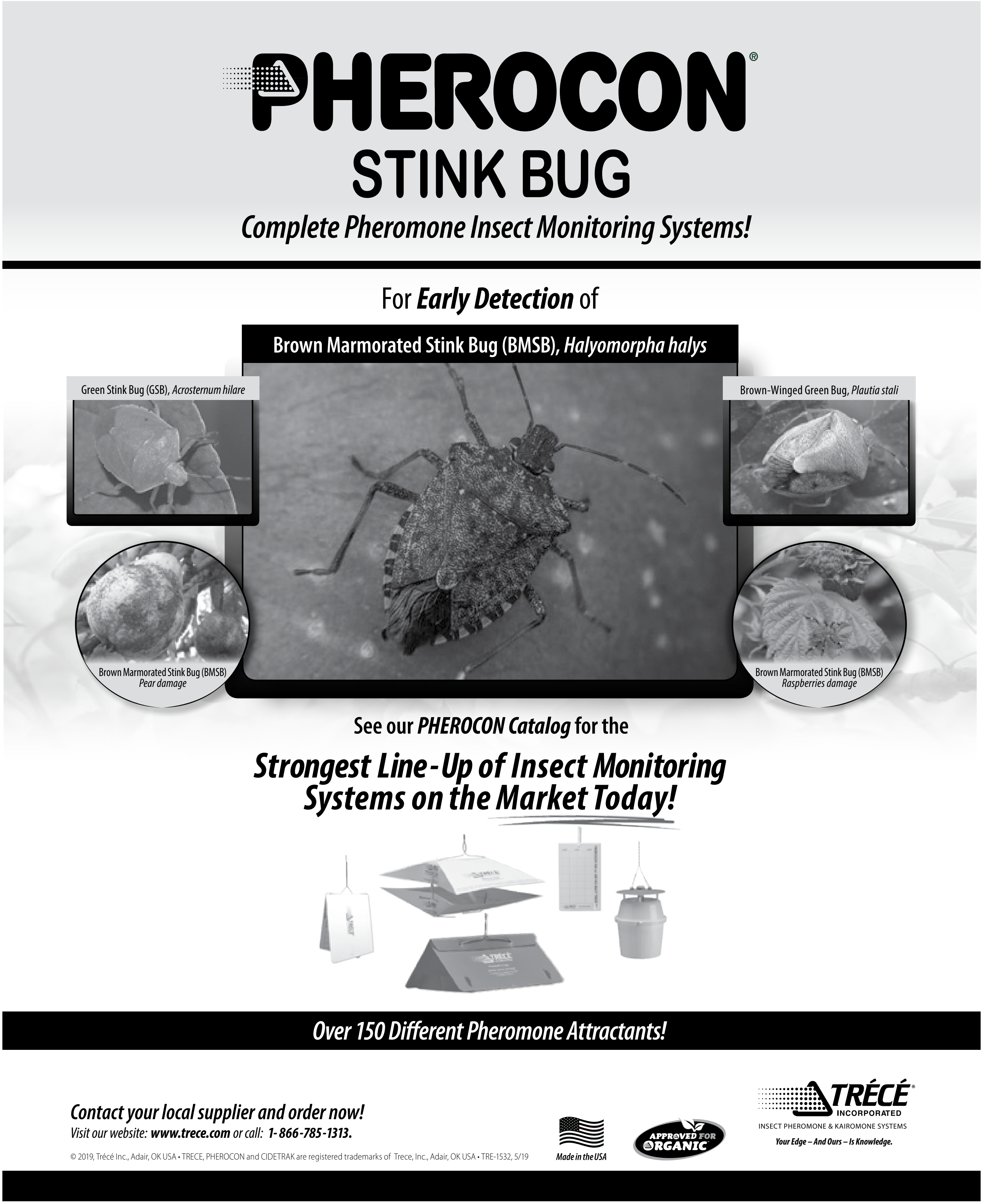
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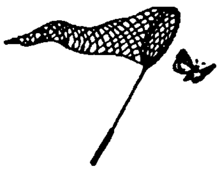

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