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Global Warming Means More Pathogens

By William Quarles

According to NASA scientists, worldwide temperatures over the past three years have been the hottest on record. In addition, average global surface temperatures have risen by 0.7°C (1.3°F) over the last 100 years. Temperatures are rising due to human activities such as the burning of fossil fuels, leading to an atmospheric accumulation of greenhouse gases (Collins et al. 2007; Karl and Trenbeth 2003).

These temperature increases, along with the drought and flooding associated with global warming may be contributing to the spread of human pathogens and increased disease (Epstein 2000; EPA 2016). Warming may be causing 150,000 deaths a year when all health effects such as food poisoning, heart attacks, and heat strokes are considered. Chronic health problems associated with warming may affect millions (Patz et al. 2005). Though plant pathogens are also increasing, this article emphasizes warming effects on human and animal pathogens, especially vectorborne pathogens.

Human Pathogens

Pathogens for human diseases such as malaria, Lyme disease, tick-borne encephalitis, yellow fever, and dengue have increased in incidence or geographic range in recent decades (Harvell et al. 2002; Patz et al. 2005). These pathogens are carried by ticks and mosquitoes that are encouraged by warmth and moisture. For instance, the Lyme disease tick, *Ixodes scapularis*, thrives at temperatures above 45°F and humidities greater than 85%. *Aedes aegypti* mosquitoes that carry dengue and Zika virus thrive at temperatures above 50°F. Cold weather can kill these pests, but warmer and shorter winters can generate larger populations of infected mosquitoes and ticks. The overall effect is complicated by land use, worldwide travel, adaptations of vectors and pathogens, pest management and other factors (Beard et al. 2016; EPA 2016; Ogden and Lindsay 2016; Ogden et al. 2014; Kovats et al. 2001).

Warmer temperatures increase mosquito reproduction and biting activity, and pathogens inside the mosquitoes mature faster. For instance, transmission of malaria requires temperatures greater than 16°C (60.8°F), and a 5°C (9°F) increase in temperature doubles the growth rate of the falciparum protozoa that causes malaria. Since 1990 small outbreaks of malaria have occurred in Texas, Georgia, Florida, Michigan, New Jersey, New York and Toronto (Epstein 2001; Epstein 2000; Gil 1920).

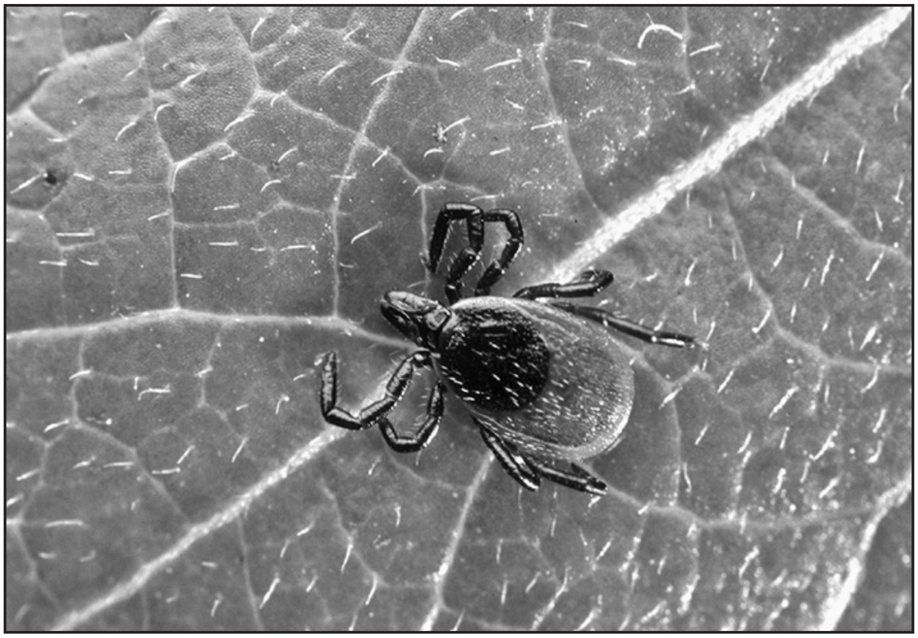
Photo courtesy of Scott Bauer USDA

Shown here is a blacklegged tick, *Ixodes scapularis*, the major vector of Lyme disease. Warmer winters have led to larger numbers of infected ticks that are now colonizing new areas.

In This Issue

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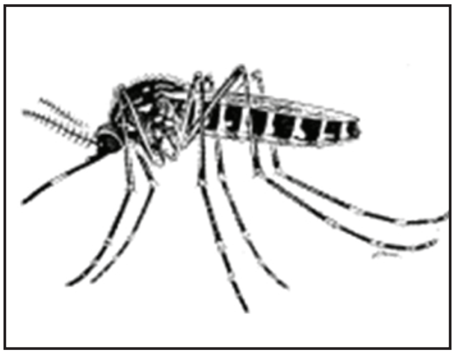
Update

Warming, Droughts and Flooding

Extreme weather conditions of drought and flooding caused by global warming provide breeding areas for mosquito larvae (Epstein 2000; Epstein 2005). Mosquitoes can breed after heavy rains, but also during droughts in containers used to store water. The result is resurgence of diseases such as chikungunya fever (Epstein 2007), and expansion of pathogens such as West Nile and Zika viruses into new areas (Epstein 2000; Hayes 2009; Quarles 2016). For instance, dengue virus, West Nile virus, chikungunya virus, and Zika virus have appeared or expanded their range in the U.S. over the last 20 years (Chan et al. 2016).



***Culex tarsalis* mosquitoes carry West Nile virus.**

West Nile fever arrived in New York City in 1999. The first cases were likely travel related, but *Culex* spp. mosquitoes were there to spread the pathogen through populations of birds and people (Epstein 2000). West Nile fever also has invaded Canada, with confirmed cases numbering about one-fifth those of the U.S. *Culex tarsalis* mosquitoes are ranging further north than ever before, and epidemics surge with warm winters (Kulkarni et al. 2015).

West Nile fever got its start in the U.S. when a mild winter led to large populations of mosquitoes early in the season. A subsequent drought forced *Culex* spp. mosquitoes that carry the pathogen into close contact with bird populations, amplifying and spreading the disease (Epstein 2001). Shrinking water holes meant that birds and mosquitoes aggregated in the same areas. Populations of predators such as dragonflies that prey on mosquitoes were reduced by drought (Epstein 2001; Epstein 2000).

Aedes spp. Mosquitoes

The first cases of dengue hemorrhagic fever in the U.S. were seen in Texas late in 2005 (Sci. News 2006). Chikungunya cases appeared in Texas and Florida in 2014, and Zika virus, the most dramatic new mosquito pathogen, arrived in Florida and Texas in 2016 (Epstein 2007; Chan et al. 2016; Quarles 2016).

Dengue, chikungunya, and Zika viruses are all spread by *Aedes* spp. mosquitoes, primarily *Aedes aegypti*, but also *Ae. albopictus* and *Ae. africanus* (Chan et al. 2016). Areas covered by vectorborne epidemics of these viruses can be no larger than the ranges of the mosquitoes that carry them. Travel related cases cannot be sustained without effective local mosquito populations (Kraemer et al. 2015).

But key vectors such as *Aedes aegypti* and *Aedes albopictus* have moved into new locations. These two species now cover the widest area ever recorded. Though they are spread by travel and trade, the most critical factor in their spread and survival is temperature (Kraemer et al. 2015; Liu-Helmersson et al. 2014). And computer models show that the ranges of these two species in the U.S. are likely to expand (Campbell et al. 2015).

Not only can *Aedes* spp. move into warming areas that favor them, they can also adapt quickly to new conditions. *Aedes japonicus* actually prefers cool temperatures, but can make an evolutionary adaptation to a warmer climate in less than 10 years (Egizi et al. 2015).

Rising Seas

Mosquitoes generally respond to rising temperatures, but rising sea levels may also be a factor. Rising sea levels encourage mosquitoes that breed in brackish or salty water. More than half the world's population lives within 60 km (36 mi) of the coastline. This population will be at increased risk from mosquitoes such as *Aedes taeniorhyncus*, *Culex tarsalis*, and *Anopheles albimanus*. *Culex* mosquitoes can carry West Nile virus, and *Anopheles* mosquitoes can vector malaria (Ramasamy and Surendran 2011).

More Pests, More Pathogens

Greater pest numbers mean larger numbers of pathogens. Old pathogens are spreading to new areas, and new pathogens are appearing that may be better adapted to the environment (Dobson and Foufopoulos 2001). Global warming may also be encouraging more virulent strains of the microbes, such as the case for the Lyme disease pathogen (Ostfeld and Brunner 2015; Gatewood et al. 2009; Ogden et al. 2008) and the Zika virus (Chan et al. 2016).

For instance, less than 20 human cases of Zika virus infection had been reported worldwide before 2007. Increased populations of *Aedes aegypti* encouraged by global warming and increased rainfall, and genetic changes in the Zika virus RNA genome may have both contributed to the explosive outbreaks of the Asian strain of Zika in Latin America in 2015, and its arrival in the U.S. in 2016 (Chan et al. 2016; Quarles 2016).


Photo courtesy CDC and James Gathany

Aedes albopictus mosquitoes can carry human pathogens.


Photo courtesy CDC and James Gathany

***Aedes aegypti* mosquitoes are encouraged by global warming. They carry dengue, yellow fever, chickungunya, and Zika viruses.**

Tickborne Diseases

Confirmed Lyme disease cases in the U.S. have doubled in the last 20 years. Both the areas affected and the number of cases are increasing. The EPA has estimated that there are 300,000 new cases of Lyme disease each year in the U.S. (EPA 2016). Lyme disease is caused by a spirochete called *Borrelia burgdorferi*, that is carried by *Ixodes scapularis* in the East and *Ixodes pacificus* in the West. Spirochetes are corkscrew shaped bacteria that cause a number of diseases including relapsing fever, leptospirosis, syphilis, and others. Lyme disease, like syphilis, can cause longterm chronic problems involving the nervous system. *B. burgdorferi* shows a lot of genetic variability, and some genotypes may be harder to treat than others (Sonenshine 1993; Burgdorfer 1993; Quarles 2000).

Due to warming, Lyme disease ticks are spreading into new areas, such as the southern regions of Canada (Leighton et al. 2012; Brownstein et al. 2005). Confirmed Lyme disease cases in Canada have increased more than 10-fold since 2005 (Kulkarni et al. 2015).

Ticks in Motion

The major pathogenic tick in the Northeast is *Ixodes scapularis*. It carries Lyme disease and a number of other pathogens. The major tick in the Southeast is the lone star tick, *Amblyomma americanum*, which carries erlichiosis and other diseases. Ticks in the Southern U.S. such as *Amblyomma* spp. are spreading northward and westward, carrying new pathogens. And a new tick, *Ixodes affinis* has been found in North Carolina. Monitoring shows about one-third of *I. affinis* are carrying *B. burgdorferi* (Stromdahl and Hickling 2012).

Tick populations associated with warming have contributed to increased tickborne encephalitis in Sweden, as infected ticks move northward (Lindgren and Gustafson 2001). Lethal tickborne Crimean Congo hemorrhagic fever appeared for the first time in Western Europe in 2016. It is usually found in colder regions of Eastern Europe and the Soviet Union (McNeil 2016).

Phenology and Ecology Important

Global warming may be encouraging the spread of pathogens, not just through increased temperatures, but also through phenology and changes in ecology. Ecology is important because deer spread the Lyme disease tick, and white footed

The white-footed mouse, *Peromyscus* sp., harbors the Lyme disease pathogen.

Drawing by Diane Kuhn

mice are a major reservoir for the infection. Changes in the distribution of these populations can change the risk for Lyme disease (Bosler 1993).

Phenology and the timing of the infection is also important. For instance, the Lyme disease tick, *Ixodes scapularis*, has egg, larval, nymphal and adult stages on a two-year cycle. Adults lay eggs in soil in June or early July that hatch into larvae starting in July. Larvae start feeding in July, and most have molted into nymphs by the following spring. If the larvae feed on an infected host, then the nymphal stage will also be infected (Bosler 1993).

Nymphs spread the infection. Infected nymphs inoculate vertebrate hosts with the pathogen starting in the spring. Early spring activity of nymphs due to shorter and warmer winters makes it possible for them to inoculate a larger percentage of the white footed mice populations before uninfected larval ticks begin feeding in July. Larger numbers of infected mice increase the numbers of infected larvae. So the overall effect of global warming on *Ixodes scapularis* is increased numbers of ticks carrying the pathogen (Levi et al. 2015).

The situation is somewhat different in California, where the *Ixodes pacificus* tick is on a three year cycle, and spends most of its time off host. This tick is susceptible to periods of drought and low rainfall. Compared to Northern California, populations in Southern California are lower due to lower rainfall, and the Lyme disease risk is less, despite the fact that Southern California has warmer winters. This kind of regional variation is superimposed on the overall effects due to global warming (MacDonald and Briggs 2016).

Changes in Animal Migrations

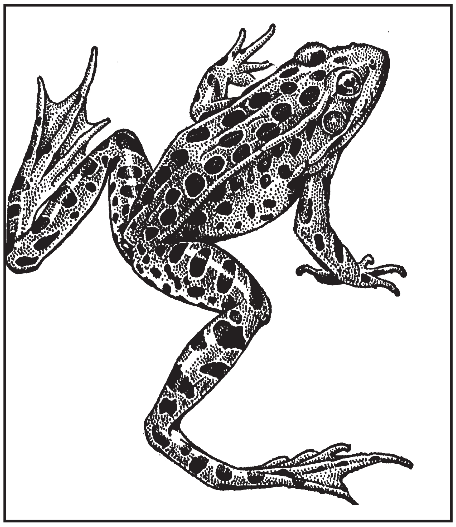
Animals can be important carriers of human pathogens. Birds carry West Nile virus, white footed mice carry the pathogen of Lyme disease. Birds can carry infected ticks such as *Ixodes scapularis* and scatter them along flight paths. Changes in migration patterns caused by global warming and development may lead to concentrations of pathogens in new areas (Altizer et al. 2011; Hofmeister et al. 2012).

New Tickborne Pathogens

As ticks move into new areas, they pick up new pathogens or the old ones adapt to new conditions. From 2010 to 2016, five new human tickborne pathogens were identified in the U.S. These include *Borrelia mayonii* (2016), Bourbon virus (2014), Heartland virus (2012), *Borrelia miyamotoi* (2011), and the microbe for 364D rickettsiosis (2010) (Pritt et al. 2016; Krause et al. 2014; Shapiro et al. 2010). The accelerated pace of discovery is astounding, since only six new pathogens, including those for Lyme disease, babesiosis and ehrlichiosis were found in the 32 year period from 1969 to 2002, doubling at that time the number of known tickborne pathogens (Stromdahl and Hickling 2012).

Tick Coinfections

A bite that transmits Lyme may also transmit other pathogens, resulting in clinical cases of multiple infections. For instance, the Lyme disease tick, *Ixodes scapularis*, carries *Borrelia burgdorferi* for Lyme disease; *Anaplasma phagocytophylium* that causes anaplasmosis*; Babesia microti* that causes babesiosis; and Powassen virus that causes Powassen encephalitis (Stromdahl and Hickling 2012). There are often co-infections with mixed Borrelia such as *B. miyamotoi* and *B. burgdorferi*. In the Northeast the human infection rate with *B. burgdorferi* is about twice that of *B. miyamotoi* (Krause et al. 2012). In the San Francisco Bay Area, *I. pacificus* ticks infected with *B. burgdorferi* are about as abundant as those with *B. miyamotoi* (Salkeld et al. 2014).



Populations of the leopard frog, *Rana pipiens*, have declined by 50%.

Drawing from Stebbins 1954

The lone star tick, *Amblyomma americanum* carries *Ehrlichia* spp. organisms that cause ehrlichiosis; *Francisella tularensis* that causes tularemia; *Rickettsia rickettsii* that causes spotted fever rickettsiosis; and weird diseases such as southern tick associated rash illness (STARI). Bites can cause multiple diseases and immune system problems (Stomdahl and Hickling 2012).

Global Warming and Fungal Diseases

Vectorborne pathogens are usually viruses or bacteria. But new fungal diseases of humans and wildlife are appearing. Fungal pathogens are becoming more virulent, and medical databases show the relative proportion of emerging infectious diseases in animals caused by fungi tripled from 1995 to 2010 (Fisher et al. 2012). Warming may be encouraging growth and spread of fungi, and animal immune systems may also be depressed both by warming and pesticides (Altizer et al. 2013; Mason et al. 2013).

For instance, global warming may be contributing to amphibian decline. Though chytrid fungus, *Batrachochytrium dendrobatidis*, has been around since 1928, it was 1998 before it was identified as a lethal pathogen of amphibians (Quarles 2015). Growth is associated with warmer summers, and cloud cover associated with increased water evaporation (Pounds et al. 2006). And white nose fungus caused by *Geomyces destructans*, has killed millions of bats in the U.S. since 2006 (Quarles 2013).

Fungi Attacking Humans

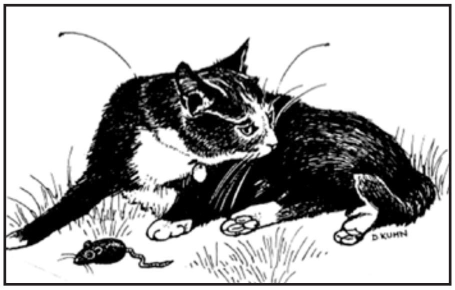
There has been a resurgence of human fungal diseases caused by *Aspergillus*, *Candida* and others. Part of the resurgence is due to HIV and medical procedures such as chemotherapy and organ transplant that depress immune function. Deaths from these fungal diseases worldwide now exceed those of malaria and tuberculosis combined, and these fungal diseases are often resistant to treatment (Berweij et al. 2009). For instance, a new lethal antibiotic resistant human fungus, *Candida auris*, appeared in hospitals in 2009 (Brown et al. 2012).

But part of the resurgence of fungal diseases in humans may be due to global warming. *Cryptococcus gattii* is usually a pathogen in tropical and subtropical areas, but in 2001 a lethal strain appeared on Vancouver Island in Canada. And global warming may have contributed to the eightfold increase in U.S. valley fever cases caused by *Coccidioides immitis* between 1999 and 2011 (Frazer 2013).

One theory about the rise of pathogenic fungi in mammals is that global warming is causing fungi to adapt to higher temperatures. As a result, the gap between mammalian temperatures and optimum temperatures for fungi is becoming smaller (Casadevall 2012; Garcia-Solache et al. 2010).

Runoff and Ocean Warming

Ocean warming and acidification plus nutrient loaded runoff from flooding is leading to increased algae blooms and shellfish poisoning from domoic acid and other toxins. Poisonous crabs and shellfish are having an impact on the fishing industry. Warming conditions are also encouraging growth of zooplankton containing the *Vibrio cholerae* organism, resulting in increased numbers of human cholera cases (Altizer et al. 2013; Brown et al. 2012). Increased runoff from flooding is carrying the pathogen *Toxoplasma gondii* from cat feces into the oceans. Dolphins and other marine animals are being killed by lethal infections of toxoplasmosis (Solomon 2013).



Drawing by Diane Kuhn

Runoff from flooding is carrying cat pathogens into the oceans.

What to do About All This?

Global warming is associated with human activities such as the burning of fossil fuels, leading to a buildup of carbon dioxide in the atmosphere. Carbon dioxide exerts a greenhouse effect, causing increased global temperatures (Quarles 2007). We can reduce global warming by encouraging renewable energy such as solar electricity, wind farms, and hydroelectric power. We can drive fuel efficient cars. Since about 15% of the greenhouse emissions are due to farming, we can encourage organic agriculture. Each acre of organic production takes about 3,500 lbs (1590 kg) of carbon dioxide from the air each year. About 20% of CO_2 emissions is caused by tropical deforestation. So planting trees can help reduce the problem (Hepperly 2007; Rosenzweig and Hillel 1995).

Mosquito Management

To protect ourselves from vectorborne pathogens, we can use IPM methods such as habitat management, repellents, reduction of breeding sources, and mosquito larval control. Mosquito adulticides are likely to have effects on non-target organisms such as bees (Olkowski et al. 1991; Quarles 2011; Quarles 2001; Olkowski 2001). Mosquito repellents such as oil of lemon eucalyptus, picaridin, and deet can protect against mosquito bites (Quarles 2009).

Mosquitoes such as *Aedes* spp. that carry Zika virus, yellow fever, encephalitis, and dengue breed in containers and bite in the daytime. Removing containers of water around dwellings, and treatment of other water sources with *Bacillus thuringiensis israelensis* (BTI) and IGRs can help control the problem (Olkowski et al. 1991).

Tick Management

Ticks are vulnerable to desiccation. Habitat management such as opening up tree canopies for sunlight, removal of leaf litter, mowing lawns can discourage them. Strategies such as bait stations to remove ticks from deer and mice are useful (Olkowski et al. 1991; Quarles 2010). Wearing clothing treated with tick repellents reduces the danger (Benelli et al. 2016; Jordan et al. 2012). As a last resort, areas around dwellings can be treated with reduced risk pesticides (Quarles 2010)(see below).

Update

Tick Biocontrol

The fungus *Metarhizium anisopliae* is pathogenic to all stages of the ticks and has much potential as a biocontrol agent. Field tests on 100 m^2 plots averaging 10 ticks per plot showed *M. anisopliae* killed about 53% of the ticks (Benjamin et al. 2002; Quarles 2003). Application of *M. anisopliae* when nymphal ticks were active led to an 87-96% reduction, but populations bounced back, and after 5 weeks reduction was 53-74% (Bharadwaj and Stafford 2010). Other field tests showed about a 56% tick reduction on lawns treated with *M. anisopliae* or *Beauveria bassiana* (Stafford and Allan 2010).

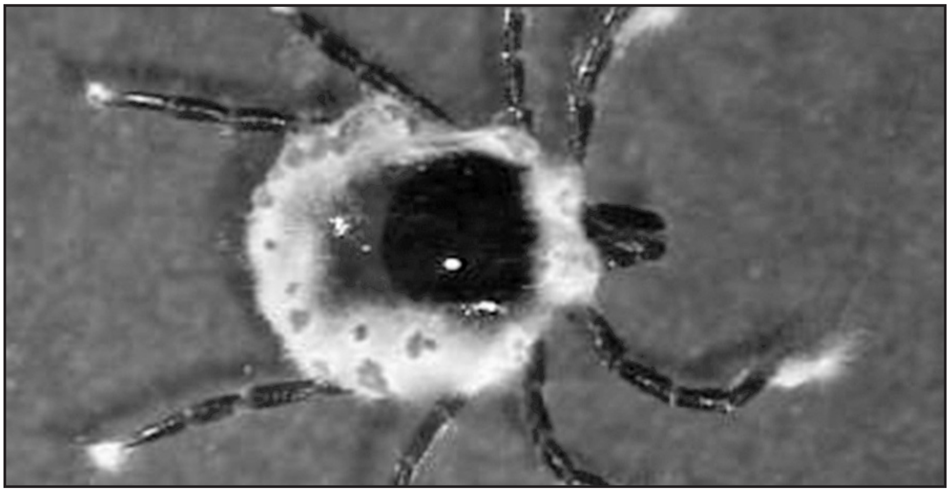


Photo courtesy Charlotte Nelson RVAU Denmark

The *Ixodes ricinus* tick shown here is infected with the fungus *Metarhizium anisopliae*. This fungus is commercially available for tick biocontrol.

Least-Toxic Tick Control

A number of botanicals can be useful in tick management. The compound noonkatone from cedar oil is one of the most effective. *Ixodes scapularis* tick reductions of about 96% for 42 days were seen in New Jersey. However, commercial development has been slow (Jordan et al. 2011).

Application of the commercial essential oil formulation IC2 to oak pine forests in Maine was just as effective as maximum label applications of bifenthrin for control of blacklegged tick, *I. scapularis*. Tick populations were controlled for 6-9 months by the essential oil. Bees were not affected, but some non-target insects showed decline for about 3 weeks. Bifenthrin protection lasted 12-16 months and had more of an impact on non-target populations (Elias et al. 2013; Rand et al. 2010).

Garlic has also been used with moderate success to control ticks. Application of Mosquito Barrier (0.2 g AI/m^2) to residential properties in Connecticut led to about 50% suppression of nymphal *I. scapularis* ticks for about two weeks (Bharadwaj et al. 2015).

Conclusion

Global warming is contributing to the spread of human pathogens. Ticks and mosquitoes carrying vectorborne pathogens are increasing in population and colonizing new areas. As conditions change, new virulent pathogens are emerging. The trends seen now will likely worsen with the higher global temperatures expected by the end of the century.

We can fight global warming with renewable energy, organic agriculture, and aggressive tree planting programs. These approaches will help reduce warming caused by carbon dioxide greenhouse gases. Vectorborne pathogens can be reduced by IPM methods such as exclusion, habitat management, repellents and least-toxic pesticides.

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Conference Notes

ESA-ICE 2016 Meeting Highlights

By Joel Grossman

These Conference Highlights were selected from among 5,396 presentations at "Entomology Without Borders," the Orlando, Florida (Sept. 25-30, 2016) joint 25th International Congress of Entomology (ICE) and annual Entomological Society of America (ESA) meetings, the largest gathering of entomologists in world history with 6,682 delegates from 102 countries. The next ESA annual meeting is November 5-8, 2017 in Denver, Colorado. For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org).

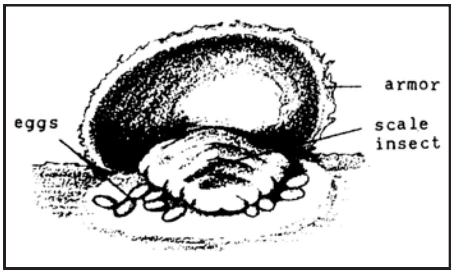
Soap or Oil for Scales?

"Smothering agents such as insecticidal soap and horticultural oil have been used since the late 1800's for control of various insect pests of fruits, shade trees and ornamental plants, selectively killing pests with minimal impact on natural enemies," said Carlos Quesada (Purdue Univ, 901 West State St, West Lafayette, IN 47907; cquesand@purdue.edu). Numerous studies on armored scale insects have shown that oil can provide over 85% reduction in scale populations. But other studies have failed to realize this level of control. For this reason, two armored scale and two soft scale species were studied to determine how morphological differences between soft and armored scales affected the control potential of oils and soaps.

Pine needle scales (armored), *Chionaspis pinifoliae*, and calico scales (soft), *Eulecanium cerasorum*, were chosen to represent species with a single large cohort of eggs, producing crawlers [immature scales] over a short period of time. Oleander scale (armored), *Aspidiotus nerii*, and striped pine scale (soft), *Toumeyella pini*, represented species that lay several eggs a day, producing crawlers over a longer time interval, with likely overlapping generations.

"Soaps are thought to penetrate the insect's body and disrupt the normal function of both cells and membranes," said Quesada. Oils block the spiracles necessary for gas exchange, with lack of oxygen leading to asphyxiation as CO_2 and toxins increase. Oils also interact with fatty acids in immature insect bodies, interfering with metabolism and destroying membranes.

Both 2% insecticidal soap (Novelty Mnf, Lancaster, PA) and horticultural oil (Whitmire Micro-Gen, St Louis, MO) controlled crawler stages of soft scales and armored scales. This is "because their integuments are relatively free of the waxes and other products that they secrete after they have settled and begun to feed," said Quesada.



Oils are best for armored scales.

Soap treatments were more effective than oil for soft scales. Soft scale insects cover their bodies with bulky wax. However, the wax on the body accounts for only 13% of its weight. Thus, the lower concentration of wax might explain why a hydrophilic compound, such as insecticidal soap, can penetrate the integument and kill soft scales. Similarly, this mechanism would also explain why a more lipophilic compound like horticultural oil is less able to kill soft scales.

Oil treatments were more effective than soap for armored scales. Armored scales produce covers made of wax (50% of their weight) which is composed of extremely hydrophobic and proteinaceous substances. Horticultural oil, due to its high lipophilic properties, can penetrate the scale cover. After infiltration, oil reaches spiracles of the insect situated on their ventral part of the body and kills it. In contrast, insecticidal soaps molecules have a polar head and non-polar tail. They are not oily enough to dissolve the wax and penetrate armored scale cover.

Asian Citrus Psyllid Biocontrol

Releases of the biocontrol agent *Tamarixia radiata* help control Asian citrus psyllid (ACP), *Diaphorina citri*, which vectors huanglongbing or citrus greening disease, said Jawwad Qureshi (Univ Florida, 2685 SR 29 N, Immokalee, FL 34142; jawwadq@ufl.edu). *T. radiata* provides low levels of ACP control early in the season, but biocontrol increases over time if the parasitoid is not killed by pesticide sprays. Winter *T. radiata* releases were tested alone and in combination with organic sprays in a 15-acre (6-ha) Florida Valencia orange orchard. Treatments were mineral oil (dormant oil 435); pyrethrins (Pyganic®); and insecticidal soap (M-pede®) .

Danitol®, a synthetic pyrethroid, applied 7 times in November and January, or 10 applications of organic spray remedies provided significant ACP control (60% less ACP), compared to no treatment. Biocontrol agents such as spiders, ants and lady beetles were few in number. Orange yields were highest with the pyrethrins plus oil. Research is underway to determine why citrus yields are higher with oil than soap.

Boric Acid Bait Stations

Two liquid boric acid bait stations placed outside homes for black ants, *Dolichoderus thoracicus*, was a successful long-term IPM strategy, significantly reducing ant populations, said Shao-Ming Huang (NCUE, 1 Jin-De Rd, Changhua 500, Taiwan; andrew6313516@

gmail.com). The green bait stations have a front feeding platform and a clear pyramidal silo that holds liquid bait. Bait stations were deployed after monitoring showed a need. Baiting, in 3 villages in Taiwan's Miaoli County, was stopped whenever monitoring indicated no ants for a month. Ant problems peaked in summer and fall. Ant foraging gradually decreased during winter, and picked up again in spring.

Combining BT and Wintergreen Oil

"Methyl salicylate (MeSA), oil of wintergreen, is a potent inducer of plant resistance," useful in rotation with copper-based fungicides to combat plant pathogens such as bacterial spot, *Xanthomonas campestris*, and bacterial speck, *Pseudomonas syringae*, said Russell Eldridge (Valent BioSci Corp, 870 Technology Way, Libertyville, IL 60048; Russell.Eldridge@valentbiosciences.com). *Bacillus thuringiensis kurstaki* (BTK), widely used to control caterpillar pests, is mixed with wintergreen oil in Leap™, a dual-action, biorational pesticide for plant disease management and insect control. Leap obtained EPA registration for pre-fruiting tomato and pepper crops in 2015. Registration for use up to harvest is expected in 2017.

Zero Gain From Neonic Seeds

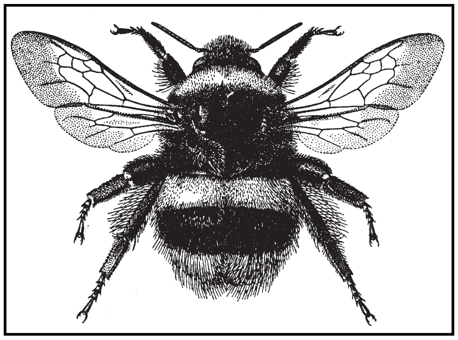
"For a lot of farmers it is hard to get untreated seeds, especially corn," as most commercial seed is treated with neonicotinoids, said Aditi Dubey (Univ Maryland, College Park, MD 20742; aditid26@gmail.com). However, in Maryland (mid-Atlantic USA), neonicotinoid seed treatments provided no significant yield gain compared to untreated seed in 3-year rotations with double-cropped soybeans, winter wheat and corn.

Unnecessary prophylactic seed treatments over many years can result in neonicotinoid soil accumulations, causing non-target and ecological effects on soil and aquatic organisms. In the mid-Atlantic region, neonicotinoid seed treatments reduced predatory carabid ground beetles, indirectly boosting slug numbers and increasing slug damage to crops.

Prey contaminated with neonics can reduce survival and fecundity of predators, producing less biocontrol. The 3-4 weeks of early season protection from sucking pests such as aphids, leafhoppers and stink bugs must be weighed against adverse non-target effects such as poisoning of natural enemies and pollinators.

Pesticide Surfactants Bad for Bees

Though officially classified as inert ingredients, hundreds of thousands of pounds of nonionic organosilicone surfactant (OSS) adjuvants are sprayed annually in California almond orchards, often during bloom to enhance the penetration and spread of pesticide active ingredients, said Diana Cox-Foster (USDA-ARS, Utah State Univ, Nat Res Biol Bldg, Logan, UT 84322; Diana.Cox-Foster@ars.usda.gov). Unfortunately, there are non-target impacts on honey bees and bumble bees, which can include reduced survival, suppression of anti-viral defense genes and synergism of viral pathogens associated with colony decline.


From Nixon 1954

Bumble bee, *Bombus* sp.

Survival of bumble bee workers was significantly reduced with increasing surfactant dosages (ppm), versus bees fed only sugar water. Israeli Acute Paralysis Virus (IAPV), replicated in adult and larval bees, reducing survival, foraging rates and brood production. Organosilicone adjuvants synergize the virus infection, most likely by suppressing bee anti-viral immune genes.

Beauveria Varroa Alternative

An isolate of insect-killing fungus, *Beauveria* spp., isolated from *Varroa destructor* mites collected inside a honey bee hive in Beltsville, MD and cultured on artificial media killed Varroa mites in 27 hours, said Francisco Posada-Florez (USDA-ARS, BARC-East 306, Beltsville, MD 20705; fjavierposada@gmail.com). Fungal strains isolated from the target pest are recommended because they are already adapted to host and environmental conditions. Powdered *Beauveria* spores reduced the 12.7 day Varroa mite life span to 1.1 days, and then the fungus replicated, producing more infective spores which get caught on Varroa mite body hairs and are hard to dislodge.

"When Varroa mites were dropped on the treated surface, some landed on their back and were unable to flip themselves over as the dusted surface did not allow them to grab a point of support," said Posada-Florez. Additionally, the agitation shown by Varroa mites exposed to powdered spores suggests these spores may directly act as a deterrent to mites. This is a double win strategy that needs further studies. Continuing research involves artificially rearing Varroa mites, developing new *Beauveria* application methods, and assessing effects on honey bees.

Foliar Nutrients Foil Soy Pests

Foliar sprays of micronutrient-enriched potassium silicate fertilizers suppressed aphids and soybean stem fly, *Melanagromyza sojae*, said Hanan Alfy (Agric Res Center, Alexandria, Egypt; hanan_isaac1@yahoo.com). Foliar treatments tested in Egypt on four common soybean cultivars included: 1) micronutrients (iron, zinc, manganese) alone; 2) potassium silicates with and without micronutrients; 3) potassium sulfate with and without micronutrients; 4) potassium hydroxide with and without micronutrients; 5) no treatment. Micronutrients increased potassium absorption, thereby strengthening plants and promoting healing after injury. Soybean plants subjected to foliar sprays of potassium silicates with micronutrients had the lowest pest damage.

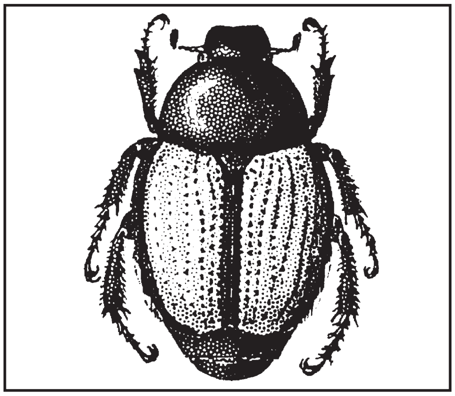
Cabbage Aphid Biocontrol

Field cage experiments in Mexico showed that one release of the parasitoid *Diaeretiella rapae* (Braconidae) can suppress the cabbage aphid, *Brevicoryne brassicae*, by 77% to 93% for over 58 days on cole crops such as broccoli, said Francisco Lopez-Monzon (Autónoma Agraria Antonio Narro Univ, Saltillo, Mexico; flopezmonzon@yahoo.com.mx). Cabbage aphids can deform and stunt plants, and plants without *D. rapae* releases were sometimes completely destroyed by aphids. *D. rapae*, a solitary wasp attacking over 60 different aphid species, can be a key component of cabbage aphid IPM on cruciferous crops.

PGPR Stop Corn Borers

Plant growth-promoting rhizobacteria (PGPR) are symbionts that obtain nutrients from plant root exudates, and in exchange "mediate plant health via increased rates of plant growth, suppression of soil pathogens, and induction of systemic resistance against plant diseases and herbivores," said Joseph Disi (Auburn Univ, 301 Funchess Hall, Auburn, AL 36849; jod0003@auburn.edu). In no-choice experiments, female moths of European corn borer (ECB), *Ostrinia nubilalis*, laid significantly fewer eggs on corn plants treated 15-18 days after planting with PGPR strain *Bacillus pumilus* INR-7 or PGPR Blend 9 (*Bacillus amyloliquefaciens* strains AP-136, AP-188, AP-219, AP-295). PGPR-treated corn was so abhorrent that ECB moths laid eggs on their cages instead.

Female moths distinguish untreated corn from PGPR-treated corn through emissions of plant volatile organic compounds (VOCs). PGPR-treated corn releases fewer VOCs than untreated corn. VOC blends released by corn plants also vary, depending on the specific PGPR strains used. VOCs identified by GC-MS (gas chromatography-mass spectrometry) included pentanal, 3-hexen-1-ol, linalool, methyl siloxanes, cyclosativene, alpha-copaene and (E)-5-methyl-2-methylene-2-hexen-1-ol. Each of these VOCs will be tested separately on ECB. The plan is to treat corn seed with PGPR blends, altering VOC emissions to reduce pest attraction and egg laying.



Japanese beetle, *Popillia japonica*

Mass Trapping Japanese Beetles

"In 2012, a mass trapping device consisting of a sex pheromone/floral volatile lure, a yellow trap top, and a 1.2 m (3.9 ft) long net sock was developed by the Lincoln University IPM program as an organic management option for Japanese beetle (JB), *Popillia japonica*," said Austen Dudenhoeffer (Lincoln Univ, 900 Chestnut St, Jefferson City, MO 65101; austen.dudenhoeffer657@my.lincolnu.edu). While this device was effective at suppressing beetle populations, farmers still needed to empty the sock traps several times per week. Dudenhoeffer sought to optimize the newly developed mass trapping system to control JB organically in an 0.4 ha (1 acre) elderberry (*Sambucus canadensis, S. nigra*) orchard.

Traps were made from 121-liter (32-gal) low-maintenance trash bins with "commercial yellow tops and were baited with one floral volatile/sex pheromone lure (Great Lakes IPM, Vestaburg, MI)," said Dudenhoeffer. The 2015 study compared ventilated bins, non-ventilated bins, and fully ventilated steel mesh socks 1.2 m (3.9 ft), which represent the standard mass trapping system. Ventilated bins were made by drilling 60 holes per side using a 9 mm drill bit...Traps were spaced about 2 m (6.6 ft) apart, about 15 meters (49 ft) from the perimeter rows.

In a peak July 2016 week, ventilated traps "intercepted 581,400 JB before they reached the cash crop, demonstrating effective JB suppression," said Dudenhoeffer. The small organic elderberry orchard had less than 1 JB per plant, well below the economic threshold of 5 JB per plant, providing farmers with a practical and effective organic control option. Air circulation (ventilation) was the key to trap success.

Composting Japanese Beetles

"In an attempt to use large amounts of Japanese beetles (JB) that have been captured using mass trapping, four compost bins were prepared using the layer method," said Traron Shivers (Lincoln Univ, 900 Chestnut St, Jefferson City, MO 65101; traron.shivers006@my.lincolnu.edu). Carbon sources used were shredded paper, wood chips, and leaves, while our sole nitrogen source was Japanese beetles. Earthworms were used in some trials to produce vermi-compost.

Both Japanese beetle compost or vermi-compost increased the yield of lettuce, with higher compost amounts providing higher lettuce leaf area and weight indexes in greenhouse pots. These results indicate that Japanese beetles can be used as a viable nutrient source for crop production.

Drosophila Exclusion Netting

Netting, whether to cover individual cherry trees, entire orchards or single rows of blueberry vines, is an effective IPM exclusion tool protecting soft fruits from spotted wing Drosophila (SWD), *Drosophila suzukii*, in northeastern Italy, said Nicola Mori (Univ Padova, Via dell'Università 16, 35020 Legnaro, Italy; nicola.mori@unipd.it). Nets were installed before the fruits changed color, to prevent any SWD from being trapped inside the nets.

Whole cherry orchards and single rows were protected with 1x1 mm mesh insect-proof nets topped by a nylon rainfly or waterproof double-layer. The netting system for individual blueberry and raspberry rows was tent-like in shape, and did not need a top rainfly. Single cherry trees were wrapped in 0.5x0.8 mm mesh insect-proof nets. No adverse microclimate or fruit quality effects were measured. Long-term economic sustainability for large acreages still needs to be calculated, before the standard insecticide regimen is abandoned and replaced by insect exclusion netting.

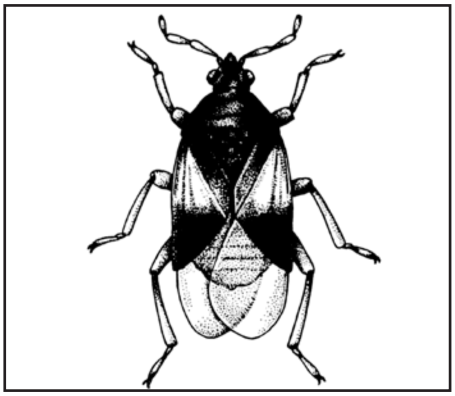
Violet Light Attracts Pirate Bugs

Light emitting diode (LED) ropes radiating violet wavelengths (405 nm) placed in banker or companion plants (e.g. blue salvia, marigold, buckwheat, sesame) bordering eggplant fields selectively attract and hold male and female minute pirate bugs, *Orius sauteri*, providing biocontrol of small pests such as melon thrips, *Thrips palmi*, which injures and deforms over $100 million of Japanese eggplant fruit, said Masami Shimoda (Nat Instit Agrobiol Sci, Ohwashi 1-2, Tsukuba, Ibaraki 305-8602, Japan; shimoda1@affrc.go.jp).

Violet light is a very selective attractant, as violet photoreceptors are very rare in insects. Light sensitivity varies greatly among insect species and is strongest at ultraviolet (340 nm), blue and green (500 nm) wavelengths. Moths are most sensitive to green. Thrips, leafhoppers and flies are more sensitive to ultraviolet (UV). House flies have blue, green and UV photoreceptors.

Another name for optical manipulation of natural enemies is "Integrated Biodiversity Management," which "includes IPM and the conservation of nature around cultivated fields," said Takumi Ogino (Univ Tsukuba, Japan; hirundorustica@affrc.go.jp). Besides thrips in eggplant fields, *Orius* spp. can provide biological control of whiteflies, leafhoppers, moth eggs, small caterpillars, spider mites and sundry other small pests.

Arena LED tests with UV, blue, green, red, yellow and violet show that male and female *O. sauteri* prefer violet (405 nm), but mated females prefer UV (365 nm). Pesticide-free eggplant fields were cultivated and monitored with sticky paper and sampling of 10 leaves per plant from June to October. In small plots of 12 eggplants surrounded by 12 banker plants with and without custom-made violet LED ropes (SHIGRAY Inc, Tokyo), violet LED plots had 185% more *O. sauteri* and 60% fewer melon thrips than plots without LEDs.



Pirate bugs, *Orius* spp. are attracted to violet light.

Greenhouse IPM Light

Growers in Norway want year-round food production during sub-zero winters with 2 hour days and 22 hour Nov/Dec nights. They are curious how artificial sources of green, yellow, blue, red, ultraviolet (UV) and other light wavelengths affect greenhouse whiteflies, thrips, predatory bugs, and plant diseases, said Nina Johansen (Norwegian Instit Bioeconomy, Ås, Norway; Nina.Johansen@nibio.no).

Creating trap crops by flooding trap plants with yellow-green light while the crop is irradiated with blue or red shows promise for management of whiteflies in poinsettia and thrips in vegetables. Whiteflies will land on blue, red and white, but these colors inhibit landing, and very few released adult whiteflies were found on blue in July. Thrips eggs developed normally under blue light, and experiments are underway to see if blue or yellow sticky traps capture more thrips when crops have blue LEDs.

Optical IPM is tightly integrated with releases of predatory mites, aphid parasitoids and other biocontrol organisms. In tomato, an extra 4-5 hours of blue light on crops increased establishment of natural enemies such as predatory pirate bugs, *Orius* spp., and *Diglyphus* parasitoids of leafminer flies.

Low, night-time doses of UV-B light can control powdery mildew disease on crops. Experiments are being conducted on disruption of diapause photo-induction in spider mites and disturbance of the circadian clock entrainment in whiteflies. Like something out of sci-fi, robots aim precise bursts of controlled light intensity (photon flux) and wavelength (color) to kill spider mite eggs, larvae and nymphs in strawberry, tomato and cucumber greenhouses.

Narrow-Band Light IPM Impact

Narrow bands of ultraviolet (UV) light, 310nm (UVB) to 385nm (UVA), and 420nm (violet) from either tubes or high-power LEDs (light-emitting diodes) can boost plant defenses (induce resistance) against herbivorous pests such as aphids, said Ole Rechner (Leibniz Univ, Herrenhaeuser Str 2, 30419 Hannover, Germany; rechner@ipp.uni-hannover.de). Different light wavelengths (photon fluxes) affect plants in varying ways, resulting in different patterns of induced plant secondary metabolites.

Calendar

January 20-22, 2017. NOFA Winter Organic Farming and Gardening Conf. Saratoga Springs, NY. Contact: NOFA, 585/271-1979; www.nofany.org

January 25-28, 2017. 35th Annual Eco-Farm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

February 5-7, 2017. Annual Conference, Association Applied Insect Ecologists, PO Box 1119, Coarsegold, CA 93614. Contact: 559/761-1064; www.aaie.net

February 6-9, 2017. Annual Meeting Weed Science Society of America. Lexington, KY. Contact: www.wssa.net

February 23-25, 2017. 28th Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

February 28-March 1, 2017. Spring Meeting BPIA. Reno, NV. Contact: www.biopesticideindustry.org

March 2, 2017. Organic Lawn Care, Chip Osborne. Walnut Creek, CA. Contact: Parents for a Safer Environment; www.pfse.net

March 2017. California Small Farm Conference. Contact: www.californiafarmconference.com

June 22-24, 2017. Annual Meeting, Pest Control Operators CA, Disneyland, CA. Contact: PCOC, 3031, Beacon Blvd, W. Sacramento, CA 95691; www.pcoc.org

August 5-9, 2017. American Phytopathological Society Conference, San Antonio, TX. Contact: APS, 3340 Pilot Knob Road, St. Paul, MN 55121; 651-454-7250; aps@scisoc.org

August 6-11, 2017. 102nd Annual Conference, Ecological Society of America, Portland, OR. Contact: ESA, www.esa.org

October 22-25, 2017. Annual Meeting, Soil Science Society of America. Tampa, FL. Contact: www.soils.org

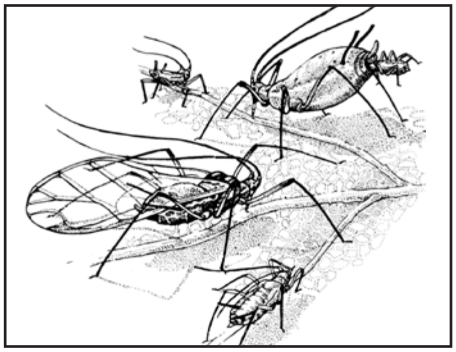
October 22-25, 2017. Annual Meeting, Crop Science Society of America. Tampa, FL. Contact: https://www.crops.org

October 22-25, 2017. Annual Meeting, American Society of Agronomy. Tampa, FL. https://www.acsmeetings.org

October 24-27, 2017. NPMA Pest World, Baltimore, MD. Contact: NPMA, www.npmapestworld.org

November 5-8, 2017. Annual Meeting, Entomological Society of America, Denver, CO. Contact: ESA, 9301 Annapolis Rd., Lanham, MD 20706; www.entsoc.org

Conference Notes



Ultraviolet light affects aphid growth.

UVA and violet light stimulate cryptochromes (flavonoids involved in circadian rhythms, sensing and other functions) and secondary plant metabolites such as glucosinolates and flavonol glycosides that have anti-herbivore effects. Broccoli plants grown for 4 weeks under UVB tubes or LEDs emitting UVA or violet light produce 34 different compounds, with varying effects on different herbivore species.

UV-B (compared to UV-A or violet light) reduces plant height and dry weight, and markedly increases quercetin, kaempferol glycosides and a glucosinolate, 4-methoxy-3-indolylmethyl. Green peach aphid (GPA), *Myzus persicae*, a generalist pest, increases its reproductive rate and gains weight with no change in developmental time with UV-B and UV-A wavelengths. In contrast, cabbage aphid, *Brevicoryne brassicae*, a specialist pest, does not thrive under UV-B; and does even worse under UV-A and violet light. The IPM goal is to customize light wavelengths, light intensities and illumination times for IPM programs for specific pests and crops.

Organic Cabbage Companions

"Establishing flowering plants in and around fields to provide pollen and nectar resources for natural enemies has shown promise as a strategy to enhance biological control of crop pests," said Binita Shrestha (Univ Missouri, 52 Agri Lab, Columbia, MO 65211; bswc2@mail.missouri.edu). The right selection of insectary plants for crop fields can improve the survival, development and fecundity of natural enemy species, thus lowering herbivore densities and crop damage. Since different natural enemies may favor different plants based on variables like floral structure, color and types of sugars in nectars, a range of flowering insectary plants were evaluated to protect organic cabbage: sweet alyssum, *Lobularia maritima*; buckwheat, *Fagopyrum esculentum*; mighty mustard, *Brassica juncea*; dwarf sunflower, *Helianthus gracilentus*; dill, *Anethum graveolens*; fennel, *Foeniculum vulgare*; and basil, *Ocimum basilicum*.

All the experimental insectary plants attracted similar natural enemies, but in varying quantities. "All seven plant species except for dill attracted high numbers of pink lady beetles," said Shrestha. Mighty mustard and fennel were dominated by the pink lady beetle. Syrphid flies were predominant on dill. Whereas sweet alyssum, dwarf sunflower, basil and buckwheat showed relatively more even distributions of the seven families of natural enemies. Buckwheat was the most attractive plant for syrphid flies and tiphiid wasps. In contrast, the response of tachinid flies was not influenced by plant species. Overall, buckwheat was a superior choice "to attract different natural enemies of insect pests of cabbage."

Buckwheat, *Fagopyrum* sp., is best for attracting beneficials in cabbage.

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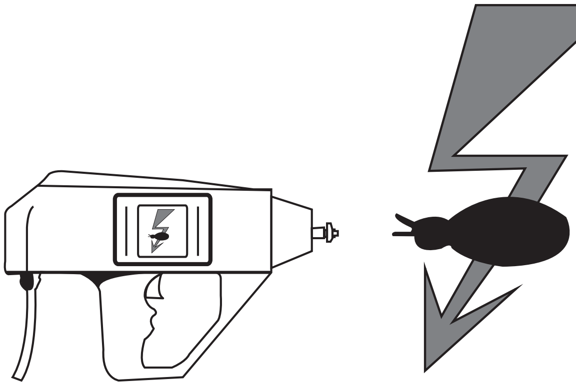

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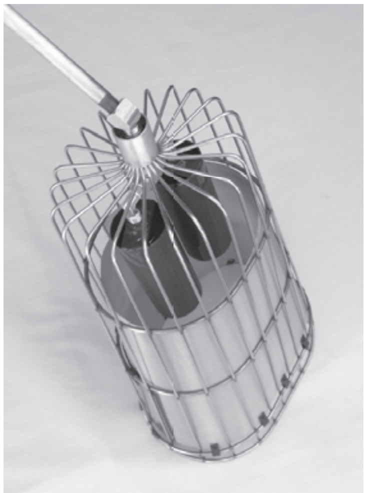

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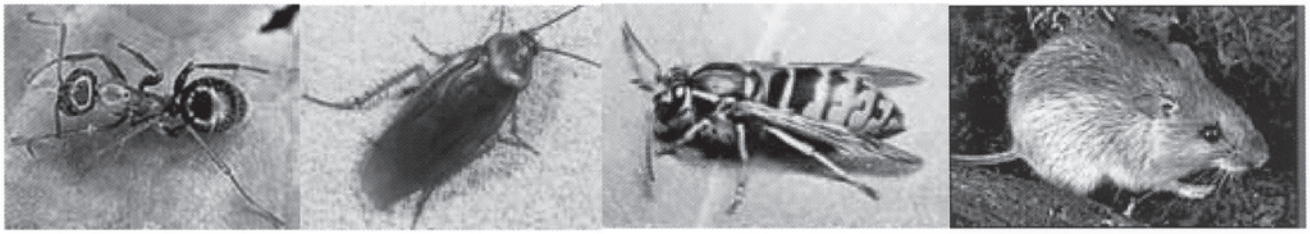

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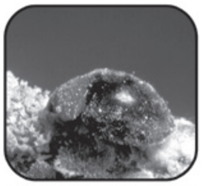

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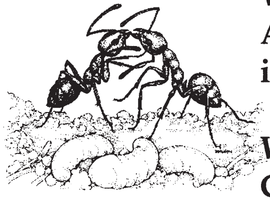

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