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IPM for *Cannabis* Pests

By William Quarles

About 35 million people in the U.S. use marijuana on a regular basis. It is the fourth most popular recreational drug after caffeine, alcohol, and tobacco (Ingraham 2017). Marijuana is legal for medical use in 31 states, and it has been decriminalized in 13 other states. Recreational marijuana is legal for adults in nine states, including Alaska, California, Colorado, Oregon, Maine, Massachusetts, Nevada, Vermont, and Washington. Legalization in Michigan and New Jersey is expected soon. There are only four states where it is totally illegal according to state law (Wikipedia 2018).

Marijuana may be the largest cash crop in the U.S. with an estimated value of $35.8 billion each year. Its closest rival is soybeans, whose value varies with yields, and recently with tariffs. Hemp also has a lot of economic potential. About $688 million of imported hemp products were sold in the U.S. in 2016 (Strickler 2018). Cultivation of both marijuana and hemp is illegal according to federal law. The federal government lists *Cannabis* as a Controlled Substances Act Schedule I drug and claims it has no medical value. The federal fate of marijuana is uncertain, but a law legalizing the cultivation of hemp throughout the U.S. was introduced into the U.S. Senate on April 12, 2018 (McConnell 2018).

Hemp

Hemp has been grown for thousands of years. It is a renewable source of fibers for ropes, bags, paper, building materials, and other products. Reusable hemp bags could replace some of the plastic bags at the grocery store. Seeds produce high quality edible oils containing unsaturated fatty acids and vitamin E. In blighted rural areas where coal mine and tobacco jobs have been lost, hemp could provide economic revitalization (Small 2015a; McConnell 2018).

Photo courtesy of Professor Whitney Cranshaw

Spider mites, *Tetranychus urticae*, have damaged this bud of *Cannabis*. Biological controls and least-toxic pesticides can control spider mite damage.

Medical Marijuana

The Trump administration claims that *Cannabis* has no medical uses, but *Cannabis* extracts were used in U.S. medicine until 1941 (Russo 2003). Several studies have shown that marijuana is an antiemetic, preventing nausea and vomiting after chemotherapy. It is effective as an appetite stimulant for wasting diseases such as AIDS. It is an antispasmodic. Some clinical tests have shown that marijuana is an analgesic for certain kinds of pain. It reduces glaucoma. Marijuana and especially cannabidiol (CBD) (see Box A) is an anticonvulsant. There is some evidence marijuana

In This Issue

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Update

may relieve symptoms of bronchial asthma and insomnia (Hollister 2001, Russo 2003). Pharmaceutical companies have developed strains that emphasize individual cannabinoids (see Box A) for clinical testing. THC may lessen the pain of opiate withdrawal. Cannabidiol is an effective anticonvulsant with few side effects (Russo et al. 2002; Russo 2003). An oral CBD drug, Epidolex®, has been recently approved by the FDA.

Pest Management Problem

Because federal law prohibits *Cannabis* production, there is a pest management problem in the states where it is legal. The EPA will not register a pesticide with marijuana or *Cannabis* listed on the label. Thus, most EPA registered pesticides cannot be applied. Yet many states allow marijuana to be grown, sold, and consumed. To make the best of a bad situation, cooperation between state and federal agencies has led to lists of approved pesticides. Pest management agencies in each state will answer questions about which pesticides are allowed (Cranshaw 2015; CA DPR 2018; WA 2018; OR 2018).

For instance, EPA registered pesticides with broad labeling that are also exempt from food tolerance requirements can be used in California. And 25b exempt materials such as clove oil are allowed. Pesticides not registered for food use, restricted pesticides such as the insecticides bifenthrin, fipronil, and cyfluthrin, pesticides on the Groundwater Protection list such as imidacloprid, and pesticides labeled Danger cannot be used (CA DPR 2018).

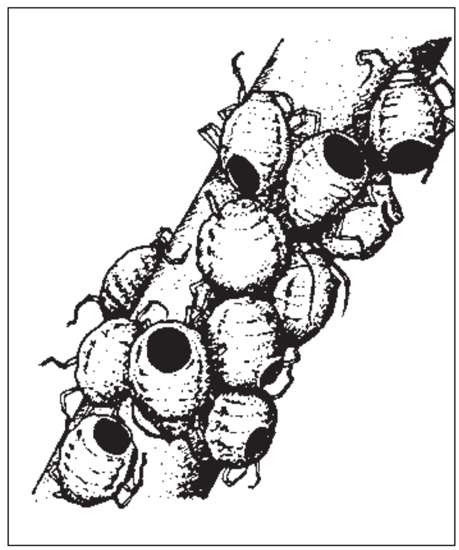
Least-Toxic Pesticides

Many of the pesticides allowed are biopesticides, soaps, and oils. Oregon and Washington have extensive lists of brandname formulations that include pyrethrins. California provides a list of generic active ingredients. By coincidence, many of the pesticides allowed for use on *Cannabis* are the least-toxic pesticides that BIRC has researched over the years, and a number of the products can be found in the *IPM Practitioner's Directory of Least-Toxic Pesticide Products* (BIRC 2015).

A Place for IPM

Because pesticides allowed are somewhat limited, the situation provides an ideal opportunity for IPM methods. IPM management should result in less environmental pollution, fewer pesticide exposures, and less pesticide contamination of the product. Less pesticide contamination is important because the California law requires that commercial marijuana be tested for pesticide residues (BCC 2018).

This article is not intended to provide a complete IPM program for each and every *Cannabis* pest. Rather to provide basic guidelines and followup to relevant literature (McPartland et al. 2000; Clarke and Merlin 2016, Pertwee 2016; Rosenthal and Imbriani 2012, Stitch and Rosenthal 2008).



Parasitoids killed these aphids.

Pests of *Cannabis*

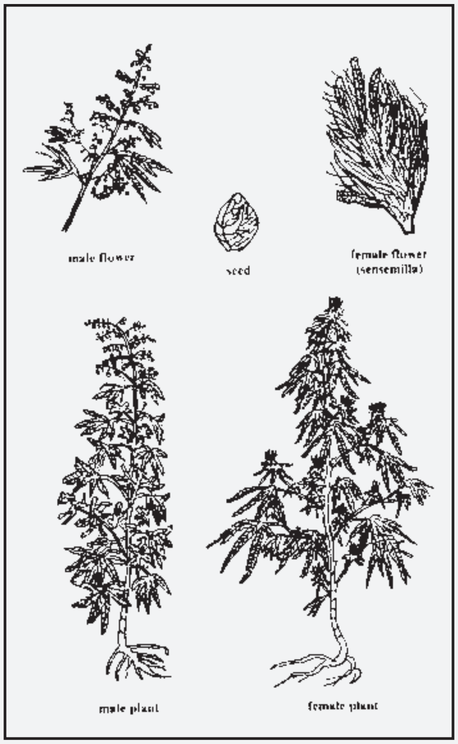
According to McPartland (1996), nearly 300 insect pests have been associated with *Cannabis*, but very few cause economic losses. At the seedling stage, pests are cutworms, birds, hemp flea beetles, crickets, slugs and rodents. Flower and leaf pests outdoors are hemp

Box A.
Biology and Chemistry of *Cannabis*

Cannabis contains more than 60 substances called cannabinoids. Major components are delta 9-tetrahydrocannabinol (THC), cannabidiol (CBD), and cannabinol (CBN). THC is the major component causing euphoria or hashish activity. Cannabidiol is an anticonvulsant and has much medical promise. It has no hashish activity and can moderate the central effects of THC. *Cannabis* strains showing equal amounts of THC and CBD are often preferred for medical marijuana use. Cannabinol is inactive centrally, and is an oxidation product of THC. These cannabinoids are secreted by the plant in the form of resins (Quarles et al. 1973; Mechoulam 1975, Small 2015a; Russo 2003; McPartland et al. 2006; Pertwee 2016).

Two kinds of *Cannabis* have economic value—hemp and marijuana. Linneaus had access only to hemp and classified what he saw as *Cannabis sativa* in 1753. Hemp has been grown for thousands of years throughout the world, and was grown in early America by Thomas Jefferson and others. According to current botanical thinking, hemp should still be called *Cannabis sativa*. It typically grows 3-5 meters (10-16 ft) high, and is characterized by fibrous stalks, long, narrow leaves and less than 0.3% THC (Schultes 1975, Small 2015a; Small and Marcus 2003).

Although there is general agreement that hemp is *Cannabis sativa*, the plant has been extensively modified, and there is a controversy whether domesticated *Cannabis* is one species with several subspecies or varieties, or two species with several subspecies or varieties. Schultes (1975) identified three species, *Cannabis sativa* (hemp), *Cannabis indica* (hashish activity), and a wild, scraggly form called *Cannabis ruderalis* (Schultes 1975; Small 2015ab).



Male and female *Cannabis* plants

Although hemp is *Cannabis sativa*, some strains are high in THC content and produce high quality marijuana. *Cannabis indica* according to Schultes (1975), is a short plant, less than 6 feet (1.8 m) high with broad leaves and a bush like growth profile. It is grown only for marijuana. Hybrids of *Cannabis sativa* and *Cannabis indica* may also contain large concentrations of THC. Commercial marijuana contains about 5-10% THC, but some strains may exceed 20%. Marijuana of the 1960s and 1970s was much less potent. For instance "Acapulco Gold" contained about 2.6% THC (Quarles et al. 1973; Schultes 1975, Small 2015ab; Clarke and Merlin 2016).

Plant breeders have produced many variants and strains of the two species. Variable terpene content gives the plants odors such as skunk, lemon, and mint. Changing the anthocyanin content leads to purple *Cannabis* (Small 2015a).

Plants are usually either male or female, but stress can produce plants with both flower types. Commercial marijuana comes from the female plant. Unfertilized flower buds, or sensemilla are the preferred product. Enough resin to produce euphoria also occurs in the leaves, but stems, roots, and seeds are inactive (Small 2015a).

According to Lewin (1964) the name *Cannabis* may have come from the old East Iranian name konaba, which became the Greek word *konabos*. Hemp is ancient and there are words for it in many languages. In Hebrew, the word is *kaneh*, sometimes linked with *bosm*, meaning aromatic. In Arabic the word is *kannab*, which leads easily to the Greek *kannabis* (Small 2015b). Hashish comes from an Arabic word meaning hay grass, garden weed, or "the herb." The slang term grass may have evolved from the association with hemp, which was known as "hempe, neckeweede, or gallow grasse." Hemp rope was used to hang medieval criminals (Lewin 1964; Rosenthal 1971; Dodoens 1578).

Cannabis along with hops and a few other plants are members of the Cannabaceae. *Cannabis* grows best in heavily fertilized, permeable, well drained soil. Seeds and roots will rot if drainage is inadequate. It thrives between 14-27°C (57-81°F) and likes sunlight. Flowering occurs 4-6 months after planting. It is an annual and reproduction can be by seeds or cloning. Due to its illegal nature, many growth operations are indoor hydroponics. Successful cultivation depends on sanitation and proper nutrient balance (Stitch and Rosenthal 2008; Small et al. 2003).

borers, budworms, leafminers, and green stink bugs. Stalks and stems are attacked by borers and beetle grubs. Roots are attacked by grubs, root maggots, termites, ants, fungus gnats and wireworms. Frequent and sometimes serious pests include aphids, whiteflies, mealybugs, mites, and chewing bugs (McPartland et al. 2000).

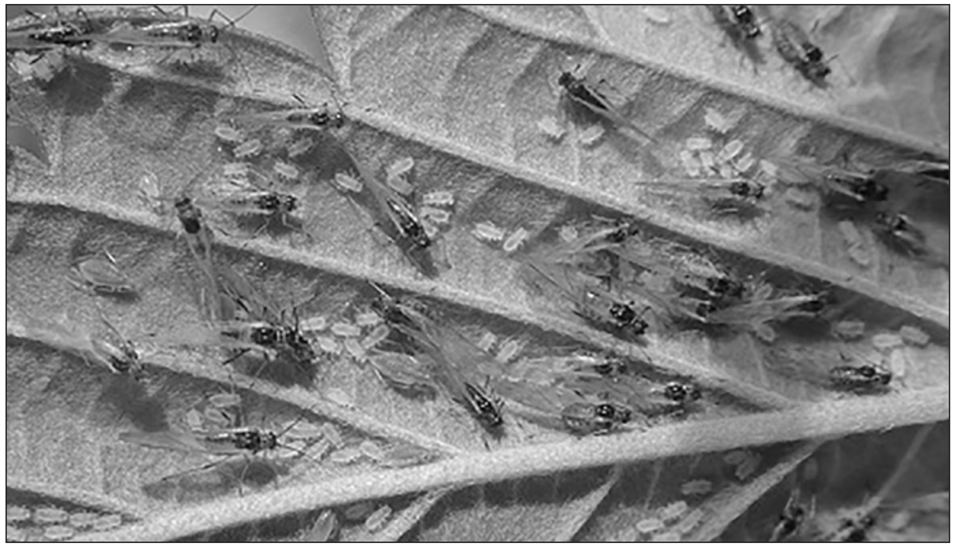


Photo courtesy of Professor Whitney Cranshaw

Aphids can be serious pests of *Cannabis*. This is a mixed infestation of winged forms and clones of the cannabis aphid, *Phorodon cannabis*.

Pests of *Cannabis* Inside

Cannabis can be grown indoors in greenhouses or grow rooms, or outside as a field crop. *Cannabis* grown inside has a different spectrum of pests and diseases than that grown outside. Plants are often grown hydroponically, which can predispose them to Pythium root rot and algae. High humidity in the grow rooms can encourage powdery mildew, botrytis and other foliage diseases. Most insect pests can be excluded, but spider mites, fungus gnats and other small arthropods may make their way inside. Flower and leaf pests inside are spider mites, aphids, whiteflies, thrips and leafhoppers. Mealybugs, scales, and true bugs can infest marijuana greenhouses. Thrips can be problems in rockwool growing rooms (McPartland 1996).

Photo courtesy of Whitney Cranshaw

Two-spotted mite, *Tetranychus urticae*

IPM methods include monitoring, sticky traps, pruning of infested material, biological controls, and application of state approved least-toxic pesticides. Possible pest entryways such as cracks and crevices should be sealed (Quarles 2006a; Murray 2016).

The grow room should be isolated physically from the rest of the structure. Ventilation systems should have filters to exclude insects and disease spores. When working with plants, clean clothes free of spores and possible insects should be used. Water should be purified by filtration or treatment with peroxide or UV light (Rosenthal and Imbriani 2012).

Pests of *Cannabis* Outside

Cannabis grown outside may have vertebrate pests, borers, grubs, leafhoppers, budworms, stinkbugs and others. Flower and leaf pests are spider mites, aphids, whiteflies, thrips and leafhoppers. Borers such as the European corn borer, *Ostrinia nubilalis* and the hemp borer, *Grapholita delineana*, can be serious pests. Other serious caterpillar pests are budworms such as *Helicoverpa armigera* (McPartland 1996; McPartland et al. 2000; McPartland 2002). According to Whitney Cranshaw (2018), the hemp russet mite, *Aculops cannabicola*, and the corn earworm, *Helicoverpa zea*, are among the most serious pests of *Cannabis* in Colorado.

Because pesticides are limited, physical, biological and microbial controls have increased importance. Plants can be monitored visually and with sticky traps. Physical controls such as fences and barriers can be used for vertebrate pests such as deer. Infested plants can be pruned. Caterpillars and similar insects can be removed by hand picking. Insectary plants grown around the perimeter can provide beneficial insects. And state approved least-toxic pesticides can be used for spider mites, diseases, whiteflies, caterpillars and other pest insects (CA DPR 2018; OR 2018; WA 2018).

Biological Controls

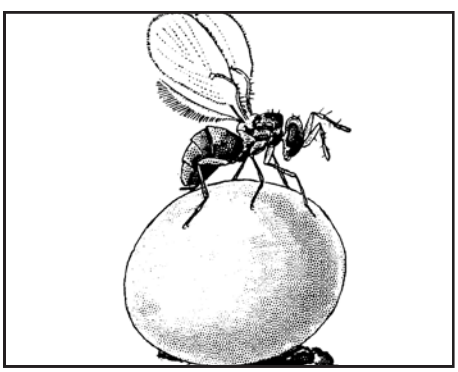
Biological controls can be used both inside and outside. Predatory mites can be used for pest mites, fungus gnats, and thrips. The mite midge, *Feltiella* sp. is a mite predator. Parasitoids such as *Aphelinus abdominalis* and *Aphidius* spp. can be used for aphids. The aphid midge, *Aphidoletes aphidimyza*, can also be effective. Lacewings are effective predators for aphids, thrips and whiteflies. Ladybugs will consume aphids, mealybugs, mites, scale, and whiteflies. Parasitoids such as *Trichogramma* spp. will attack caterpillar eggs. Parasitoids such as *Dacnusa sibirica* can reduce leafminer damage. Nematodes can be applied for beetle grubs, fungus gnats, and root borers. Species and suppliers can be found in the *IPM Practitioner's 2015 Directory of Least Toxic Pest Control Products* (BIRC 2015).

Sucking Pests

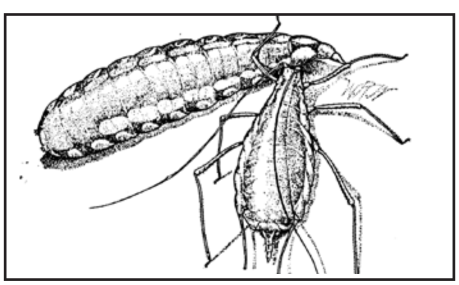
Pesticides for mealybugs, aphids, scale, whiteflies, and spider mites are similar. Application of soaps or oils can reduce populations. Neem oil containing azadirachtin can be effective. Essential oil sprays of clove, cinnamon, or rosemary can provide relief. But essential oil pesticides should be monitored for phytotoxicity (Rosenthal and Imbriani 2012; Quarles 2005). Biocontrols are discussed above.

IPM for Mites

Two kinds of mites can be serious pests of *Cannabis*—the two-spotted mite, *Tetranychus urticae*, and the hemp russet mite, *Aculops cannabicola*. Since plants grown inside are packed close together, mite infestations can quickly spread through the whole crop. These mites can be controlled by application of neem oil containing azadirachtin, and by application of predatory mites such as *Neoseiulus*



***Trichogramma* and caterpillar egg**



The aphid midge kills aphids.

Photo courtesy of Professor Whitney Cranshaw

The Eurasian hemp borer, *Grapholita delineana*, can be a serious pest of field grown *Cannabis*. IPM solutions are parasitoids, cultural methods, and least-toxic pesticides.

sp. and *Phytoseiulus* sp. The neem oil will not kill the predatory mites so they can be applied at the same time. Neem is best applied to foliage, but predatory mites can be applied to mite populations in flowers. Predatory mites are also effective for the occasional infestation of greenhouse thrips or western flower thrips (Quarles 2006b; Bernardi et al. 2013; McPartland and Hillig 2003).

Chewing Pests

Budworms such as *Heliothis* can be controlled by handpicking, biological controls, soap sprays, applications of the microbial pesticide *Bacillus thuringiensis* (BT), or application of neem oil containing azadirachtin (Olkowski et al. 1991; 2013). Egg parasitoids such as *Trichogramma* can help with caterpillar control. Stink bugs and flea beetles can be managed with row covers or state approved least toxic pesticides such as pyrethrins or neem with azadirachtin (McPartland et al. 2000).

Borers

The hemp borer, *Grapholita delineana*, is a moth that lays 300-400 eggs on leaves and stalks of *Cannabis* plants. The caterpillars first attack the leaves, then bore into stalks, forming galls. Larvae reach 9-10 mm (0.4 in) in length. Larvae pupate within the stems. The adult can fly 20 km (12 mi). Parasitoids, BT, pheromone monitoring traps, burying crop debris, deep plowing, and early harvesting are IPM measures. Neem with azadirachtin can provide control if applications are timed with egg laying. Pyrethrins can also be effective at this stage (BA 2010; McPartland et al. 2000). Root borers can be controlled with nematodes. Treatment of seeds or soil with *Metarhizium anisopliae* may help with wireworm attacks. The European corn borer can be controlled with BT and biological controls such as *Trichogramma*, lacewings and ladybugs (Olkowski et al. 1991; 2013).

Diseases

Common diseases, especially for plants grown inside, are powdery mildew caused by *Podosphaera macularis*, and gray mold caused by *Botrytis cinerea*. Good ventilation should be provided, and humidity maintained below 70%. Strict sanitation protocols should be followed, including dedicated clean room clothing. Powdery mildew and botrytis will respond to oils, potassium bicarbonate, and induced systemic materials such as potassium phosphate. Microbial controls such as compost tea, *Bacillus subtilis*, and *Bacillus amyloliquefaciens* can be used for diseases (Quarles 2013). Root diseases such as Pythium

Photo courtesy of Whitney Cranshaw

Powdery mildew, *Podosphaera macularis*

may be controlled by sanitation of the rooting medium with peroxide (Stitch and Rosenthal 2008; Rosenthal and Imbriani 2012).

Similar least-toxic treatments including compost tea can be used for foliage diseases outside. In addition, outside plants are vulnerable to soilborne pathogens. Soil can be solarized before planting. Compost can be added. Crop rotation can be practiced. Treatments of seed or soil with *Trichoderma* spp. can be effective (McPartland et al. 2000; Quarles 2000; Quarles 2004; Quarles 2018).

Factors in Legalization

Public support for legal marijuana has been increasing in the last decade. A majority of Americans now support legalization. One of the reasons is the success of medical marijuana programs. Increased tax revenues and reduced prison populations are also strong arguments for legalization (McGinty et al. 2017). Another reason may be increased misery and depression in America. The suicide rate has increased about 28% since 1999 (CDC 2018). The percentage of the population taking prescription psychoactive drugs to relieve depression, anxiety and pain has more than doubled in the last 30 years. About 98 million people in the U.S. (30%) are habitual users of antidepressants (10.7%), anxiolytics (5.3%), analgesics (9.1%), and anticonvulsants (4.9%). Many of these drugs are addictive and can have serious withdrawal symptoms (US 2017: Lembke et al. 2018; Comerci et al. 2018). People taking these drugs may look with favor to a legal alternative with less addictive potential and mild withdrawal effects (Hollister 1978; Russo 2002).

IPM Certified *Cannabis*

Colorado entomologist Whitney Cranshaw calls the era of totally illegal *Cannabis* the Wild West stage. Growers could use toxic pesticides and many of them did. Pre-harvest rules may not have been followed, and pesticide residues may have been extensive. Pest management information could not be obtained from state agencies and sources were hearsay and the internet (Cranshaw 2015).

Illegal marijuana operations outside were marked by pesticide and fertilizer pollution. Problems included rodenticide poisoning of owls and pollution of streams. State licensed, legally grown marijuana provides an opportunity to reduce environmental pollution (Giannoti et al 2017). Because it is still illegal under federal law, USDA organically certified marijuana cannot be produced. But an Eco or IPM label for marijuana grown with organic methods and low environmental impact is possible.

Growers may view a certified product with favor because quality control already exists. Marijuana in California is regulated by the Bureau of Cannabis Control. Marijuana sold in California must be tested for percent cannabinoids (see Box A), moisture content, solvents, residual pesticides, microbes (mostly *Aspergillus* spp.), microbial pathogens (*E. coli* and *Salmonella*), foreign materials, terpenoids, mycotoxins, and heavy metals (BCC 2018).

Conclusion

Cannabis can be grown and consumed responsibly. It does not have to be destructive. Hemp can provide renewable products to replace some of the plastics that are contaminating the land and the oceans. *Cannabis* can contribute to society through taxes, and production of jobs in blighted rural areas and elsewhere.

Marijuana and hemp may eventually legalized throughout the U.S. Meanwhile, in states where *Cannabis* is legal, IPM methods can protect against pests. IPM methods can reduce pesticide residues and environmental pollution. An Eco or IPM label for *Cannabis* would insure attention to good environmental practices.

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Calendar

July 29-August 3, 2018. American Phytopathological Society Conference, Boston, MA. Contact: APS, 3340 Pilot Knob Road, St. Paul, MN 55121; 651-454-7250; aps@scisoc.org

August 5-10, 2018. 103rd Annual Conference, Ecological Society of America, New Orleans, LA. Contact: ESA, www.esa.org

September 21-22, 2018. Board of Directors, Pest Control Operators CA, Dana Point, CA. Contact: PCOC, 3031, Beacon Blvd, W. Sacramento, CA 95691; www.pcoc.org

October 22-24, 2018. 9th International Oak Society Conference. Davis, CA. Contact: www.internationaloaksociety.org

October 23-26, 2018. NPMA Pest World, Orlando, FL. Contact: NPMA, www.npmapestworld.org

November 4-7, 2018. Annual Meeting, Crop Science Society of America. Baltimore, MD. Contact: https://www.crops.org

November 4-7, 2018. Annual Meeting, American Society of Agronomy. Baltimore, MD. https://www.acsmeetings.org

November 7-10, 2018. California Invasive Plant Council Symposium. Monterey, CA. Contact: California Invasive Plant Council, 1442 Walnut St., No. 462, Berkeley, CA 94709. www.cal-ipc.org

November 11-14, 2018. Annual Meeting, Entomological Society of America, Vancouver, BC. Contact: ESA, 9301 Annapolis Rd., Lanham, MD 20706; www.entsoc.org

November 28, 2018. Association of Applied Insect Ecologists. Visalia Convention Center, Visalia, CA. Contact: www.aaie.net

January 6-9, 2019. Annual Meeting, Soil Science Society of America. San Diego, CA. Contact: www.soils.org

January 23-26, 2019. 39th Annual EcoFarm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

February 11-14, 2019. Annual Meeting Weed Science Society of America. New Orleans, LA. Contact: www.wssa.net

February 21-23. 2019. 30th Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

Update

Global Warming and Water Pollution

By William Quarles

The Trump administration has launched an unprecedented, amazingly comprehensive attack on the environment. Global warming has been denied, the endangered species act has been targeted, oil drilling offshore and in the Arctic wildlife refuge is moving forward, GMOs and neonicotinoid pesticides have been approved for wildlife refuges (Rosane 2018; Greshko et al. 2018). Many other changes were engineered by Scott Pruitt, who resigned from the EPA July 5, 2018 in a cloud of scandal. When EPA scientists recommended a ban on chlorpyrifos because of its toxic effects on the brains of children, Pruitt refused to implement the EPA scientific recommendation (Greshko et al. 2018). Because Pruitt ignored the EPA's regulatory duty, the Ninth Circuit Court of Appeals in San Francisco recently ordered the EPA to ban chlorpyrifos (Elliott 2018).

Pruitt rolled back fuel emission standards for automobiles and trucks, which will lead to more air pollution and increased numbers of respiratory deaths. He narrowed the scope of toxics monitoring for the 10 most hazardous industrial chemicals, ignoring 68 million pounds of toxic emissions in air and water. He repealed the 2015 WOTUS Rule extending Clean Water Act protection (Greshko et al. 2018).

Trump administration actions will increase global warming and water pollution. The Clean Water Act applies to navigable waterways. The WOTUS rule extended Clean Water protection to tributaries, wetlands, and adjacent waters. These secondary waterways may now see more pollution from confined animal feeding operations (CAFOs) and other sources (Fed Reg 2015). .

CAFO Contamination

Currently, CAFOs are unregulated unless they intentionally release waste into surface water that is protected by the Clean Water Act. Then, they have to apply for a National Pollutant Discharge Elimination System (NPDES) permit (Hribar 2010).

CAFO lagoon overflows contain human pathogens such as *Salmonella* and *E. coli*. As a result, crops can become contaminated by irrigation water. Cases of pathogenic produce have been increasing in frequency and severity. Fresh produce was involved in 0.7% of food poisoning cases in 1970 and 6% in 1997 (Sivapalasingam et al. 2004). In 2007 fresh produce caused 14% of commodity related food poisoning (Boore 2010). *Salmonella* and *E. coli* can enter plant tissues, and may not be removed by washing (Schikora et al. 2012; Brandl 2006; Golberg et al. 2011).

This year Romaine lettuce grown in Arizona contaminated with *E. coli* O157 sickened 210 people in 36 states causing 96 hospitalizations and 5 deaths. According to the CDC, the pathogen came from contaminated canal water. The pathogen was resistant to chloramphenicol, streptomycin, sulfioxazole, tetracycline, and trimethoprimsulfamethoxazole. Multiple antibiotic resistance suggests feedlot origin of the pathogen (CDC 2018a; Lefebvre et al. 2008).

CAFO pollution is unnecessary, because runoff remediation methods are available, and pathogens can be killed by composting (Thapa et al. 2016).

Agricultural Water Pollution

The Trump administration is not responsible for pollution from normal farming operations, but its actions will encourage global warming and that will make this pollution worse (see below). Many streams are polluted by pesticides and fertilizer. Nitrogen fertilizers have increased 7-fold and pesticides 3-fold in the last 40 years. Much of the increase has been recent, as GMOs often require more fertilizer than conventional cultivars. In 133 streams sampled from 1992-2004, nitrogen and phosphorus levels were 2-10 times greater than levels known to affect wildlife. Nearly 30% of agricultural streams had nitrate levels higher than the MCL (Maximum Contaminant Levels)(Fox et al. 2007; Dubrovsky and Hamilton 2010; Quarles 2017).

Fertilizer pollution can be reduced by regenerative agriculture and IPM methods. Cover crops can provide fertilizer. Microbials can reduce fertilizer and pesticide applications. Buffer vegetation along field edges can reduce polluted runoff. Hedgerows can also provide crop biocontrol (Quarles 2018ab).

Harmful Algae Blooms (HABs)

Because of increased fertilizer runoff and increasing temperatures, harmful algae blooms (HABs) are contaminating both fresh water and seawater, releasing deadly toxins that kill fish and make swimming dangerous (Zhu et al. 2017; Chapra et al. 2017).

According to the CDC (2018b), HABs are increasing in severity and frequency because of "farming practices, stormwater runoff, wastewater overflows, and increasing temperature." In 2016, 43 states had illness and death associated with HABs. Outflows from U.S. rivers are carrying so much pesticide, fertilizer, and CAFO nutrient contamination that thousands of square miles of the oceans are developing dead zones due to depletion of oxygen. The entire U.S. coastline is peppered with dead zones (CDC 2018b).

Lake Okeechobee in Florida recently had 90% of its 730 mi2 area covered by *Microcystis* algae. The algae flowed outward, contaminating waterways, leading the Governor to declare an emergency (Gomez 2018).

Update

Southwest Florida is plagued with red tides of marine algae such as *Karenia brevis* that secrete deadly brevetoxins. Recently, nearly 300 sea turtles were killed by brevetoxins. Red tides are caused by ocean warming and increased offshore nutrients. Red tides have increased in frequency, duration, and abundance in the last few years (Pierce and Henry 2008; Chow 2018).

The Finger Lakes in New York and Lake Erie have also seen toxic algae outbursts. The algae can contaminate drinking water, and water cannot be purified by boiling (Carmichael et al. 2016; Gomez 2018).

Kinds of Algae

Algae that grow in freshwater have different toxins from those that thrive in salt water. *Microcystis* sp. grows in fresh water, releasing microcystins and other toxins. These toxins can cause gastrointestinal upset and damage to the liver. Dogs swimming in contaminated water can be killed. Drinking water must be purified by water treatment plants to prevent widescale poisoning (Chapra et al. 2017).

Pseudo-nitzschia grows in salt water, releasing the neurotoxins domoic acid and saxitoxin. Domoic acid causes memory loss, and saxitoxin can produce paralysis. Domoic acid from algae periodically shuts down crab fishing in the Pacific Ocean when shellfish become contaminated (Zhu et al. 2017; Grattan et al. 2018).

In San Francisco Bay and other estuaries, where fresh water streams meet ocean water, both marine and freshwater algae can be present (Peacock et al. 2018).

Marine Mammals Affected

Domoic acid has caused significant poisoning of marine mammals along the West Coast in the last 20 years. Saxitoxin, which causes paralytic shellfish poisonings, has caused human illness and deaths in the Aleutians and the Gulf of Alaska. Oceans are becoming so contaminated that marine mammals even in the Arctic are seeing higher tissue levels of domoic acid and saxitoxin. For example, when 13 species of Arctic marine mammals were examined, saxitoxin was found in 10 of 13 species. All 13 species contained domoic acid. Highest prevalence was in bowhead whales (68%) and harbor seals (67%). Pacific walruses had levels high enough to cause seizures. Sublethal amounts of domoic acid cause nerve damage and memory loss and lead to stranded and beached animals. Domoic acid crosses the placental barrier and was found in fetuses of whales, porpoises and sea lions (Lefebre et al. 2016).

Trump administration actions on global warming and water pollution in Washington can have consequences that reach across the world, even into remote areas of the Arctic.

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Conference Notes

ESA 2017 Meeting Highlights

By Joel Grossman

These Conference Highlights were selected from the Denver, Colorado (Nov. 5-8, 2017) Entomological Society of America (ESA) annual meeting. The next ESA annual meeting, November 11-14, 2018 in Vancouver, British Columbia (BC), Canada is a joint meeting with the Entomological Societies of Canada and BC. For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org).

Herbal Miticides

Worldwide, 80 acaricides are applied against spider mites and related pests, creating pest resistance and health risks from pesticide exposures, said Bilal Khan (Univ Agric, New Insectary Bldg, Faisalabad, Pakistan; dr.bilal.saeed@uaf.edu.pk). Pakistan's economy employs 46% of its 200 million population in agriculture. Pakistan's small farmers by financial necessity delegate pest spraying chores to their young children, who lack protection and bear the brunt of exposure.

Botanical oils such as neem, *Azadirachta indica*; eucalyptus, *Eucalyptus globulus*; lemon, *Citrus limon*; and peppermint, *Mentha piperita*, minimize environmental risk and child applicator exposure to pesticide residues. Essential oils of neem, eucalyptus, lemon and peppermint were tested in serial dilution (2.5%, 5%, 10%, 20%) leaf-dip bioassays against adult female *Tetranychus urticae*, two-spotted mite. Toxic effects increased with dosage and post-exposure time intervals (24-96 hours) for neem, lemon, eucalyptus and peppermint oil. Maximum rates of neem oil were most potent, killing 49% of mites in 24 hours and 99% in four days. Field tests will evaluate essential oil formulation, stability and degradation.

Netting Versus Neonics

Flea beetles, so named because they are small like fleas (1.5-5 mm = 0.06-0.2 in) with enlarged femurs enabling flea-like jumps, are "critical economic pests of vegetables, particularly cabbage and eggplant," said James Mason (Virginia Polytech, 216 Price Hall, Blacksburg, VA 24061; jmason91@vt.edu). Adult flea beetles, *Phyllotreta* spp. leaf feeding in cabbage and *Epitrix* spp. in eggplant, reduce photosynthesis, resulting in indirect crop loss. Insecticide treated mosquito nets, long used to exclude malaria mosquitoes, were the inspiration for treated row covers to stop cabbage and eggplant flea beetles. Untreated screen row covers are common, but tiny pests like aphids and whiteflies often slip through the mesh; and pests such as flea beetles pupating in the soil can emerge as adults under plants and be trapped under the netting.

Comparisons were made between untreated row covers and deltamethrin-incorporated ZeroFly® netting (Vestergaard Frandsen; Lausanne, Switzerland). Mesh screen bioassays exposed flea beetles for 10 seconds and evaluated mortality one hour later. Mortality was 0% with untreated screens, versus 100% for treated netting.

Deltamethrin-incorporated ZeroFly® row covers are long-lasting, and can be removed, stored and used again. Two-year field studies and six week trials on 30 small plots with cabbage and eggplant transplants compared: 1) soil applications of a neonicotinoid, dinotefuran; 2) untreated screens; 3) black deltamethrin-treated screens; 4) yellow deltamethrin-treated screens; 5) control (no treatment). Yellow and black deltamethrin-treated row covers worked best, with zero flea beetles. Dinotefuran was initially equal to treated row covers; but the neonic benefits wore off over time, and flea beetle populations rebounded to higher levels than no treatment.

Powerful Microbes

"Several field, greenhouse, and laboratory studies conducted from 2010-2016 in California evaluated the microbial control potential and endophytic and mycorrhiza-like role of entomopathogenic fungi (EPF) to promote sustainable strawberry and vegetable production," said Surendra Dara (Univ California Coop Ext, 2156 Sierra Way, Ste. C, San Luis Obispo, CA 93401; skdara@ucdavis.edu). *Trichoderma, Pseudomonas, Streptomyces, Bacillus, Azobacter, Rhizobius and Rhizophagus* are among the microbial genera that increase nutrient absorption and plant growth, and are antagonists of insect pests and plant pathogens.

Holistic microbes appeal to farmers when they are effective, compatible with current farming practices, not overly costly and do not need repeated applications like chemical pesticides. *Beauveria bassiana* can work as an endophyte (living inside plants) interacting with herbivores, or it can be applied as a foliar spray to reduce pests such as green peach aphid (GPA), *Myzus persicae*. By boosting plant quality, *B. bassiana* also allows plants to support or tolerate slightly higher green peach aphid populations.

Spray Drift Reduced 87%

"Current pesticide spray technologies frequently result in over-application and excessive off-target losses and spray drift," prompting development of "a concept-proven precision air-assisted sprayer for ornamental nurseries, orchards and vineyards," said Heping Zhu (USDA-ARS, 1680 Madison Ave, Wooster, OH 44691; heping.zhu@ars.usda.gov). The sprayer is equipped with a high-speed laser sensor and variable rate nozzles, and can control the outputs of each individual nozzle independently to match tree canopy size, shape and leaf density as well as travel speeds. Compared to commonly used conventional constant-rate air-blast sprayers, the laser-guided sprayer is able to reduce airborne spray drift by up to 87%, and spray loss onto the ground by 68% to 93%."

New York School Soccer Field IPM

New York State's 2010 Child Safe Playing Fields Act bans most pesticides from school grounds, presenting "a unique challenge for turfgrass managers" trying to maintain safe and attractive school athletic fields, said Maxwell Helmberger (Cornell Univ, 630 W North St, Geneva, NY 14456; msh326@cornell.edu). Insect-killing, entomopathogenic nematodes (EPNs), are predators rather than chemicals, are not considered pesticides by the EPA and can be used on school soccer fields. However, EPNs are sensitive to soil properties, which vary across soccer fields and are influenced by foot traffic, which is heavier mid-field and near goals.

The nematodes *Steinernema feltiae* and *Heterorhabditis bacteriophora* were watered into two Geneva, New York soccer fields with loam soils to combat grubs of the Japanese beetle, *Popillia japonica*. The nematodes provided modest control of 3rd instar grubs, working best in soils with higher sand content and larger pore spaces allowing more nematode movement. *Steinernema scarabaei*, which is being commercialized and is better against white grubs, is likely to be the New York school soccer field EPN of choice in the future.

Steam Heat Kills Bed Bugs

Steam, dry heat, freezing and physical removal are among the non-chemical bed bug controls becoming mainstream, said Stephen Kells (Univ Minnesota, 1980 Folwell Ave, Rm 219, St Paul, MN 55108; kells002@umn.edu). Bed bug eggs are killed at 50°C (122°F); adults at 45-48°C (113-118°F). But to account for heat loss and reach bed bug refuges, higher temperatures must be delivered. Heat chambers and new steam equipment able to quickly distribute 71-82°C (160-180°F) steam heat in whole rooms provide 100% control. At 61-72°C (142-162°F), control is 80%. A 2-bedroom apartment requires 6-8 hours. The success rate is 98%. PCO steam heat concerns include propane fires; and heat damage to fragile materials and fabrics, which are best removed pre-treatment.

Even with steam heat, IPM approaches may use residual chemical barriers to slow new invasions. Freezing bed bugs is only used when people refuse pesticides, heat, alcohol and everything else. Alaska is the only USA locale using building-wide freezes; i.e. opening doors in winter to expose furniture and everything to the cold in areas with no PCO service access. "You are good to go for control" with -24°C (-11°F) to -30°C (-22°F) for 2 days, said Kells.

Non-chemical physical removal tools include Climbup® Insect Interceptor Bed Bug Traps, bean leaves, sticky tape and vacuuming. "Which are better than DIY (Do It Yourself) home pesticide use," said Kells. The insect-killing fungus *Beauveria bassiana* needs 60% relative humidity; and is dormant half the year in Minnesota when winter relative humidity drops to 10%.

Corn Neonics Redundant

"Bt has largely controlled corn rootworm but has led to an insurance-based approach to maize pest management," with "neonicotinoid seed treatments the newest tool in the insurance approach," said Adam Alford (Purdue Univ, 901 West State St, West Lafayette, IN 47907; adammalford@gmail.com). "All conventional USA maize is treated despite no evidence of pest damage or threat increase." However, resistance to Bt, crop rotations, and conventional pesticides make the corn rootworm worrisome.

"Overall, neonicotinoid seed treatments only performed better than other tested compounds in stand count," but "this stand increase did not lead to a higher yield," suggesting corn plants compensated for early rootworm damage, said Alford. "It is clear that neonicotinoid seed treatments can provide root protection and provide the same increase as previous chemistries under heavy pest pressure. However, their use is usually redundant given they are often deployed in concert with another insecticide."

Neonics Go Aquatic

"Neonicotinoid insecticides (neonics) are the most widely used class of insecticides in the world," and being "water-soluble they readily move away from crop fields," said Sarah McTish (Penn State Univ, 101 Merkle Lab, University Park, PA 16802; stm5283@psu.edu). "We collected water from lysimeter plots planted with thiamethoxam-coated corn seed to determine when and how (surface or groundwater) neonics leave crop fields. Thiamethoxam concentrations were higher in surface runoff versus ground runoff (leaching). However, water flow was greater in groundwater, causing a dilution effect."

"Thiamethoxam clearly leaves crop fields, possibly with greater concentrations in surface flow," said McTish. "Concentrations decrease quickly within a week following planting." Only 5% of neonic active ingredient applied to corn and other seeds enters the seedling. Thus, 95% of the water-soluble neonic active ingredient remains in the soil. How much active ingredient enters lakes and other aquatic systems is still unknown.

Sunflower Neonics

Sunflower extra-floral nectar (EFN) is a neonicotinoid ecological transmission pathway reducing natural enemy populations that provide biological pest control, said Michael Bredeson (South Dakota State Univ, SNP Box: 2140B, Brookings, SD 57007; michael.bredeson@sdstate.edu). Neonicotinoid "seed dressings" such as Cruiser® (thiamethoxam) "has become nearly ubiquitous within conventional row-crop agriculture," even though prophylactic or "insurance" neonics fail to boost crop yields. Sunflower EFN collected as crystallized sugars in greenhouse studies had 1.23-4.83 ppb (parts per billion) thiamethoxam. After early season peaks, thiamethoxam and its toxic metabolite, clothianidin, drop to low levels in leaf tissue.

Lady beetles feeding on thiamethoxam-laden nectar all season are less fit and produce fewer progeny. Corn and sunflower IPM alternatives include inter-seeding legumes or cover crops that can provide natural enemy micro-habitats (refuges) and volatile emissions that confuse pests. Compared to bare ground, corn fields with inter-row cover crops have several hundred percent more predators. Some sunflower growers have adopted cover cropping despite a paucity of scientific studies in sunflowers. Promising sunflower interplanting alternatives include flax, a non-competitive cash crop that does not reduce yields when used in corn.

Pumping Up Tomato Defenses

Greenhouse tomatoes inoculated with field-collected mycorrhizal spores had higher resistance to feeding by the cabbage looper, *Trichoplusia ni*, said Zoe Getman-Pickering (Cornell Univ, Comstock Hall, Ithaca, NY 14850; zg94@cornell.edu). "It is vital that studies testing the effect of mycorrhizae on plant biomass or herbivory properly account for nutrient levels in their growing media," because mycorrhizae effects on plant growth and pest suppression vary with soil fertility. Mycorrhizal plants had less cabbage looper damage than non-mycorrhizal plants, but higher fertility levels resulted in plants with more biomass and more pest damage.

In other experiments, tomato plants were inoculated with one of three mycorrhizal species: *Acaulospora morrowiae, Claroideoglomus etunicatum,* or *Rhizophagus intraradices,* said Danielle Rutkowski (Cornell Univ, Comstock Hall, Ithaca, NY 14850; dmr279@cornell.edu). Half the experimental plants were also treated with jasmonic acid (JA) once a week for five weeks. Regardless of the mycorrhizal species, JA induced defenses were 70% higher; but tomatoes were 5% smaller. Tomato plant growth benefits were higher with mycorrhizal species having greater levels of root colonization. Thus, plants inoculated with *Rhizophagus intraradices* had twice the root colonization and were 10% larger than plants grown with the other mycorrhizae.

Rye Cover Retards Thrips

Southeastern USA cotton "growers currently rely on neonicotinoid (IRAC Group 4A) seed treatments" to combat thrips, despite pollinator declines and increasing pest resistance, said Sarah Hobby (Univ Georgia, 2360 Rainwater Rd, Tifton, GA 31793; shobby@uga.edu).

"Data show that thrips populations were suppressed when planted with a rye cover crop compared to no cover," said Hobby. "Thrips counts on neonicotinoid seed treated seedlings increased slightly compared to fungicide only treated seedlings, while foliar insecticide applications always decreased immature thrips populations. Yield differences were relatively small, regardless of treatment." Even without insecticides, fall-planted rye cover crops reduced immature thrips 48% and adults 37% in subsequent cotton crops.

"Rye cover provided consistent thrips suppression with less risk than foliar applications," said Hobby. "The presence of a cover crop with a well-timed foliar spray could replace a neonicotinoid seed treatment."

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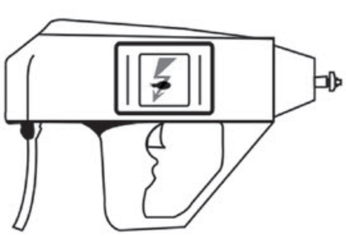

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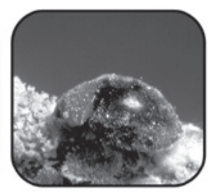

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