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Special Pheromone Issue

IPM for the Western Bean Cutworm

By William Quarles

Western bean cutworm (WBC), *Striacosta albicosta*, is a pest created by modern agriculture, as monocultures, genetically engineered crops, and climate change encourage it (Hutchinson et al. 2011; Blickenstaff and Jolley 1982; Dorhout and Rice 2010).

WBC was found in Arizona in 1887, and it was a low intensity western pest of corn and beans for 75 years (Dorhout 2007; Archibald et al. 2017). In the 1970s and 1980s "intensified cropping and modern agriculture" accelerated its dispersal and increased its pest status. It spread throughout the Great Plains and to Texas, Mexico, and Canada (Blickenstaff and Jolley 1982; Sanchez-Pena et al. 2016).

Introduction of genetically engineered corn in 1996 (see below) led to an explosive range expansion. It spread throughout the Midwest corn belt and into corn producing areas of eastern states in a period of just 10 years (Dorhout 2007; Dorhout and Rice 2010; Michel et al. 2010).

WBC appeared in Minnesota in 1999, Iowa and South Dakota in 2000; Illinois and Missouri in 2004; Michigan and Ohio in 2006; finally reaching Pennsylvania and New York in 2009. In 10 years it colonized 11 new states (Smith et al. 2018).

Rapid expansion into new ecological areas has presented challenges for management. Conventional pest management is by genetically engineered corn, neonicotinoid seed treatments, and pyrethroid sprays. But WBC is resistant to genetically engineered Cry1F corn (Michel et al 2010; Smith et al. 2018), and may be getting resistant to pyrethroids (Archibald et al. 2017). Neonicotinoid seed treatments may make the problem worse by killing biocontrols (Seagraves and Lundgren 2012; Difonzo et al. 2015). This article discusses an IPM program that can reduce or eliminate pesticide applications.

Photo courtesy of Adam Sisson, Iowa State University, Bugwood.org

The western bean cutworm moth, *Striacosta albicosta*, can be identified by cream colored stripes and two characteristic spots on the forewings. It is a strong flier and has recently invaded the Midwest and Northeast.

Damage

Western bean cutworm is misnamed. WBC is no longer just a western pest, and it does not act like a cutworm that clips plant stems. Furthermore, it prefers corn to beans, and most economic damage is done through feeding on plant seeds. WBC acts more like a corn earworm than a bean cutworm (Michel et al. 2010). (See Box A for WBC Biology).

WBC is a late season pest, directly damaging bean pods and corn kernels. The pest can significantly reduce yields and quality of field corn and fresh corn. Larvae eat kernels of corn, ruining it for the fresh market and otherwise lowering yields and quality. Several larvae can infest the same ear of

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Update

Photo courtesy of Professor J. Obermeyer, Purdue Cooperative Extension

WBC larvae eat corn kernels. WBC feeding, shown here, can cause fungal infections that produce mycotoxins.

corn. Field damage of 30-40% has been seen. Some fields in Iowa have had a 96% loss (Michel et al. 2010; Paula-Moraes et al. 2012).

Damage includes fungal infections that reduce quality of the grain. For instance, WBC infestation significantly increases Gibberella ear rot. Fungal infections produce mycotoxins that can make livestock sick when infected corn is used as a feed (Parker et al. 2017).

Average infestations of one larva per plant can reduce corn yields by 3.7 to 15 bu/acre (Appel et al. 1993; Paula-Moraes et al. 2013). One larva per plant could result in a yield loss of 8.6%, or about $55/acre (Macrotrends 2019).

WBC prefers corn, but it can also be an economic pest of dry beans, *Phaseolus vulgaris*. It damages pods and developing bean seeds. Damage in beans can be up to 8-10%. It is difficult to separate damaged pods ("pick") from healthy ones, and "pick" lowers the purchase price. Pick amounts greater than 2% could cause buyers to refuse entire shipments (Michel et al. 2010; Difonzo et al. 2015).

Tomato is also a possible host plant. Successful management in corn and beans might cause it to move to tomatoes (Blickenstaff and Jolley 1982; Antonelli and O'Keeffe 1981).

Why Did it Spread?

Pests become serious through a number of reasons. For instance, an alien invasive pest can spread into areas where there are no natural enemies. This is the case for the emerald ash borer, *Agrilus planipennis*. It has killed millions of trees and spread through 35 states in about 20 years (Herms and McCullough 2014). Another factor is pesticide resistance and mutation. According to Metcalf (1983), widespread dispersal of the western corn rootworm, *Diabrotica* sp., was encouraged by chlorinated pesticides. Pesticide applications led to resistance and a genetic mutation linked with dispersal (Wang et al. 2013). But WBC is a native pest, and its spread is not the result of a pesticide induced mutation (Lindroth et al. 2012).

WBC has a natural tendency to spread. It is a strong flier, and virgin females can cover 24 km (14.4 mi) in 8 hours (Dorhout 2007). Planting large monocultures in the 1970s and 1980s gave it a ready food supply that favored migrating populations. Introduction of genetically engineered corn promoted cropping practices that encouraged WBC (see below). Climate change may also have been a factor, as it must overwinter in soil. Milder winter temperatures may have allowed the pest to invade cold

Box A. Biology of the Bean Cutworm

WBC is a native noctuid moth in the same guild as the corn earworm, *Helicoverpa zea*, and the European corn borer, *Ostrinia nubilalis*. There is one generation per year. Life stages are eggs, larvae, prepupae, pupae and adults (Dorhout 2007).

Gray-brown moths are about 20 mm (0.8 in) long, and wingspan is about 40 mm (1.6 in). They can be identified by the cream-colored stripes along the outer edges of the forewings, and two characteristic wing spots on each forewing. Moths fly at night and rest in the crop in the daytime. Mating and egglaying is in July and August, with females producing about 300-400 eggs. Egg masses averaging about 50 eggs are laid on upper leaf surfaces in corn when it is near the tassel stage of development. Eggs are laid on the underside of bean leaves deep in the canopy. Eggs are about 0.75 mm (0.03 in). Eggs are initially white, but turn purple before they hatch in about 5-7 days (Dorhout 2007; Michel et al. 2010).

Larvae eat their egg shells and disperse upward to tassels in corn, then later crawl downward and enter the ears. One ear may contain several larvae. Larvae in corn move from plant to plant, within and between rows, dispersing in a 3 m (10 ft) circle about a hatching egg mass. About 75% of hatching larvae are found within 1.7 m (5.6 ft) of the egg mass. About 32% are recovered in the same row as the egg mass (Panuti et al. 2012; Michel et al. 2010). Fortunately, larval survival in a corn field is low, ranging from 4-12% in Nebraska (Paula-Moraes et al. 2013).


F. Peairs, CSU, Bugwood.org

Eggs of western bean cutworm


J. Obermeyer, Purdue Cooperative Extn.

Larva of WBC feeding at the tip of a corn ear.

WBC goes through six larval instars on a plant. The first instars have black heads and are about 2.5 mm (0.1 in) long. Early larvae in beans feed on leaf tissue, then later larval instars chew their way into bean pods. The larval stage is variable, but can last an average of about 30 days. Larvae are light tan or pink with longtitudinal stripes. Fourth instars or later have two black rectangles as markings directly behind the head. The 6th instars are about 35 mm (1.4 in) long (Dorhout 2007; Michel et al. 2010).

There is a prepupal and a pupal stage in the soil. WBC overwinters as a prepupa about 7.6 to 20 cm (3 to 8 in) deep in soil. Pupae measure about 17 mm (0.66 in) in the longest direction. Sandy soils are preferred to clay soils. The soil stage makes treatment with nematodes a possibility (see Nematodes). It completes pupation in spring and emerges as an adult in the summer (Dorhout 2007; Michel et al. 2010).

areas such as Michigan and Minnesota (Blickenstaff and Jolley 1982; Hutchinson et al. 2011).

GMOs Encourage Pest

Cropping practices associated with GMOs encourage the pest. Roundup Ready® corn meant growers could switch from cultivation to no-till and apply herbicides for weed control. As a result, WBC pupating in the soil was no longer killed by cultivation (Hutchinson et al. 2011). Blickenstaff (1979) had observed that cultivation killed 90% of overwintering WBC.

Neonicotinoid treatments added to GMO seeds do not control late season pests, but can have a negative impact on biocontrols (Difonzo et al. 2015). Predator populations can be reduced by 25% (Seagraves and Lundgren 2012). In corn, treated seeds have killed 80% of exposed *Harmonia axyridis* ladybug larvae (Moser and Obryki 2009). Mullin et al. (2005) found 100% mortality in beneficial carabid beetle larvae exposed to neonicotinoid corn seedlings.

BT for the western corn rootworm (WCR), *Diabrotica virgifera virgifera*, was introduced in 2003. Plantings of BT corn for the rootworm meant fewer soil insecticide treatments were needed. BT for the rootworm led to a situation where WBC pupae could develop without exposure to pesticides (Gassmann et al. 2011).

Update

Pest Replacement

Genetically engineered BT corn may also have triggered pest replacement. Pest replacement occurs when treatment of one pest provides conducive conditions for another. The western bean cutworm is not killed by many of the currently available BT corn varieties. Insect competitors such as the corn earworm and European corn borer are eliminated by BT protein, thus leaving an ecological niche for WBC (Dorhout and Rice 2010).

On non-BT corn, corn earworm and corn borer larvae eat WBC, thus removing the competition. Consistent with this theory, experiments in the laboratory and in the field show that corn earworms and corn borers reduce survival of WBC larvae (Dorhout 2007; Dorhout and Rice 2010; Bentivenha et al. 2016).

Much of the corn in Iowa in 2000 contained BT proteins and was resistant to glyphosate (Roundup Ready®). In 2000, WBC was only in the west, but four years later it was doing economic damage throughout Iowa (Dorhout 2007).

Professor J. Obermeyer, Purdue Cooperative Extension

Larval instars of the western bean cutworm, shown here, can proliferate on BT corn. The GMO kills competing pests such as the corn earworm and the European corn borer.

IPM Program for WBC

IPM for the western bean cutworm consists of monitoring with pheromone traps, scouting fields for egg masses and damage, cultural controls, conservation biocontrol, releases of parasitoids and nematodes, host resistance, and application of least-toxic pesticides as a last resort.

Monitoring and scouting fields for WBC leads to a reduction in pesticide applications, and is extensively practiced by crop consultants in Nebraska (Archibald et al. 2017). IPM for WBC is recommended by Cooperative Extension in many states (Obermeyer 2009; Peairs 2014; Tooker et al. 2012; Michel et al. 2010).

Pheromone Monitoring

Females of WBC produce a sexual pheromone that attracts males. Klun et al. (1983) isolated the WBC pheromone from extracts of female ovipositors. Components were (Z)-5-dodecenyl acetate; (Z)-7-dodecenyl acetate; 11-dodecenyl acetate and dodecyl acetate in the ratio 5:1:5:5. Trécé uses this 4-component blend in the standard monitoring lure (Tooker et al. 2012). Scentry also produces a WBC lure (Dorhout 2007).

Critical to management success is pheromone monitoring traps that identify the flights of the insect. Three kinds of traps are in use: jug traps, wing traps, and universal (bucket) traps, and they are equally effective. The jug trap is just a one gallon milk jug with holes cut into it to allow moth entry. Ethylene glycol and soapy water in the bottom kills the moths. A pheromone lure is attached to the lid with a paper clip (Dorhout and Rice 2008). According to Obermeyer (2019), Purdue has abandoned the jug trap for the bucket trap, because the bucket trap is easier to use.

Best placement is between cornfields at heights of about 1.2 to 1.8 meters (3.9-5.9 ft). For beans, best placement is at opposite ends of a bean field at the same height as in corn.

Automated Trap

Recently, an automated pheromone trap has been introduced. The automated trap can give a useful real time picture of areawide infestations, as it has a camera, and can be linked to the internet (see ESA Conference Notes) (Michel et al. 2010; Dorhout 2007; Williams et al. 2018ab).

Pheromone monitoring gives a picture of moth flights, and can alert growers to the peak flight times. Pheromone trap captures do not strictly correlate with field infestations in corn. But fields with infestation rates above economic thresholds (5%) have pheromone captures larger than fields below the threshold. Fields must be scouted for eggs and larvae when pheromone traps reveal moth flights. In beans, pheromone traps correlate better with field infestations and crop damage (Williams et al. 2018ab; Michel et al. 2010).

Scouting and Economic Thresholds

Scouting should begin in corn when moth flights are detected and numbers are increasing in pheromone traps. Twenty consecutive plants in five different field areas should be inspected for egg masses or larvae. Infestations are patchy, so several trips to the field may be needed. Upper leaves, tassels, and silks should be inspected for larvae (Michel et al. 2010). Paula-Moraes et al. (2011) describe a presence-absence sequential sampling method that needs inspection of only 38-41 plants to make a treatment decision. The University of Nebraska has developed a smart phone application that makes scouting easier (Nebraska 2019).

Extension entomologists and consultants recommend treatment when 5-8% of corn plants have egg masses or larvae. This threshold is adjusted downward for higher corn prices and for eastern states where higher humidity results in increased egg and larval survival (Michel et al. 2010). Paula-Moraes et al. (2013) recommend treatment when more than 4% of the corn plants have an egg infestation.

Scouting for eggs and larvae in beans is difficult, as larvae often drop off plants and egg masses are hidden in the canopy. Instead, pheromone trap data is combined with scouting for bean damage. For beans, fields should be scouted when 700 or more moths appear in pheromone traps before peak flight. For cumulative pheromone moth catches of 1000 or more, economic bean damage is likely. If a bean field is adjacent to corn, it should be scouted if infestations in corn are above economic thresholds. Insecticides should be applied 10-21 days after peak flight (Michel et al. 2010; Difonzo et al. 2015).

Cultural Controls

To be effective, cultural controls should be practiced areawide. Otherwise local farms would be vulnerable to flights from farms nearby. The best cultural control would be a breakup of large monocultures. Smaller, more diverse fields would give the pest less food directly in its flight path. Rotating crops in smaller fields would have an effect similar to intercropping (Altieri 2004).

Photo courtesy Scott Williams and DTN

Automated pheromone traps can monitor WBC populations. The Z-trap on the right uses a bucket trap to collect WBC moths.

Another way to break up the BT monocultures is to increase the amount of non-BT refuge to 50%. The non-BT corn would have more corn earworms and corn borers but could be managed accordingly if the planting was clearly separated into discrete blocks. The larger refuge could also preserve the effectiveness of BT corn (Michel et al. 2010).

Cover crops would encourage biological controls (Lundgren and Fergen 2010). Planting insectary plants, windbreaks, and hedgerows at the edge of fields would provide conservation biocontrols and would also impede flights of moths that like to fly about 1-2 meters (3-6 ft) above the ground. Hedgerow perennials could provide longterm protection. Hedgerow plantings in California about 3 m (9.8 ft) wide containing perennials such as coyote bush, *Baccharis pilularis*; California lilac, *Ceanothus griseus*; and others provided beneficial insects in fields for biocontrols. About 78% of insects in the hedgerows were beneficials (Long et al. 1998; Bugg et al. 1998).

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WBC pupae bury themselves in soil. Cultivation destroys 90% of them.

Crop Rotation

Crop rotation can be effective, at least by reducing the number of acres of continuous corn. Western bean cutworm is not a pest of soybeans, and soybeans are a good rotation crop (Dorhut 2007). If tillage is practiced, pupae are killed as the field is prepared for soybeans (Seymour et al. 2010). However, tillage should be reserved for years when populations are very high, as no-till or strip-till production is better for the environment (Quarles 2018; 2019).

If no-till practices are used, rotation may have less of an effect. Soybeans would be planted in fields infested with WBC pupae. The emerging adults would not harm the soybeans. But because corn fields are often adjacent to soybean fields, WBC that emerges in soybeans may just fly over to the nearest corn field (Hutchinson et al. 2011; Michel et al. 2010).

Delayed planting works to control the western corn rootworm, but delayed planting for WBC might not be effective because the pest has a wide (3-month) window of emergence (Michel et al. 2010; Levine and Oloumi-Sadeghi 1991; Quarles 2017).

Pheromone Mating Disruption

Pheromone mating disruption might work, but would be expensive. WBC is a strong flier (Dorhout 2007), so already mated females might fly into the treated areas, negating at least some of the effect. If this method were used, treatment would have to be areawide and over a period of two months (Quarles 1994).

Biocontrols

Bats should provide some biocontrol of the WBC adult stage, as the moths fly at night above corn and bean fields. Since organic farms have larger numbers of bats than conventional farms, bats could be especially effective in organic production. Bats could be encouraged by providing bat houses (Quarles 1996; Wickramsinghe et al. 2004).

Birds might do some predation of larvae in corn, but larvae in beans hide on the ground and in the canopy. Skunks and other such vertebrates may dig up the prepupae and pupae, but these predators could damage the corn (Michel et al. 2010).

Lacewings, lady beetles, pirate bugs and other beneficial insects will eat WBC eggs. Egg and larval predation by ground beetles and lacewing larvae has been seen (Michel et al. 2010). The most abundant predators in Nebraska cornfields are *Orius* bugs, *Harmonia axyridis* and *Coleomegilla maculata* lady beetles, lacewings and spiders. *Coleomegilla* was one of the best egg predators tested in the laboratory (Archibald 2017).

Neonicotinoids may interfere with biocontrol, and biocontrol would be more effective if neonicotinoid seed treatments were eliminated (Seagraves and Lundgren 2012; Difonzo et al. 2015).

Photo by Juan Morales Ramos courtesy USDA

***Heterorhabditis* spp. nematodes might destroy soil stages of WBC.**

Parasitoids

Trichogramma ostriniae releases have been effective for the corn earworm and the European corn borer, which are in the same insect guild as WBC (Hoffmann 1998). Releases of 90,000 *T. ostriniae* wasps per acre in New York organic sweet corn led to large numbers of parasitized WBC eggs. In areas with large WBC populations, 59% of egg masses and 64% of eggs within each mass were parasitized. But this level of control was not enough to keep economic damage below the 1% damage threshold in sweet corn. Weekly applications of spinosad (Entrust®) were needed (Seaman 2017).

In areas with lower WBC populations, 100% of egg masses and an average of 89% of eggs in each egg mass were parasitized. Damage to organic sweet corn was 4.6% without the use of pesticides (Seaman 2017).

Though parasitoid releases were somewhat effective in sweet corn, similar releases in organic field corn had no significant effect. Damage was 14% in release areas and 15% in non-release areas (Seaman 2017).

Nematodes

Western bean cutworm does best in sandy soils. Nematodes are also successful in sandy soil. The WBC prepupa digs down about 7.6 to 20 cm (3 to 8 in), which is a manageable depth for *Heterorhabditis bacteriophora* nematodes (Dorhout 2007; Toepfer et al. 2010).

Nematode treatments would be more economically viable if they were applied simultaneously for more than one pest. Nematodes are effective for the western corn rootworm (WCR) (Jackson 1996; Toepfer et al. 2010; Kurtz et al. 2007; 2009). Application of *H. bacteriophora* when corn is planted can cause 70% corn rootworm mortality (Toepfer et al. 2010).

Nematode treatment for western corn rootworm should also kill WBC pupae. Eggs of western corn rootworm hatch in late May or early June, and nematodes are applied before this time (Levine and Oloumi-Sadeghi 1991). In May or early June, WBC would still be in the soil in the prepupal or pupal stage (Michel et al. 2010). Apparently, nematodes have not been tried for control of WBC.

Microbials

Nosema infections have been shown to infect WBC in the field, but *Nosema* has not been tried for biocontrol. *Nosema* for biocontrol should be used with caution, as it is a pathogen of bees (Michel et al. 2010).

The entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* occur naturally in 55-60% of Iowa cornfields. *Metarhizium anisopliae* applied to fields persists for at least 15 months (Rudeen et al. 2013).

Beauveria bassiana has been used on the western corn rootworm, but apparently has not been tried on WBC. In the more humid eastern regions these microbials might have more of an effect than in drier western states (Levine and Oloumi-Sadeghi 1991; Michel et al. 2010).

Update

Resistance and BT Corn

BT Cry1Ab corn effective for the corn earworm and the European corn borer will not control WBC. BT corn containing Cry1F is about 80% effective in Iowa, but the pest is becoming resistant (Ostrem et al 2016; Farhan et al. 2018). Cry1F is ineffective in the Great Lakes Region (Smith et al. 2018).

Organic farmers objected to BT corn because they thought it likely that resistance would develop. The EPA initially required 20% non-BT corn refuges to reduce resistance. But lately EPA has allowed a blend of 5% non-BT seeds mixed with the BT seeds. The 5% non-BT "refuge in a bag" provides variable toxin exposure and may "increase the rate of resistance evolution." In the Great Lakes Region, only BT Vip3A is effective (Smith et al. 2018).

Resistant beans have been identified, but they are not commercially acceptable varieties (Antonelli and O'Keeffe 1981).

Insecticides

The pesticides of choice so far have been foliar sprays of pyrethroids. But pyrethoids can increase spider mite problems and kill biocontrols due to long residual activity. Biopesticides such as *Chromobacterium* sp. (Grandevo®) and spinosad (Entrust®) are labeled for the western bean cutworm. These biopesticides have less of a negative effect on biocontrols and can be used in organic production (Quarles 2013).

In Michigan dry beans thiamethoxam seed treatments or aldicarb soil treatments resulted in greater damage than no treatment. Possibly, the seed and soil treatments killed biocontrols that had been providing protection (Difonzo et al. 2015).

Conclusion

Pheromone monitoring and scouting can reduce WBC pesticide applications. Biocontrol would be more effective if neonicotinoid seed treatments were eliminated. Breaking up monocultures would make it harder for moths to find the host. Crop rotation combined with periodic cultivation could reduce areawide WBC populations. Organic farms can practice conservation biocontrol, release parasitoids, or apply nematodes. When damage thresholds are exceeded, biopesticides can control the pest while sparing biocontrols.

William Quarles, Ph.D., is an IPM Specialist, Executive Director of the Bio-Integral Resource Center (BIRC), and Managing Editor of the IPM Practitioner. He can be reached by email, birc@igc.org

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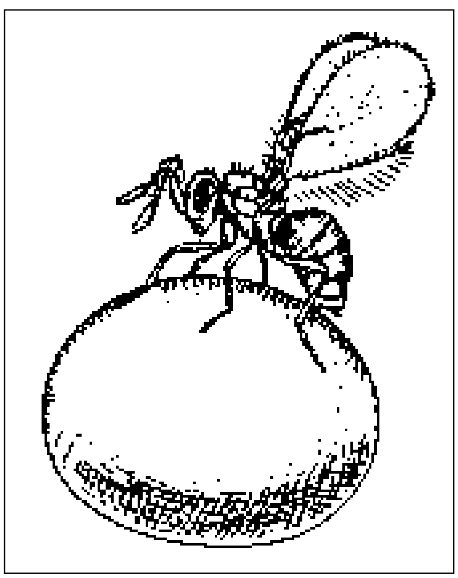


***Trichogramma* sp., an egg parasitoid.**

Calendar

June 18-June 21, 2019. PCOC Annual Expo. Carlsbad, CA. Contact: PCOC, 3031, Beacon Blvd, W. Sacramento, CA 95691; www.pcoc.org

July 28-31, 2019. 74th Annual Meeting Soil Water Conservation Society. Pittsburg, PA. Contact: www.swcs.org/19AC

August 3-7, 2019. American Phytopathological Society Conference, Cleveland, OH. Contact: APS, 3340 Pilot Knob Road, St. Paul, MN 55121; 651-454-7250; aps@scisoc.org

August 11-16, 2019. 104th Annual Conference, Ecological Society of America, Louisville, KY. Contact: ESA, www.esa.org

October 15-18, 2019. NPMA Pest World, San Diego Conference Center, San Diego, CA. Contact: NPMA, www.npmapestworld.org

October 15-18, 2019. California Invasive Plant Council Symposium. Riverside, CA. Contact: California Invasive Plant Council, 1442 Walnut St., No. 462, Berkeley, CA 94709. www.cal-ipc.org

November 10-13, 2019. Annual Meeting, Crop Science Society of America. San Antonio, TX. Contact: https://www.crops.org

November 10-13, 2019. Annual Meeting, American Society of Agronomy. San Antonio, TX. https://www.acsmeetings.org

November 10-13, 2019. Annual Meeting, Soil Science Society of America. San Antonio, TX. Contact: www.soils.org

November 17-20, 2019. Annual Meeting, Entomological Society of America, St. Louis, MO. Contact: ESA, 9301 Annapolis Rd., Lanham, MD 20706; www.entsoc.org

November 20-22, 2019. Association of Applied Insect Ecologists. Visalia Convention Center, Visalia, CA. Contact: www.aaie.net

January 22-25, 2020. 40th Annual Eco-Farm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

February 27-29, 2020. 31st Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

March 2-5, 2020. Annual Meeting Weed Science Society of America. Maui, HI. Contact: www.wssa.net

March 15-18, 2021. 10th International IPM Symposium. Denver, CO. Contact: https://ipmsymposium.org

Conference Notes

Special Pheromone Report

By Joel Grossman

This is a Special Pheromone Report selected from presentations at the Nov. 11-14, 2018 joint Annual Meeting of the Entomological Societies of America (ESA), Canada (ESC) and British Columbia (ESBC). The next ESA annual meeting is November 17-20, 2019 in St. Louis, Missouri. For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org).

Pheromones and Stink Bugs

Peach and apple growers in Virginia, West Virginia, and New Jersey are adopting IPM-CPR or IPM-Crop Perimeter Restructuring. IPM-CPR "aims to reintroduce IPM tactics" such as mating disruption and perimeter treatments, neglected during "more than a decade of intense insecticide-based management" of brown marmorated stink bug (BMSB), *Halyomorpha halys*, said Clement Akotsen-Mensah (Rutgers, 121 Northville Rd, Bridgeton, NJ 08302; ca555@scarletmail.Rutgers.edu). "*H. halys* feeding causes corking and darkened depressed sites, making fruit unmarketable. Large, late season populations just prior to harvest cause high levels of injury."

IPM-CPR includes: 1) pheromone monitoring (Trécé CM-DA or OFM lures) and mating disruption (Isomate OFM/CM TT) for codling moth, *Cydia pomonella,* and oriental fruit moth, *Grapholita molesta;* 2) removal of broadleaf weeds that harbor tarnished plant bugs, *Lygus lineolaris*; 3) pheromone trap BMSB thresholds (Trécé pyramid trap) to time perimeter treatments of the outer two peach orchard rows.

IPM-CPR and conventional insecticides were equal in terms of BMSB populations and fruit injury. "Damage due to internal worms was low (<1%) in the IPM-CPR blocks where mating disruption was included," and pesticide use was reduced over 75%, said Akotsen-Mensah.

Pheromones and Plum Curculio

Plum curculio (PC), *Conotrachelus nenuphar*, a "pervasive" tree fruit pest in eastern North America, is best managed by targeting all life stages from egg to adult with multiple tools, including synergized pheromones, entomopathogenic nematodes (EPNs) and netting, said Tracy Leskey (USDA-ARS, 2217 Wiltshire Rd, Kearneysville, WV 25430; Tracy.Leskey@ars.usda.gov). Plum curculio lays eggs in a wide range of fruits, including blueberries, peaches and apples, causing fruit drop and less-saleable scarred fruit.

The treatment threshold is one fresh scar per 25 fruit. Conventional management relies on whole orchard sprays of organophosphate, pyrethroid, neonicotinoid and other insecticides. Early season monitoring, before natural fruit volatiles overwhelm traps, relies on black pyramid traps baited with the male-produced aggregation pheromone, grandisoic acid, and benzaldehyde, a host fruit volatile.

Photo: NE IPM Center, StopBMSB.org

Adult brown marmorated stink bug, *Halyomorpha halys*

One management strategy is placing attract and kill (A&K) traps 50 m (164 ft) apart on border trees. There is plum curculio spillover from A&K trap trees onto nearest neighbor apple trees. So, border trap tree areas are sprayed. Spraying only perimeter trees allows a significant reduction in pesticide applications.

Compared to conventional whole orchard sprays, plum curculio insecticide sprays are reduced 90% with equivalent results. "Multiple years of study found that not only could the proportion of orchard treated with insecticides targeting PC be reduced by over 90% using this approach, but PC injury to fruit was equivalent to standard grower insecticide programs," said Leskey.

"We need to find long-lasting insecticide treated nets," like those used for mosquitoes and brown marmorated stink bug, where baited netting is replacing A&K trap trees," said Leskey. Netting can be deployed around trunks, scaffold limbs, and other areas. Sticky bands are also used around tree trunks. PC adults emerging from soil pupation and walking up trees turn around and walk away in response to sticky bands.

"Efficacious entomopathogenic nematode (EPNs) strains were applied to the soil beneath baited 'attract and kill' trees to control larvae emerging from fallen fruit and attempting to pupate in soil, further reducing overall PC populations," said Leskey. "*Steinernema riobrave* killed greater than 95% of larvae" in dropped fruit under trap trees in field trials. *S. feltiae* can be applied annually for cooler soils, but persistent strains that permanently establish and create suppressive soils would be better. Nematodes, pheromones, synergists, trap trees, sticky bands and netting will likely be part of plum curculio IPM in Canada and the USA.

Pheromones, Bollworms, and Texas

Old World bollworm (OWB), *Helicoverpa armigera*, has most likely moved through Europe, Asia, Africa, Oceania and South America on international trade routes, reaching Costa Rica and Puerto Rico in 2014, and in 2015 pheromone monitoring traps detected a male moth in Bradenton, Florida, said Megha Parajulee (Texas A&M AgriLife, 1102 East FM 1294, Lubbock, TX 79403; m-parajulee@tamu.edu). "It is anticipated that this pest will invade the southern USA in the near term and some entomologists have speculated that the invasion has already occurred. Ecological niche modeling indicates that the majority of the USA is a suitable habitat for the permanent establishment of reproductive OWB populations."

For four years from 2015 to 2018 in the Texas High Plains, effectiveness of five trap and pheromone combinations were compared. Traps and lures studied were: 1) Texas Trap with Trécé™ *H. zea* lure; 2) Texas Trap with Trécé™ *H. armigera* lure; 3) Bucket Trap with Trécé *H. zea* lure; 4) Bucket Trap with Trécé *H. armigera* lure; 5) Bucket Trap with USDA Cooperative Agricultural Pest Survey (CAPS) lure. Texas Traps baited with Trécé *H. armigera* lures captured the most *Helicoverpa* species all four years. The USDA CAPS lure had lower catches. Molecular marker studies of 1,500 specimens has not yet revealed *H. armigera* in South Texas, but pheromone trap monitoring is continuing.

Pheromone Traps and Sweet Corn IPM

"Sweet corn is a popular fresh-market vegetable crop in Virginia," but "more than 80% of sweet corn ears will be damaged by insects if control measures are not taken," said Andrew Dechaine (Virginia Polytech, Blacksburg, VA 24061; dechaine@vt.edu). Commercial growers make "multiple applications of pyrethroid insecticides" against corn earworm, *Helicoverpa zea*, Virginia's primary sweet corn pest. But pyrethroid resistance "is rapidly developing," and bees, lady beetles and other beneficials are harmed by the half dozen or more annual corn earworm sprays.

"Field experiments showed that the IPM approach reduced the number of pyrethroid insecticide applications without sacrificing crop loss," said Dechaine. In 2017 and 2018, on over two dozen commercial farms in 17 Virginia counties, pheromone traps, scouting, and action thresholds for corn earworm and fall armyworm, *Spodoptera frugiperda*, guided insecticide applications. The diamide insecticide chlorantraniliprole was substituted for pyrethroids "during sweet corn pollen shed" to lessen adverse impacts on beneficial insects.

Pheromones Monitor Quebec

"The province of Quebec (Canada) represents the northernmost area of distribution of several pests," which due to Quebec's cold winters migrate in annually from native distribution areas, and are monitored with pheromone traps and scouting provincewide, said Julien Saguez (CÉROM, 740 chemin Trudeau, Beloeil, QC J3G 0E4, Canada; julien.saguez@cerom.qc.ca). Corn earworm, *Helicoverpa armigera*, is monitored with pheromone traps, but has not yet been observed in Quebec. Pheromone traps monitoring true armyworm, *Mythimna unipuncta*, an occasional pest of corn, soybean, cereal and grass, include the Multi-Pher®, Scentry® Heliothis, and the automated Trapview (Adama, St Leonards, Australia) that photographs and relays trap information.

Adult moths of western bean cutworm, *Striacosta albicosta*, in corn and dry beans are monitored with pheromone traps. Scouts look for eggs masses and larvae, with a treatment threshold of 5% infested plants. Brown marmorated stink bug (BMSB), *Halyomorpha halys*, is monitored with bait traps, sweep nets and visual inspections in corn, soybean and other crops; 2.5-3.5 BMSB per 15 sweeps is the treatment threshold. Soybean aphid, *Aphis glycines*, is monitored by scouts from June to August; and has an economic threshold of 250 aphids per plant. Good biocontrol and resistant varieties have sharply reduced soybean aphid pesticide sprays.

Automated Bean Cutworm Pheromone Trap

With its range expansion to the eastern corn belt and resistance to transgenic (Bt) corn varieties, "western bean cutworm (WBC), *Striacosta albicosta*, has become one of the most significant pests of corn (also dry beans) over the past 15 years," said Scott Williams (DTN, 1281 Win Hentschel Blvd, West Lafayette, IN 47906; scott.williams@dtn.com). The "Z-trap" is an automated pheromone trap with a camera that tracks WBC flight trends, zaps moths dead in a bucket trap, relays photos of trap contents, and using an algorithm provides alerts when WBC population trends require field scouting. The Z-trap sends out an automated warning when the trap is full and needs cleaning or a new sticky card.

Growers can purchase the Z-trap and camera for $360, but it is usually part of larger service agreements that may include trap monitoring, field scouting, and soil nitrogen. At a $90 price, the Z-trap and camera are snapped up by farmers, suggesting mass production of the product is possible. Z-traps and cameras could fit into larger geographic IPM networks, with perhaps one trap every 25 miles (40 km) tracking moth movements in real-time and issuing scouting alerts via the internet or cell phones.

Easier to use than standard green bucket traps, Z-traps mainly require putting in new pheromone lures every four weeks and cleaning when necessary. The real value is alerting growers to "the very narrow window when moths peak" and WBC demands immediate attention to avert crop loss.

Podisus Aggregation Pheromone

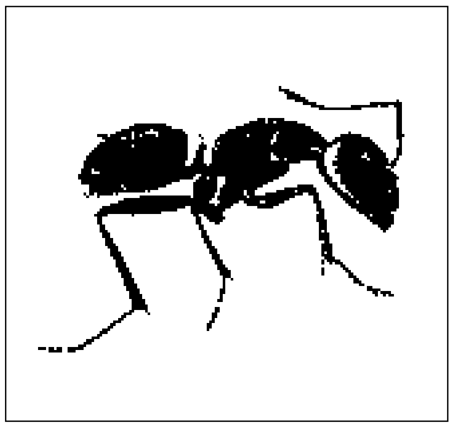
Colorado Potato Beetle (CPB), *Leptinotarsa decemlineata*, alters its behavior in response to the aggregation pheromone of a natural enemy, the spined soldier bug, *Podisus maculiventris* (Pentatomidae), a predatory stink bug, said Ari Grele (Cornell Univ, Comstock Hall, Ithaca, NY 14853; ajg346@cornell.edu). "*P. maculiventris* pheromone is comprised of five main components, two of which are green leaf volatiles (GLVs) produced by potatoes, one of CPB's host plants. Because several of these components overlap with CPB's host plant," it was "hypothesized that CPB were not altering their feeding behavior in response to potato GLVs, but rather the remaining predator unique volatiles."

In zero-choice olfactometer assays, CPB "were exposed either to no pheromones or one of three pheromone blends: a two component blend comprised of just potato GLVs; a three component blend comprised of *P. maculiventris* unique volatiles; and the full five component blend." Potato GLVs reduced male CPB growth, but not female CPB growth. Both CPB sexes grew less when exposed to the unique three component *P. maculiventris* blend, and "marginally less" when exposed to the full five component blend. The amount of CPB potato leaf consumption was not affected by exposure to *P. maculiventris* aggregation pheromone.

Flower Thrips Pheromone Ecology

Western flower thrips (WFT), *Frankliniella occidentalis*, an omnivore, produces an aggregation pheromone, a mixture of (*R*)-lavandulyl-acetate and neryl (*S*)-2-methylbutanoate, said Ana Pineda (Netherlands Instit Ecol, Droevendaalsesteeg 10, 6708 PB Wageningen, Netherlands; A.Pineda@nioo.knaw.nl). The aggregation pheromone impacts higher ecological trophic levels, including the aphid natural enemy *Sphaerophoria rueppellii*, a predatory hover fly (Syrphidae) "commonly released to control aphids." European sweet pepper growers release *S. rueppellii* to control green peach aphid, *Myzus persicae*. However, when plants are infested with WFT or their aggregation pheromone, female *S. rueppellii* avoid laying eggs on sweet pepper plants.

The effects of thrips and their aggregation pheromone "can scale up until the third trophic level," said Pineda. In other words, WFT and its aggregation pheromone harm the host plant (sweet pepper), retard other herbivores (aphids), and reduce the fecundity (but not the fertility) of natural enemies (hover flies). The mechanisms of action are still being explored.



Carpenter ant, *Camponotus sp.*

Carpenter Ant Pheromones

Queens of the western carpenter ant, *Camponotus modoc*, have a "big investment" in defending nests with multi-generational broods, and are an ecologically important food source for birds in the Pacific Northwest USA, said Asim Renyard (Simon Fraser Univ, 8888 University Dr, Burnaby, BC, Canada V5A 1S6; asim_renyard@sfu.ca). When in distress, *C. modoc* workers emit an alarm pheromone spray to recruit nestmates. In Y-tube olfactometers, worker ants were attracted or "recruited" by poison gland contents, but not by Dufour's gland contents. To unravel "alarm communication ecology," GC-MS (gas chromatography-mass spectrometry) identified 12 possible alarm pheromone components in poison gland extracts.

Deletion experiments started with a blend that worked as an alarm pheromone, then methodically dropped component compounds and observed the effects. Formic acid and benzoic acid are essential *C. modoc* alarm pheromone components. In group bioassays, carpenter ants located pheromone components on filter paper. A blend of hydrocarbons (4 alkanes) and formic and benzoic acids was highly attractive.

"In arena experiments ants were attracted to the micro-location treated with our synthetic blend of pheromone components," said Renyard. "Both the alkanes (saturated hydrocarbons) and the acids (formic & benzoic) appear to be sprayed by distressed ants," and both are "required for recruitment." However, the blend is very volatile, and needs to be stabilized for constant release rates to be more useful in research and IPM programs.

Multi-Species Ant Pheromone Blends

A multi-species trail pheromone blend catching all urban pest ant species is an IPM solution for homeowners who rarely know one ant species from another, said Jaime Chalissery (Simon Fraser Univ, 8888 University Dr, Burnaby, BC, Canada V5A 1S6; jchallis@sfu.ca). Since European Fire Ant (EFA), *Myrmica rubra*, trail pheromone, 3-ethyl-2,5-dimethylpyrazine, boosts EFA recruitment to food baits, "this made us wonder whether a multi-species trail pheromone blend prompts multiple ant species to follow it. Our objectives were to test whether EFAs, western carpenter ants, *Camponotus modoc*, black garden ants, *Lasius niger*, and thatching ants, *Formica oreas*, both antennally sense, and behaviorally respond to, a multi-species trail pheromone blend."

Using field collected ants and gas chromatographic-electroantennographic detection (GC-EAD), it was shown that "EFAs, *C. modoc*, *L. niger*, and *F. oreas* all sense their own trail pheromone and at least that of 3 heterospecifics," said Chalissery. EFAs follow their own trail pheromone plus the trail pheromone blend of multiple species. Black garden ants follow the multi-species trail pheromone blend better than their own pheromone, 3,4-dihydro-8-hydroxy-3,5,7-trimethylisocoumarin. Western carpenter ant workers follow their own pheromone, 2,4-dimethyl-5-hexanolide, and the multi-species blend with equal intensity.

Methyl Benzoate

Methyl benzoate is a natural plant semiochemical, said Xiang-Bing Yang (Univ California, 1636 East Alisal St, Salinas, CA 93905; xbya@ucdavis.edu). It has contact toxicity to brown marmorated stink bug (BMSB), *Halyomorpha halys*; diamondback moth, *Plutella xylostella*; and spotted wing drosophila, *Drosophila suzukii*. In laboratory fumigation tests western flower thrips (WFT), *Frankliniella occidentalis* on apples were killed in 24 hours at 2°C (35.6°F). Apple fruit quality (3 varieties) remained excellent four weeks after treatment.

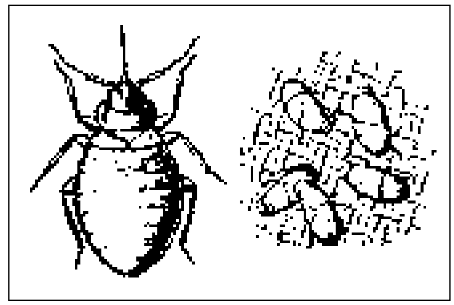
Dried residues of methyl benzoate are 100-300% more effective against gypsy moth and BMSB than pyriproxyfen and acetamiprid, said Rob Morrison (USDA-ARS, 1515 College Ave, Manhattan, 66502; william.morrison@ars.usda.gov). Methyl benzoate is also a phosphine and methyl bromide fumigant alternative. Methyl benzoate is comparable to phosphine against red flour beetle, *Tribolium castaneum*, and lesser grain borer, *Rhyzopertha dominica*. However, phosphine is superior against warehouse beetle, *Trogoderma variabile*, and rice weevil, *Sitophilus oryzae*.

Methyl benzoate has “a repellent effect on individual bed bugs, and is toxic to both susceptible and pyrethroid-resistant bed bugs,” said Nicholas Larson (USDA-ARS, 10300 Baltimore Ave, 1040 BARC-E, Beltsville, MD 20705; nicholas.larson@ars.usda.gov). But in large volume bag fumigation tests, Cirkil®, a neem oil bed bug fumigant designed for treatment of “sensitive materials such as books or papers within garbage bags,” was significantly more effective than methyl benzoate.

Bed Bug Pheromone

The common bed bug, *Cimex lectularius*, and the tropical bed bug, *C. hemipterus*, produce aldehyde pheromones “known to have both alarm and aggregation functions,” said Mark Dery (Univ California, 900 University Ave, Riverside, CA 92521; mdery001@ucr.edu). “By examining eggs, nymphs, or their freshly shed exuviae, the production of (E)-2-hexenal, 4-oxo-(E)-2-hexenal, (E)-2-octenal, and 4-oxo-(E)-2-octenal was examined throughout the development of bed bugs.”

The pheromone aldehydes are not detected in eggs or recently hatched bed bugs. In other words, bed bugs are not born with the pheromone aldehydes. But over time, by 48 hours after egg hatch, all the aldehydes are present, though there are changes over time. Just before bed bugs take a blood meal, all four pheromone aldehydes are present. *C. lectularius* produces more (E)-2-octenal than *C. hemipterus*. Each bed bug species has a different ratio of the aldehydes in its pheromone blend, which has implications for monitoring devices.



Bed bug, *Cimex lectularius*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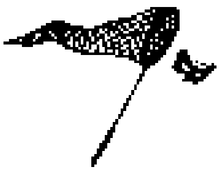

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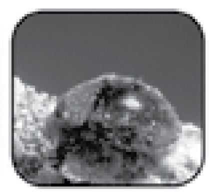

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