The IPM Practitioner
Monitoring the Field of Pest Management
Volume XXXV, Number 9/10 (Published May 2017)
Special Pheromone Issue

IPM for the Western Corn Rootworm

By William Quarles

The western corn rootworm (WCR), *Diabrotica virgifera virgifera*, is a billion dollar superbug created through continuous corn monocultures and pesticide misuse. Corn losses and management costs in the U.S. exceed $1 billion per year. Larval feeding on corn roots interferes with uptake of water and nutrients, reducing yields. Damage to roots can cause the plant to topple and fall (lodging). The adult form of the pest is a leaf beetle. Adults eat corn pollen, silks, foliage, and developing kernels. Adult feeding can interfere with pollination, leading to yield reduction (Meinke et al. 2009; Spencer et al. 2009; Metcalf 1986).

The rootworm is a major pest because of prolific reproduction, widespread dispersal, and resistance both to pesticides and genetically engineered traits. Many predators eat it only as a last resort, due to body fluids that are chemically and physically repelling. Global warming may also be a factor, as warmer winters may allow more eggs to survive. Crop diversification would reduce damage, but obsession with large corn monocultures make this alternative unlikely (Gray et al. 2009; Meinke et al. 2009; Lundgren and Fergen 2014, Cullen et al. 2013; Chiang 1973).

The pest has become more of a problem in recent years due to increased plantings of corn (21% increase), and over-reliance on genetic engineering (80% of acreage) as the sole management strategy. Growers have abandoned effective, economical IPM methods that protect the environment. This article describes an IPM program for the western corn rootworm that will effectively manage the insect while preventing pesticide resistance and environmental damage (Andow et al. 2016; Gray et al. 2009; Gray 2011; Cullen et al. 2013).


Photo by Tom Hlavaty courtesy of USDA

Shown here is an adult female beetle of the western corn rootworm, *Diabrotica virgifera virgifera*. Larvae feed on roots, adults feed on pollen, corn silks, and developing kernels, reducing corn yields.

Where did it Come From?

The western corn rootworm is native to North America. It may have developed on corn in Mexico, then moved northwards as plantings of corn moved northward. But the larval form is also able to reproduce on roots of grasses, and populations can be sustained in the absence of corn if adults are able to find nutrition. It was first collected and identified in 1865 in Kansas on wild buffalo gourd, *Cucurbita foetidissima*. There were no corn plantings in the area at that time (Moeser and Hibbard 2005).

WCR became a pest in the U.S. after the widespread planting of corn. It was first noticed in Colorado cornfields in 1909. The pest followed a slow path of dispersal eastward to Nebraska in the 1930s and 1940s (Spencer et al. 2005).

In This Issue

Corn Rootworm 1
Conference Notes 12
Calendar 15

The IPM Practitioner
Monitoring the Field of Pest Management

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

Managing Editor	William Quarles
Contributing Editors	Sheila Daar Tanya Drlik Laurie Swiadon
Editor-at-Large	Joel Grossman
Business Manager	Jennifer Bates
Artist	Diane Kuhn
Research Intern	Erin Berg

For media kits or other advertising information, contact Bill Quarles at 510/524-2567, birc@igc.org.

Manuscripts
The IPMP welcomes accounts of IPM for any pest situation. Write for details on format for manuscripts or email us, birc@igc.org.

Subscriptions/Memberships
A subscription to the IPMP is one of the benefits of membership in BIRC. We also answer pest management questions for our members and help them search for information. Memberships are $60/yr (institutions/libraries/businesses); $35/yr (individuals). Canadian subscribers add $15 postage. All other foreign subscribers add $25 airmail postage. A Dual membership, which includes a combined subscription to both the *IPMP* and the *Common Sense Pest Control Quarterly*, costs $85/yr (institutions); $55/yr (individuals). Government purchase orders accepted. Donations to BIRC are tax-deductible.
FEI# 94-2554036.

Change of Address
When writing to request a change of address, please send a copy of a recent address label.

ISSN #0738-968X

Update

Creation of a Superbug

Applications of the chlorinated insecticides aldrin and chlordane in the 1950s turned the insect into a superbug. It became resistant to the pesticides, but the insecticides also encouraged survival of variants that dispersed toward untreated fields. Long distance dispersal then became part of the insect's behavior. Before the pesticides, movement averaged 19 km/year (11 mi/year). After the pesticides, from 1961 to 1964, movement averaged 193 km/year (116 mi/year), and the pest moved from Nebraska to Wisconsin (Metcalf 1983; Metcalf 1986; Spencer et al. 2005; Meinke et al. 2009). Dispersal may have been linked with resistance, as Eastern populations today still have greater resistance to chlorinated pesticides than western populations (Wang et al. 2013).

By the 1980s, it had reached the East Coast. In 1995, it found its way to Europe. Since 1995 there have been several European introductions, leading to 80% damage in some cases. Populations can quadruple each year without adequate management. In the U.S. infestations up to 100 million eggs/ha (40 million/acre) and 10.9 million adults/ha (4.4 million/acre) have been found. The current insect is resistant to many pesticides, and may be quite different from the one living in the 1950s (Spencer et al. 2005; Metcalf 1983; Lemic et al. 2016; Meinke et al. 2009).

Pest Larvae, Pest Adults

Though other species of *Diabrotica* will attack corn, the western corn rootworm is the most damaging (see Box A). It produces eggs, 3 larval stages, pupae and adults. Eggs, larvae and pupae live in the soil, and the wormlike larval stages are the most destructive forms. There is one generation a year, and the larval stage can only develop on corn roots and roots of a few related grasses (see Box A) (Spencer et al. 2005).

Female adults of the western corn rootworm resemble adults of the striped cucumber beetle, *Acalymma vittatum* (see Box A). Adults use corn pollen, silks, foliage and developing kernels as a source of food, but are able to eat a number of other plants. WCR beetles are attracted to cucumbers, squash and other plants in the *Cucurbitaceae*. Feeding on cucurbits may be part of a defensive strategy. The bitter curcurbitacins may protect the insect against predators. The chemicals are sequestered in their eggs, and may protect developing larvae (Tallamy et al. 2005).

Monitoring Adults

Monitoring adults is important, as it can reduce pesticide applications. Adults can be monitored by visual counts and direct sampling, by sticky traps, pheromone traps, and by attract and kill traps. Measurement of adult populations in cornfields in one year can provide estimates of economic damage for the following year (Olkowski 1986; Hein and Tollefson 1985).

For visual monitoring, whole plant counts of beetles are more efficient than ear counts. The idea is to sample only enough plants to get reliable prediction, as this reduces cost. The field is divided into quadrants, then subquadrants, and samples are taken from as many areas as possible. Steffey et al. (1982) found sampling 2 plants at 27 sites optimized precision (30%) and cost. Sampling 10 plants at 10 sites gave slightly higher precision (37%), but increased cost.

Penn State recommends 2 plant samples at 40 sites. The Penn State economic threshold is 1.0 beetle/plant in first year rotation fields and 1.5 beetles/plant in continuous corn. Consultants in Kansas mostly use 11-20 whole plant counts in fields averaging 114 acres. If averages are 0.5 to 1 beetle per plant or higher, treatment in the following year is recommended to prevent damage (Calvin 2003; Daves et al. 2007). More information on monitoring can be found in Tollefson (1986), Steffey et al. (1982), and Calvin (2003).

Box A. Biology of the Western Corn Rootworm

The western corn rootworm, *D. virgifera virgifera* is the most damaging, but the northern corn rootworm, *Diabrotica barberi*; the Mexican corn rootworm, *D. virgifera zeae*, and the southern corn rootworm, *D. undecimpunctata howardi* will also attack corn. The southern corn rootworm is also called the spotted cucumber beetle, and the western corn rootworm resembles the striped cucumber beetle, *Acalymma vittatum* (Krysan 1986; Olkowski 1986).

The western corn rootworm produces eggs, 3 larval stages, pupae, and adults. Eggs are laid in soil, usually near the base of a corn stalk. Female beetles use earthworm burrows and natural soil crevices to bury their eggs. Peak egglaying and adult emergence is in August, but eggs are laid late July to Mid-september, and the WCR overwinters in the egg stage (Spencer et al. 2005). Eggs hatch late May or early June, normally in the year after they were laid. Adult emergence starts in early July in the Midwest, and there is one generation a year (Levine and Oloumi-Sadeghi 1991). Adults tend to aggregate in the fields, and the egg distribution tends to be patchy (Meinke et al. 2009; Steffey and Tollefson 1982).

The white 0.1 mm eggs are shaped like footballs. The wormlike larval stages are white except for dark brown heads and terminal tail sections. Size ranges from 1/8 (3.2 mm) to ½ inches (12.7 mm), and larval stages last 4-6 weeks. Pupae are white and generally the shape of adults. The adults are about ¼ inch (6.4 mm) long with a typical beetle appearance. Females have yellow to green backs with 3 parallel black stripes, extending toward the end of the abdomen. Backs of males are completely black, except for the posterior quarter, which is yellow-green (Chiang 1973).

Photo by Stephen Ausmus courtesy of USDA

Shown here is a female adult beetle on a corn leaf.

Photo by Scott Bauer courtesy of USDA

Shown here is a third stage larva of the western corn rootworm.

In the field, females lay a lifetime average of about 300-400 eggs. Eggs are laid at night, preferably in moist soil. In Iowa, most eggs (66%) are laid within 8 inches (20 cm) of the surface, but some eggs can be found at 12 inches (30 cm) (Gray and Tollefson 1988). In colder areas, eggs are laid deeper. In South Dakota about 40% were found in the first 8 inches (20 cm), but 60% between 8 and 12 inches (20-30 cm) (Gray et al. 1992).

Oviposition is more shallow in irrigated fields, and with rotation resistant insects. Egg mortality is 35-70% according to temperature and soil conditions. Low temperatures can kill the eggs, and mortality increases with the length of the overwintering period. The developmental threshold is 53°F (11.6°C) (Toepfer and Kuhlmann 2005; Chiang 1973).

Larvae must establish on corn roots within 24 hours of hatching, and they are attracted to roots by the CO_2 released by plant respiration (Vemmer et al. 2015). Because eggs are often laid close to plants, movement is limited. Younger larvae eat fine roots, older larvae bore into larger roots, destroying them (Schumann and Vidal 2012; Tallamy et al. 2005).

Greenhouse mortality of the 3 larval stages and pupae ranges from 60-85%. Natural field mortality of immature stages can be greater than 90%. More larvae are killed in very wet or very dry soil. Mortality is higher in sandy loam than clay soils (Chiang 1973). Adult emergence is about 5-10 days after pupation. Males emerge about 5 days before females. About 14 days after emergence, females start laying eggs. Adults in the field live an average of 52 days (Toepfer and Kuhlmann 2005).

Adults will eat cucurbits, such as cucumbers, squash, and pumpkins, and may appear in these crops at the same time as striped cucumber beetles. Female WCR are similar in appearance to females of the striped cucumber beetle, *Acalymma vittatum*, but the stripes of *A. vittatum* extend to the end of the abdomen. The abdomen of WCR is yellow, whereas the abdomen of *A. vittatum* is black (Chiang 1973).

Photo courtesy Landon Momberg Iowa State University

The Pherocon AM® sticky trap is useful for monitoring adult beetles. Trap catches can be correlated with economic thresholds, preventing unnecessary pesticide applications.

Sticky Traps

The Pherocon AM® sticky trap produced by Trécé Inc. has been used to estimate economic thresholds. Peak beetle emergence is in August, and Pherocon traps are deployed for about a week in August. About 12 traps per field are used (Tollefson 1986). Hein and Tollefson (1985) found that 6 beetles a day per trap in continuous corn meant significant root damage the following year unless treatments were applied. The Pherocon sticky trap has also been used to measure rotation resistant populations (see below). A catch of 5 adults/day per trap in a soybean field means that when planted to corn, moderate damage is likely (O'Neal et al. 2001).

Rondon and Gray (2003) used the Pherocon trap to monitor adult beetles in alfalfa and oat stubble. Catches in alfalfa were similar to soybeans, but levels in oats were lower than the threshold, at least in one year. Females predominated in all the rotation crops (see Rotation Resistance below).

Traps with Attractants

Much of the initial monitoring for adults of the western corn rootworm was done with Pherocon sticky traps. A non-sticky trap commercially available from Trécé combines a lure of plant volatiles and cucurbitacins with a stun pill containing carbaryl. Adults are attracted to the trap, then killed. The lure trap is preferred by some researchers (Tallamy et al. 2005).

The sex pheromone is (R-)-8-methyl-(R)-2-decylpropanoate, and it is produced by female beetles. Northern corn rootworms (see Box A) also react to this pheromone. Multigard® (Scentry Inc.) pheromone monitoring traps are commercially available, and are useful to detect low populations (Metcalf 1986; Lemic et al. 2016).

A good review of attractants can be found in Tallamy et al. (2005). A mixture of 1,2,4-trimethoxybenzene, indole and cinnamaldehyde is attractive to adults. It is a simplified *Cucurbita* volatile aroma. Shaw et al. (1984) developed a vial trap made of 60 ml capped vials with holes drilled for beetle entry. Attractants were plant volatiles and cucurbitacins from buffalo gourd. It has been used successfully by several researchers, but it is no longer commercially available (Levine and Gray 1994; Rondon and Gray 2003; Tallamy et al. 2005).

Monitoring Root Damage

Monitoring root damage from feeding larvae can provide early warning about crop damage. The Iowa scale is the best known, easy to use, and gives effective results (Hills and Peters 1971). This is a scale of 1-6. No feeding is assigned a value of 1. Root feeding with minimal damage (damaged roots >3.8 cm; 1.5 in) is assigned 2. Moderate damage with several roots attacked is assigned 3.

Corn roots sprout from the stalk in a circular fashion. A circle with all the roots the same distance down the stem is called a node. If one complete node of roots is destroyed, the scale number is 4. If two complete nodes of roots, 5; and three complete nodes, 6. On this scale, economic damage in a field will be seen if there is an average rating greater of 3 or more. Corn yields are reduced 15-17% with each node of root injury (Dunbar et al. 2016). Other scales have also been suggested (Oleson et al. 2005).

Soil Insecticides

Soil insecticides were the first widely applied chemical management tool. At one point in the 1980s about 60% of the corn acreage was being treated with soil insecticides. The insecticides were overused, as monitoring showed only 11-19% of the corn acreage was infested. Effectiveness of soil insecticides can be variable according to the site and environmental conditions. Inconsistent results can sometimes be due to microbial degradation (Olkowski et al. 1986; Levine and Oloumi-Sadeghi 1991).

The rootworms are now resistant to chlordane and other chlorinated pesticides. Because of a change to granular in-row applications, larval resistance to organophosphates and carbamates has been slow to develop. Larger roots near the stalk are protected, but feeding is possible on fine roots. Soil insecticides protect corn roots, but do not kill emerging beetles, preventing resistance, but leading to repeated annual applications (Olkowski 1986; Metcalf 1986; Ludwick and Hibbard 2016; Levine and Oloumi-Sadeghi 1991).

Adult Baits

Pruess (1974) showed adult control could prevent larval damage. Reducing the adult population reduces the number of eggs laid and the subsequent damage seen the following year. Aerial sprays have been used, but there is extensive environmental damage. And resistance to foliar applications of organophosphates, carbaryl, and bifenthrin has occurred (Chandler 2003; Ludwick and Hibbard 2016).

Baits have been used in areawide management programs to reduce the numbers of adult beetles. Baits contain cucurbitacin feeding attractants, an insecticide, and an edible carrier. Baits can reduce the amount of insecticide applied by 95-98%. Cucurbitacins are extracted from the buffalo gourd, *Cucurbita foetidissima*. Trécé Inc. sells Cidetrak® CRW which is a feeding stimulant. Cidetrak CRW can be mixed with an insecticide to make a sprayable bait. Invite® (Rockwell Inc.) is also a feeding stimulant to which insecticide can be added. The products SLAM® and Adios® (Microflo Inc.) contain a feeding stimulant and carbaryl. Areawide management in Illinois, Kansas, and Iowa with baits led to reduced root damage in corn. Costs were either equal to or less than applications of soil insecticides (Chandler 2003; Gerber et al. 2005; Metcalf et al. 1987).

Larval Baits

Since rootworms are attracted to CO_2 released by plant roots, experimental baits have been developed that release CO_2, attracting the rootworms to a lethal fungus. The approach has promise, but is not commercially available (Vemmer et al. 2016). Modifications of this method have so far not been very successful (Schumann et al. 2013; 2014).

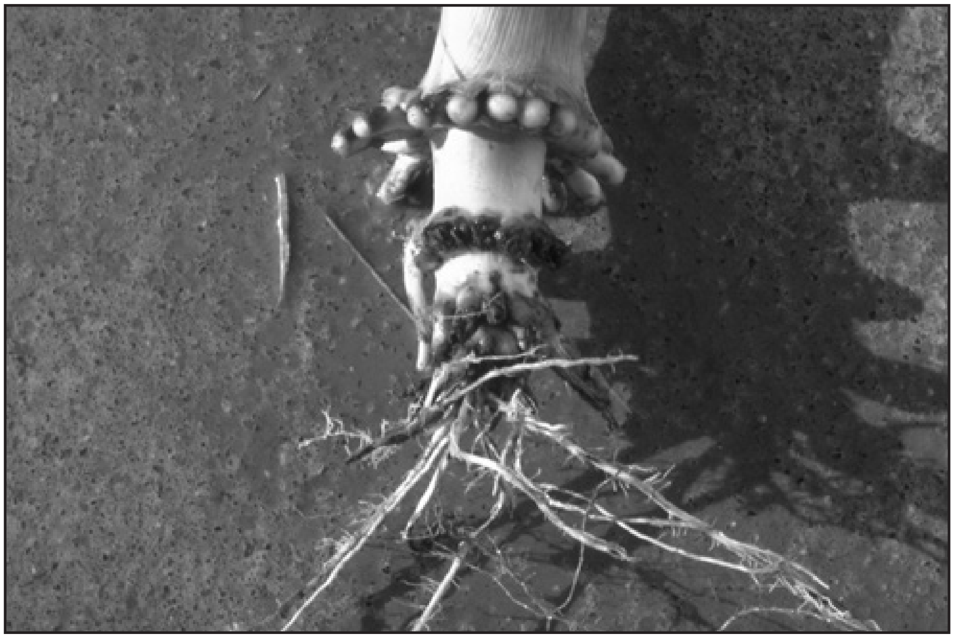


Photo courtesy Kansas State Univ. Dept. of Entomology

Larval feeding shown here can destroy roots, leading to reduced uptake of water and nutrients, and lower yields. Extreme feeding causes the stalk to fall to the ground (lodging).

Plant Less Corn

One obvious solution to the western corn rootworm problem is to plant less corn. Continuous corn cropping is being driven by crop subsidies, crop insurance, and the mandate for ethanol in automobile fuel. U.S. acreage planted to corn increased by 21% between 2003 and 2013. And acreage devoted to continuous corn increased from 21% in 2000 to 29% in 2010 (Andow et al. 2016).

Problems with the corn rootworm would decrease if less corn were planted and the landscape were more diversified. Diverse landscapes are known to mitigate pests, especially specialists, and lead to fewer pesticide applications (Onstad et al. 2003a; O'Rourke and Jones 2011).

Cultural Controls

Corn rootworms do not move very far in soil. They mostly move about a foot or two, and the maximum distance is about 100 cm (39 in). In continuous corn, moving the planting rows each year can reduce damage. Larval populations can be reduced about 33% for each 10 inches (25.4 cm) a new corn row is moved. Application of nitrogen fertilizer or manure reduces damage. Heavy ground cover of plant debris from cover crops deters egg laying and reduces larval populations. Winter cover crops also encourage predators (Lundgren and Fergen 2011; Lundgren and Fergen 2010a; Allee and Davis 1996; Riedell et al. 1996; Chiang 1973).

Moisture is important. Beetles prefer to lay eggs in moist soil, but irrigation with 5-10 cm (2-4 in) of water when beetles are in the pupal stage can reduce adult emergence by 50%. Rootworm damage is worsened by drought, and plants may survive if rainfall is adequate for root regrowth. Egg laying, egg mortality, and adult emergence is generally unaffected by the type of tillage. But root damage can be less in no-till, perhaps due to predation. Larval mortality is higher in sandy soil. Cold weather can kill rootworm eggs. Eggs held at -10°C (14°F) for 21 days have 100% mortality (Levine and Oloumi-Sadeghi 1991; Lundgren and Fergen 2010a).

Delayed Planting

Delayed planting is an excellent cultural strategy. Rootworms must find corn roots within 24 hrs of hatching (Moeser and Hibbard 2005; Branson 1989). When eggs hatch, corn is not there to provide nutrition. Late plants also act as trap crops to help manage rotation resistant rootworms (see below)

Sanitation is important when crop rotation is practiced. Volunteer corn left in soybean fields can attract egg laying beetles. Green and yellow foxtail are also hosts, but since most cornfields and rotation soybean fields are aerially sprayed with herbicides, host weeds are not likely to be a problem (Levine and Oloumi-Sadeghi 1991; Quarles 2016b).

Some corn varieties are tolerant to feeding, but research on naturally resistant species stalled with the development of genetically engineered corn containing BT toxins (Levine and Oloumi-Sadeghi 1991; Gray et al. 2009)(see below).

Crop Rotation

Since the larval stage of the corn rootworm can only develop on corn or a few grassy weeds, crop rotation is the best cultural strategy. When eggs laid in cornfields hatch in a rotation crop such as soybeans, larvae cannot develop on the rotation crop. Rotation has been used successfully since the beginning of corn cultivation. Only recently, in areas such as Illinois where most of the acreage is planted to corn, has resistance to rotation developed. For instance, in Ford County Illinois, 89% of the land is under cultivation and 98% of that is planted to either corn or soybeans, and nearly all (98%) of the soybeans are rotated back to corn the following year. Classical crop rotation is still effective in most of the U.S. (Levine et al. 2002; Dunbar and Gassmann 2013).


Photo courtesy John Obermeyer, Purdue Extension Entomology

Rotation resistant beetles shown here are feeding on soybean leaves. Eggs laid in soybeans hatch out in rotation cornfields, causing damage.

Rotation Resistance

The cause of rotation resistance in WCR is beetle migration. Corn rootworm females generally lay their eggs in the corn fields where they develop. But rotation resistant beetles migrate from corn into other crops to lay at least some of their eggs. WCR females will migrate into soybeans, oats, alfalfa, and wheat to lay eggs. If these fields are planted to corn in the next year, the corn will be damaged (Rondon and Gray 2003; O'Neal et al. 2002).

If the corn rootworm likes corn so much, why does it desert its favorite food? One reason is that corn is less appealing to adults later in the year when silks have turned brown. Another reason is that constant applications of glyphosate to Roundup Ready® genetically engineered corn kills weeds that could provide alternate food to keep them in the corn fields. Another reason is that insecticides changed the stay-at-home rootworm into a wanderer that has dispersal as part of its behavior (O'Neal et al. 2001; 2002; 2004; Metcalf 1983; Quarles 2014a).

Rotation resistant WCR beetles are more active than the normal variety. A genetic basis for the behavior is suspected, but has not been proven. Rotation resistant individuals, however, have higher levels of digestive enzymes than rotation susceptible rootworms (Knolhoff et al. 2006; Miller et al. 2006; Curzi et al. 2012).

Rotation resistant insects lay their eggs higher in the soil. In Illinois 60% are laid in the top 10 cm (4 in), while rotation susceptible insects lay most of their eggs deeper (Spencer et al. 2009). Rotation resistance is concentrated in Eastern states such as Illinois and Indiana, and is not present to any extent in Iowa (Dunbar and Gassmann 2013).

The northern corn rootworm, *D. barberi*, can also show rotation resistance. But resistance in *D. barberi* is due to extended egg diapause (see Box A). Instead of hatching after one year, some of them hatch after two. Eggs are laid in corn, but eggs do not hatch in rotation soybeans, but right in the middle of corn on a two year rotation (Levine and Oloumi-Sadeghi 1991).

Cure for Rotation Resistance

Late planted corn can be a cure for WCR rotation resistance. Rotation resistant WCR beetles do not prefer soybeans over corn. As conventional corn matures, it becomes a less acceptable food and dispersal begins. Late planted corn can act as a trap crop because the younger corn is more attractive later in the year when other fields are senescing. Late planted corn draws beetles away from other crops. In the next year the field can be planted to soybeans or wheat, destroying the larvae (O'Neal et al. 2004). For instance, Pierce and Gray (2006) found that beetles left early planted corn and laid eggs in soybeans, but late planted corn acted as sink for the beetles, attracting them away from soybeans and early planted corn.

Onstad et al. (2003b) developed models that show rotation resistant beetles can be managed by a 3 year rotation of wheat, then corn, then soybeans. Three year rotations would also be effective for the northern corn rootworm. Schroeder et al. (2005) found in small plot tests that corn following wheat had the least root damage, and corn following soybeans had root damage near the economic threshold.

Genetically Engineered Corn

Today's western corn rootworm is likely very different from the one found in cornfields in 1909 (Metcalf 1983; Metcalf 1986). Similarly, today's corn is definitely quite different. Corn planted now may contain several traits added to it by genetic engineering techniques. These traits may include one or more of four different BT traits for rootworm control, BT for the European corn borer, traits for resistance to glyphosate and other herbicides. Seeds may be treated with neonicotinoids and fungicides. In fields where rootworm control failures have occurred, soil insecticides such as Aztec® (tebupirimphos and cyfluthrin) are applied (Gray et al. 2009; Cullen et al. 2013).

Problems include consumer resistance, destruction of wildlife, contamination of food with systemic pesticides, and expensive introductions of new traits as old ones fail—the genetic treadmill (Quarles 2012; 2014a; 2016ab). Aerial applications of glyphosate may change the microbial composition of the soil (Johal and Huber 2009; Kremer and Means 2009), possibly affecting rootworm management. Fungicides applied as seed treatments may destroy natural biocontrols such as *Beauveria bassiana* and *Metarhizium anisopliae* (Quarles 2012).

Natural predators such as carabid beetles may be killed by neonicotinoid seed treatments (Mullin et al. 2006; Gray and Steffey 2006) (see Biocontrol below). Neonicotinoids may also kill bees, birds and other beneficials (Goulson 2013, Krupke et al. 2012, Quarles 2014b). The reality may be the simultaneous application of conflicting management tools.

When BT corn with rootworm resistance was introduced, it quickly become the major control for the corn rootworm. It was convenient and effective, and farmers discarded IPM methods, and relied mostly on BT to protect their corn. Although regulators required BT corn to be planted with refuges of non-BT corn to slow resistance, refuges were not effective. The reason for failure in some instances might have been non-compliance. Field resistance to BT corn has developed (Gray 2011; Gassmann et al. 2011; Gassmann et al. 2016).

BT Resistance

About 80% of the corn crop in the U.S. had a genetically engineered BT trait in 2014. BT for the rootworm was introduced in 2003. Farmers welcomed it enthusiastically because they could grow continuous corn without soil insecticides. However, the rootworm rapidly became resistant to the first trait introduced, Cry3Bb1. Resistance can develop within three years of continuous BT plantings. A 3-6 fold increase in resistance leads to substantial damage in the field (Gassmann et al. 2011; Andow et al. 2016).

Major reasons for resistance development were low expression of the insecticidal trait, a resistance allele that was not recessive, inade-

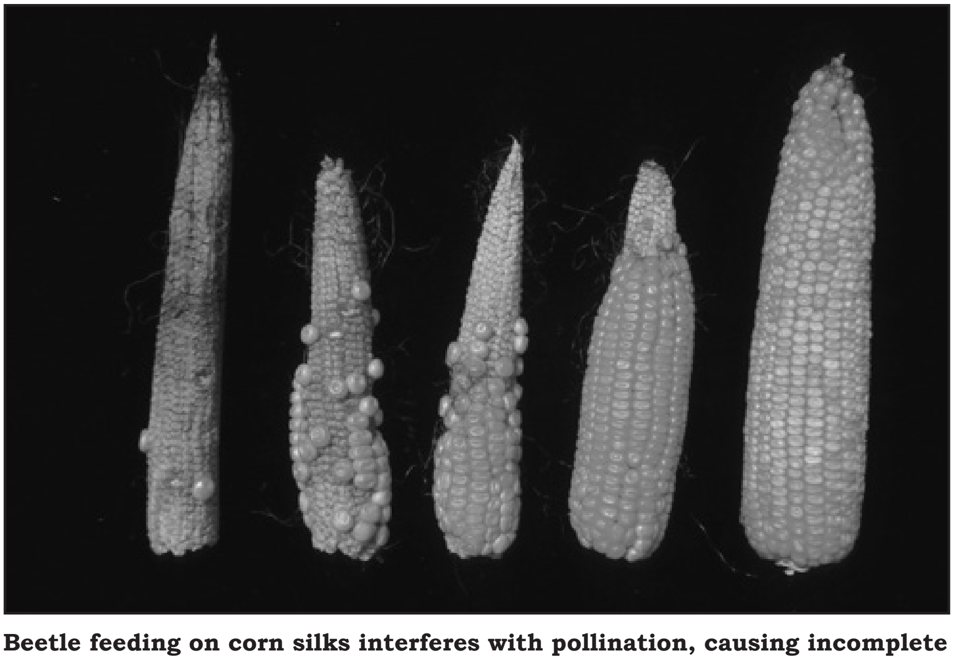


Photo courtesy John Obermeyer, Purdue Extn. Entomology

Beetle feeding on corn silks interferes with pollination, causing incomplete development of corn ears.

quate BT-free refuges, and excessive reliance on one management strategy instead of IPM (Petzold-Maxwell et al. 2012; Cullen et al. 2013; Tabashnik and Gould 2012).

Greenhouse tests show resistance is possible to all four commercial BT rootworm traits, and also to "pyramids" containing more than one trait. Field resistance to some of these traits has already developed and others are at risk (Andow et al. 2016; Cullen et al. 2013; Gassmann et al. 2011; Gassmann et al. 2016).

Resistance to BT usually develops in field "hot spots." The best mitigation is immediate implementation of IPM methods, such as areawide crop rotation. Another possibility is increasing refuge size of non-BT corn to 50% of the BT acreage. It is best to implement IPM methods before resistance occurs (Tabashnik and Gould 2012; Martinez and Caprio 2016).

Reaction to Resistance

Though IPM methods are the solution, Dunbar et al. (2016) found that the reaction of Iowa farmers to development of resistance to BT (Cry3Bb1) was to grow continuous corn with a different BT, or to apply soil insecticides or both. This approach was taken even though rotated fields had the same or less damage, but planted less BT corn, and used less soil insecticide. Where it was implemented, crop rotation in Iowa led to protection equal to or better than chemical management.

Help from Soil Microbes

The underground ecology is important for WCR survival. Since corn rootworm lives in the soil, it is reasonable that changes in soil microbes might affect root damage. Some microbes might make the insect sick, or microbe interaction with corn might make the plant less attractive. Dematheis et al. (2012) found that western corn rootworm larval feeding changed the microbial composition of the corn root rhizosphere. Demathesis et al. (2013) inoculated corn with the mycorrhizal fungus *Glomus (Rhizophagus) intraradices*. The inoculant slowed the growth rate of the larvae, making them more susceptible to predators.

Photo by Juan Morales-Ramos courtesy USDA

***Heterorhabditis* spp. nematodes can help manage the western corn rootworm.**

Photo by Jonathan Lundgren courtesy USDA

The carabid *Cyclotrachelus alternans* can provide biocontrol.

Santos et al. (2014) inoculated corn with the beneficial microbe *Azospirillum brasilense*. The inoculated corn suffered less rootworm *(Diabrotica speciosa)* attack than untreated corn. Larvae that fed on the inoculated corn weighed less than those feeding on untreated corn. Inoculated corn had elevated emissions of *(E)-beta*-caryophyllene, which the rootworm may avoid. This chemical also attracts beneficial nematodes that may contribute to plant protection (Rasmann et al. 2005).

Biocontrol

The tachinid parasitoid *Celatoria compressa* is being considered as a biocontrol for the western corn rootworm in Europe. The eggs of the parasitoid contain larvae that are injected into adult beetles. During a mean egglaying period of 23 days, 33 beetles can be parasitized. Maximum 24 hr parasitism rate in the laboratory is 27% (Zhang et al. 2004; Kuhlmann et al. 2005).

Ground beetles can be predators, but larval rootworms are not preferred prey. Rootworms have a hemolymph defense that makes them distasteful. Predators vigorously clean mouthparts after encounters. The hemolymph may also contain chemical repellents such as cucurbitacins. Chewing predators are deterred more than fluid feeders. Rootworm predation increases with predator density (Lundgren et al. 2009; Lundgren et al. 2010b; Lundgren and Fergen 2014; Tallamy et al. 2005).

Mites feed on eggs and larvae, but applications of predatory mites to corn fields made the rootworm problem worse. Mites may have interfered with a natural biocontrol (Prischmann et al. 2013).

Nematodes and Fungi

Nematodes and fungi can be effective biological controls for the western corn rootworm. Soil is the natural habitat for nematodes, fungi, and rootworms. Success with nematodes and fungi increases with soil moisture and temperature, and nematodes are more effective in sandy soils. Some corn varieties release plant volatiles that attract nematodes, increasing efficacy. *Heterorhabditis* spp. are more effective than *Steinernema* spp. In many cases, nematodes are just as effective as soil insecticides. In Europe, they are used in commercial corn production under the brandname Dianem® (Hiltpold et al. 2010; Wright et al. 1993; Toepfer et al. 2008; Hoffmann et al. 2014).

Because they attack the larvae, nematode and fungi applications must persist in the soil until rootworm eggs hatch. Persistence of nematodes in the fields is variable. Wright et al. (1993) found *S. carpocapsae* nematodes persisted 28 days one year, but only 7 days the next year. But in European field experiments, Kurtz et al. (2007) found *Heterorhabditis* spp. and *S. feltiae* persisted for 2-5 months. Because of possibly limited persistence, applications after planting time may be more successful than those at planting.

The entomopathogenic fungi *Beauveria bassiana* and *Metarhizium anisopliae* occur naturally in 55-60% of Iowa cornfields (Rudeen et al. 2013). And *Metarhizium anisopliae* applied to cornfields persists for at least 15 months (Pilz et al. 2011). About 1.4% of western rootworm larval field infestations are infested (Pilz et al. 2008).

Heterorhabditis spp. More Effective

In laboratory tests, Kurtz et al. (2009) found that the 3rd larval stage of the rootworm was the most susceptible to nematodes, and that *Heterorhabditis bacteriophora* and *H. megidis* were more effective than *S. feltiae.*

Toepfer et al. (2008) found that *H. bacteriophora* and *H. megidis* caused 70% rootworm mortality, and *S. feltiae* caused 32% mortality when applied at field application rates of 3.4 x10^9/ha. In another experiment Toepfer et al. (2010) found *H. bacteriophora* applied in the field reduced root injuries due to rootworm feeding by 25-79%. Highest reduction in rootworm density (68%) occurred with application of nematodes at planting.

Though *Heterorhabditis* spp. are more effective, studies have shown that *Steinernema carpocapsae* nematodes are effective in controlling larval rootworms in the field. The 2nd and 3rd larval stages of the rootworm are the most vulnerable. About 6% of eggs reached adult stage in the controls, whereas about 1% of eggs reached adulthood in treated fields (Journey and Ostlie 2000).

Petzold et al. (2013) found that *H. bacteriophora* and *S. feltiae* plus the fungus *Metarhizium brunneum* reduced root injury of BT corn when rootworm levels were high, and reduced injury to non-BT corn when levels were low. In both cases, corn yields were increased by the treatment.

Nematodes Versus Soil Insecticides

Wright et al. (1993) found high rates of nematodes 2.5 x10^9/ha applied to natural infestations were more effective than the soil insecticide terbufos and had similar effectiveness to chlorpyrifos in preventing root damage. Nematodes were applied through irrigation after planting.

When nematodes were applied at planting time, Jackson et al. (1996) found that *S. carpocapsae* and *H. bacteriophora* were not as effective as terbufos at preventing root damage. Adult emergence was reduced 66-98% by the nematodes, and 94-95% by the insecticide. Jackson may have had less success because the nematodes did not persist long enough to attack the rootworms.

Pilz et al. (2009) compared efficacy of the soil insecticide tefluthrin with clothianidin seed treatments, *H. bacteriophora* nematodes, and the fungus *M. anisopliae*. The pesticides and the nematodes gave similar reductions in adult emergence: tefluthrin (60%), H. b. (60%) and clothianidin (70%). The fungus reduced emergence by only 31%. Effectiveness of the fungus might have improved with increased application rates (Pilz et al. 2009).

Conclusion

Crop diversification would be the best longterm solution, but farmer resistance is likely. If corn monocultures are planted, the best strategy for the corn rootworm is an IPM program that includes cultural controls and crop rotation. Crop rotation of corn with soybean or wheat should be effective in areas where rotation resistance is not a problem. In areas with rotation resistance, late planted corn can be rotated with regular corn plantings, soybeans, and wheat. This rotation would also be effective for the northern corn rootworm. Neither BT corn nor soil insecticides should be needed, and costs would be low.

If monitoring shows that economic damage is likely when a field is planted to corn, nematode treatments can be a viable alternative to soil insecticides. This IPM approach will work both for organic and conventional corn. If nematodes are unavailable, soil insecticides or adult baits might be used as a last resort.

Experiments with larval baits and microbial ecology show promise, and more research on resistant species is needed. Stubborn adherence to continuous corn protected only by BT traits is bound to fail.

The western corn rootworm is a superbug created by poor agronomic practices. Conversion to IPM methods will lead to sustainable corn production and less environmental destruction. As a result, both farmers and consumers will be winners.

Acknowledgement

The author would like to thank Erin Berg for help with research on this article.

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

References

Allee, L.L. and P.M. Davis. 1996. Effect of manure and corn hybrid on survival of western corn rootworm. *Environ. Entomol.* 25(4):801-899

Andow, D.A., S.G. Pueppke, A.W. Schaafsma et al. 2016. Early detection and mitigation of resistance to Bt Maize by the western corn rootworm (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* 109(1):1-12.

Branson, T.F. 1989. Survival of starved neonate larvae of *Diabrotica virgifera virgifera. J. Kansas Entomol. Soc.* 62:521-523.

Calvin, D. 2003. Western and northern corn rootworm management in Pennsylvania. Pennsylvania State Cooperative Extension.

Chandler, L.D. 2003. Corn rootworm areawide management program: United States Department of Agriculture—Agricultural Research Service. *Pest Manag. Sci.* 59:605-608

Chiang, H.C. 1973. Bionomics of the northern and western corn rootworms. *Annu. Rev. Entomol.* 18:47-72.

Cullen, E.M., M.E. Gray, A.J. Gassmann et al. 2013. Resistance to Bt corn by western corn rootworm (Coleoptera: chrysomelidae) in the U.S. corn belt. *J. Integ. Pest Mngmt.* 4(3):1-6.

Curzi, M.J., J.A. Zavala, J.L. Spencer et al. 2012. Abnormally high digestive enzyme activity and gene expression explain the contemporary evolution of a *Diabrotica* biotype able to feed on soybeans. *Ecol. Evol.* 2(8):2005-2017.

Daves, C.A., R.A. Higgins, P.E. Sloderbeck et al. 2007. How Kansas crop consultants scout for western corn rootworms (Coleoptera:

Chrysomelidae) in field corn. *Am. Entomol.* 53(1):8-12.

Dematheis, F., U. Zimmerling, C. Flocco et al. 2012. Multitrophic interaction in the rhizosphere of maize: root feeding of western corn rootworm larvae altered the microbial community composition. *PLoS ONE* 7:0037288.

Dematheis, F., B. Kurtz, S. Vidal et al. 2013. Multitrophic interactions among western corn rootworm, *Glomus intraradices* and microbial communities in the rhizosphere and endorhiza of maize. *Frontiers Microbiol.* 4: article 357

Dunbar, M.W. and A.J. Gassmann. 2013. Abundance and distribution of western and northern corn rootworm and prevalence of rotation resistance in eastern Iowa. *J. Econ. Entomol.* 106(1):168-180.

Dunbar, M.W., M.E. O'Neal and A.J. Gassmann. 2016. Effects of field history on corn root injury and adult abundance of northern and western corn rootworm (Coleoptera: Chrysomelidae). *J. Econ. Entomol.* 109(5):2096-2104.

Gassmann, A.J., J.L. Petzold-Maxwell, R.S. Keweshan et al. 2011. Field-evolved resistance to Bt maize by western corn rootworm. *PLoS ONE* 6(7):e22629.

Gassmann, A.J., R.B. Shrestha, S.R.K. Jakka et al. 2016. Evidence of resistance to Cry34/35Ab1 corn by western corn rootworm: root injury in the field and larval survival in plant based assays. *J. Econ. Entoml.* 109(4):1872-1880.

Gerber, C.K., C.R. Edwards, L.W. Bledsoe et al. 2005. Application of the areawide concept using semiochemical based insecticide baits for managing corn rootworm (*Diabrotica virgifera virgifera* Le Conte) variant in the eastern Midwest. In: Vidal et al., pp. 221-238.

Goulson, D. 2013. An overview of the environmental risks posed by neonicotinoid insecticides. *J. Appl. Ecol.* 50:977-987.

Gray, M.E. and J.J. Tollefson. 1988. Influence of tillage systems on egg populations of western and northern corn rootworms. *J. Kansas Entomol. Soc.* 61(2):186-104.

Gray, M.E., G.L. Hein, M.A. Boetel et al. 1992. Western and northern corn rootworm egg densities at three soil depths: implications for future ecological studies. *J. Kansas Entomol. Soc.* 65(3):354-356.

Gray, M.E. and K. Steffey. 2006. Bt corn and neonicotinoid seed treatments: are non-target effects and potential insecticide resistance justified concerns? *Bull. IPM* No. 1, Article 4, March 24, 2006.

Gray, M.E., T.W. Sappington, N.J. Miller et al. 2009. Adaptation and invasiveness of western corn rootworm: intensifying research on a worsening pest. *Annu. Rev. Entomol.* 54:303-21.

Gray, M.E. 2011. Relevance of traditional integrated pest management (IPM) strategies for commercial corn producers in a transgenic ecosystem: a bygone era? *J. Agric. Food Chem.* 59:5852-5858.

Hein, G.L. and J.J. Tollefson. 1985. Seasonal oviposition of northern corn rootworms and western corn rootworms in continuous cornfields. *J. Econ. Entomol.* 78:1238-1241.

Hills, T.M. and D.C. Peters. 1971. A method for evaluating postplant insecticide treatments for control of western rootworm larvae. *J. Econ. Entomol.* 764-765.

Hiltpold, I., S. Toepfer, U. Kuhlmann et al. 2010. How maize root volatiles affect the efficacy of entomopathogenic nematodes in controlling the western corn rootworm? *Chemoecology* 20:155-162.

Hoffmann, A.M., G.W. French, S.T. Jaronski et al. 2014. Effects of entomopathogens on mortality of western corn rootworm and fitness costs of resistance to Cry3Bb1 maize. *J. Econ. Entomol.* 107(1):352-360.

Jackson, J.J. 1996. Field performance of entomopathogenic nematodes for suppression of the western corn rootworm. *J. Econ. Entomol.* 89(2):366-372.

Johal, G.S. and D.M. Huber. 2009. Glyphosate effects on diseases of plants. *Eur. J. Agron.* 31:144-152.

Journey, A.M. and K.R. Ostlie. 2000. Biological control of the western corn rootworm using the entomopathogenic nematode, *Steinernema carpocapsae. Environ. Entomol.* 29(4): 822-831.

Knolhoff, L.M., D.W. Onstad, J.L. Spencer et al. 2006. Behavioral differences between rotation resistant and wild type *Diabrotica virgifera virgifera. Environ. Entomol.* 35(4):1049-1057.

Kremer, R.J. and N.E. Means. 2009. Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. *Eur. J. Agron.* 31:153-161.

Krupke, C.H., G.J. Hund, B.D. Eltzer et al. 2012. Multiple routes of pesticide exposure for honey bees near agricultural fields. *PLoS ONE* 7(1):e29268. 8pp.

Krysan, J.L. 1986. Introduction: biology, distribution, and identification of pest *Diabrotica*. In: Krysan and Miller, pp. 1-23 of 260 pp.

Krysan, J.L. and T.A. Miller. 1986. *Methods for the Study of Pest Diabrotica*. Springer Verlag, New York. 260 pp.

Kuhlmann, U., S. Toepfer and F. Zhang. 2005. Is classical biological control against western corn rootworm in Europe a potential sustainable management strategy? In: Vidal et al., pp. 263-284 of 300 pp.

Kurtz, B., S. Toepfer, R.U. Ehlers et al. 2007. Assessment of establishment and persistence of entomopathogenic nematodes for biological control of the western corn rootworm. *J. Appl. Entomol.* 131(6):420-425.

Kurtz, B. I. Hiltpold, T.C.J. Turlings et al. 2009. Comparative susceptibility of larval instars and pupae of the western corn rootworm to infection by three entomopathogenic nematodes. *BioControl* 54:255-262.

Lemic, D., K.M. Mikac, A. Kozina et al. 2016. Monitoring techniques of the western corn rootworm are the precursor to effective IPM strategies. *Pest Manag. Sci.* 72:405-17.

Levine, E. and H. Oloumi-Sadeghi. 1991. Management of diabroticite rootworms in corn. *Annu. Rev. Entomol.* 36:229-55.

Levine, E. and M.E. Gray. 1994. Use of cucurbitacin vial traps to predict corn earworm larval injury in a subsequent crop of corn. *J. Entomol. Sci.* 29:590-600.

Levine, E., J.L. Spencer, S.A. Isard et al. 2002. Adaptation of the western corn rootworm to crop rotation: evolution of a new strain in response to a management practice. *Amer. Entomol.* 48(2):94-107.

Ludwick, D.C. and B.E. Hibbard. 2016. Rootworm management: status of GM traits, insecticides and potential new tools. *CAB Reviews* 11:048

Lundgren, J.G., T. Haye, S. Toepfer et al. 2009. A multifaceted hemolymph defense against predation in *Diabrotica virgifera virgifera* larvae. *Biocontrol Sci. Technol.* 19(8):871-880.

Lundgren, J.G. and J.K. Fergen. 2010a. The effects of a winter cover crop on *Diabrotica virgifera virgifera* populations and beneficial arthropod communities in non-till maize. *Environ. Entomol.* 39:1816-1828.

Lundgren, J.G., S. Toepfer, T. Haye et al. 2010b. Haemolymph defence of an invasive herbivore: its breadth of effectiveness against predators. *J. Appl. Entomol.* 134:439-448.

Lundgren, J.G. and J.K. Fergen. 2011. Enhancing predation of a subterranean insect pest: a conservation benefit of winter vegetation in agroecosystems. *Appl. Soil Ecol.* 51:9-16.

Lundgren, J.G. and J.K. Fergen. 2014. Predator community structure and trophic linkage strength to a focal prey. *Mol. Ecol.* 23:3790-3798.

Martinez, J.C. and M.A. Caprio. 2016. IPM use with the deployment of a non-high dose Bt pyramid and mitigation of resistance for western corn rootworm. *Environ. Entomol.* 45(3):747-761.

Meinke, L.J., T.W. Sappington, D.W. Onstad et al. 2009. Western corn rootworm population dynamics. *Agric. For. Entomol.* 11:29-46.

Metcalf, R.L. 1983. Implications and prognosis of resistance to insecticides. In: G.P. Georghiou and T. Saito, eds. *Pest Resistance to Pesticides*. Plenum Press, New York. pp. 703-733 of 809 pp.

Metcalf, R.L. 1986. Foreword. In: Krysan and Miller, pp. vii-xvi.

Metcalf, R.L., J.E. Ferguson, R. Lampman et al. 1987. Dry cucurbitacin containing baits for controlling diabroticite beetles. *J. Econ. Entomol.* 8:870-875.

Miller, N.J., K.S. Kim, S.T. Ratcliffe et al. 2006. Absence of genetic divergence between western corn rootworms resistant and susceptible to control by crop rotation. *J. Econ. Entomol.* 99(3):685-690.

Moeser, J. and B.E. Hibbard. 2005. A synopsis of the nutritional ecology of larvae and adults of *Diabrotica virgifera virgifera* in the new and old world—nouvelle cuisine for the invasive maize pest *Diabrotica virgifera virgifera* in Europe? In: Vidal et al., pp. 41-66 of 310 pp.

Mullin, C.A., M.C. Saunders, T.W. Leslie et al. 2005. Toxic and behavioral effects to Carabidae of seed treatments used on Cry3Bb1 and Cryh1Ab/c protected corn. *Environ. Entomol.* 34:1626-1636.

Oleson, J.D., Y.L. Park, T.M. Nowatzki et al. 2005. Node-injury scale to evaluate root injury by corn rootworms. *J. Econ. Entomol.* 98(1):1-8.

Olkowski, W. 1986. Integrated pest management for corn rootworms and cucumber beetles. *IPM Practitioner* 8(11/12):1-8.

O'Neal, M.E., M.E. Gray, K. Steffey et al. 2001. Predicting western corn rootworm larval injury to rotated corn with Pherocon® AM traps in soybeans. *J. Econ. Entomol.* 94:98-105.

O'Neal, M.E. C.D. DiFonzo and D.A. Landis. 2002. Western corn rootworm feeding on corn and soybean leaves affected by corn phenology. *Environ. Entomol.* 31:285-292.

O'Neal, M.E., D.A. Landis, J.R. Miller et al. 2004. Corn phenology influences *Diabrotica virgifera virgifera* emigration and visitation to soybean in laboratory assays. *Environ. Entomol.* 33(1):35-44.

Onstad, D.W., D.W. Crowder, S.A. Isard et al. 2003a. Does landscape diversity slow the spread of rotation-resistant western corn rootworm?. *Environ. Entomol.* 32(5):992-1001.

Onstad, D.W., D.W. Crowder, P.D. Mitchell et al. 2003b. Economics versus alleles: balancing integrated pest management and insect resistant management for rotation-resistant western corn rootworm. *J. Econ. Entomol.* 96(6):1872-1885.

O'Rourke, M.E. and L.E. Jones. 2011. Analysis of landscape scale insect pest dynamics and pesticide use: an empirical and modeling study. *Ecol. Appl.* 21(8):3199-3210.

Petzold-Maxwell, J.L., X. Cibils-Stewart, B.W. French et al. 2012. Adaptation by western corn rootworm to Bt maize: inheritance, fitness costs, and feeding preference. *J. Econ. Entomol.*

105(4):1407-1418.

Petzold-Maxwell, J.L., S.T. Jaronski, E.H. Clifton et al. 2013. Interactions among Bt maize, entomopathogens, and rootworm species in the field: effects on survival, yield, and root injury. *J. Econ. Entomol.* 106(2): 622-632.

Pierce, C.M.F. and M.E. Gray. 2006. Western corn rootworm, *Diabrotica virgifera virgifera* oviposition: a variant's response to maize phenology. *J. Econ. Entomol.* 35(2):423-434.

Pilz, C., R. Wegensteiner and S. Keller. 2008. Natural occurrence of insect pathogenic fungi and parasitic nematodes in *Diabrotica virgifera virgifera* populations. *BioControl* 53:353-359.

Pilz, C., S. Keller, U. Kuhlmann et al. 2009. Comparative efficacy assessment of fungi, nematodes and insecticides to control western corn rootworm larvae in maize. *BioControl* 54: 671-684.

Pilz, C., J. Enkerli, R. Wegensteiner et al. 2011. Establishment and persistence of the entomopathogenic fungus *Metarhizium anisopliae* in maize fields. *J. Appl. Entomol.* 135:393-403.

Prischmann-Voldseth, D.A. and K.E. Dashiell. 2013. Effects of releasing a generalist predator (Acari: *Gaeolaelaps aculeifer*) on a subterranean insect herbivore (Coleoptera: *Diabrotica virgifera virgifera*). *Biol. Control* 65:190-199.

Pruess, K.P. J.F. Witkowski and E.S. Raun. 1974. Population suppression of western corn rootworms by adult control with ULV malathion. *J. Econ. Entomol.* 67:651-655.

Quarles, W. 2012. Brave new world—systemic pesticides and genetically engineered crops. *IPM Practitioner* 33(3/4):1-9.

Quarles. W. 2014a. What are you eating? Labeling genetically engineered food (GMOs). *IPM Practitioner* 35(5/6):1-9.

Quarles, W. 2014b. Neonicotinoids, bees, birds, and beneficial insects. *Common Sense Pest Control Quarterly* 28(1-4):3-10.

Quarles, W. 2016a. Genetic engineering and pest control. *IPM Practitioner* 35(3/4):1-9.

Quarles, W. 2016b. Glyphosate toxicity—smoke or fire? *IPM Practitioner* 35(5/6):1-7.

Rasmann, S., T.G. Kollner, J. Degenhardt et al. 2005. Recruitment of entomopathogenic nematodes by insect damaged maize roots. *Nature* 434:732-737.

Riedell, W.E., T.M. Schumacher and P.D. Evenson. 1996. Nitrogen fertilizer management to improve crop tolerance to corn rootworm larval feeding damage. *Agron. J.* 88:27-32.

Rondon, S.I. and M.E. Gray. 2003. Captures of western corn rootworm adults with Pherocon® AM and vial traps in four crops in East Central Illinois. *J. Econ. Entomol.* 96(3):737-747.

Rudeen, M.L., S.T. Jaronski, J.L. Petzold-Maxwell et al. 2013. Entomopathogenic fungi in cornfields and their potential to manage larval western corn rootworm *Diabrotica virgifera virgifera*. *J. Invert. Pathol.* 114:329-332.

Santos, F., M.F.G.V. Penaflor, P.W. Pare et al. 2014. A novel interaction between rhizobacteria and roots: colonization induces corn resistance against the root herbivore *Diabrotica speciosa*. *PLoS ONE* 9(11):e113280.

Schroeder, J.B., S.T. Ratcliffe and M.E. Gray. 2005. Effect of four cropping systems on variant western corn rootworm adult and egg densities and subsequent larval damage in rotated maize. *J. Econ. Entomol.* 98(5):1587-1593.

Schumann, M. and S. Vidal. 2012. Dispersal and spatial distribution of western corn rootworm larvae in relation to root phenology. *Agric. Forest Entomol.* 14:331-339.

Schumann, M., A. Patel and S. Vidal. 2013. Evaluation of an attract and kill strategy for western corn rootworm larvae. *Appl. Soil Ecol.* 64:178-189.

Schumann, M., S. Toepfer, M. Vemmer et al. 2014. Field evaluation of an attract and kill strategy against western corn rootworm larvae. *J. Pest Sci.* 87:259-271.

Shaw, J.T., W.G. Ruesink, S.P. Briggs et al. 1984. Monitoring populations of corn rootworm beetles with a trap baited with cucurbitacins. *J. Econ. Entomol.* 77:1495-1499.

Spencer, J.L., E. Levine, S.A. Isard et al. 2005. Movement, dispersal, and behaviour of corn rootworm adults in rotated maize and soybean fields. In: Vidal et al., pp. 121-144.

Spencer, J.L., B.E. Hibbard, J. Moeser et al. 2009. Behaviour and ecology of the western corn rootworm (*Diabrotica virgifera virgifera* LeConte). *Agric. Forest Entomol.* 11:9-27.

Steffey, K.L. and J.J. Tollefson. 1982. Spatial dispersion patterns of northern and western corn rootworms in Iowa cornfields. *Environ. Entomol.* 11:283-286.

Steffey, K.L., J.J. Tollefson, and P.N. Hinz. 1982. Sampling plan for population estimation of northern and western corn rootworm adults in Iowa cornfields. *Environ. Entomol.* 11:287-291.

Tabashnik, B.E. and F. Gould. 2012. Delaying corn rootworm resistance to Bt corn. *J. Econ. Entomol.* 105(3):767-776.

Tallamy, D.W., B.E. Hibbard, T.L. Clark et al. 2005. Western corn rootworm, cucurbits and cucurbitacins. In: Vidal et al., pp. 67-94 of 300 pp.

Toepfer, S. and U. Kuhlmann. 2005. Natural mortality factors acting on western corn rootworm populations: a comparison between the United States and Europe. In: Vidal et al., pp. 95-120 of 300 pp.

Toepfer, S., A. Peters, R.U. Ehlers et al. 2008. Comparative assessment of the efficacy of entomopathogenic nematode species at reducing western corn rootworm larvae and root damage in maize. *J. Appl. Entomol.* 132:337-348.

Toepfer, S., R. Burger, R.U. Ehlers, et al. 2010. Controlling western corn rootworm larvae with entomopathogenic nematodes: effect of application techniques on plant-scale efficiency. *J. Appl. Entomol.* 134:467-480.

Tollefson, J.J. 1986. Field sampling of adult populations. In: Krysan and Miller, pp. 123-146 of 259 pp.

Vemmer, M., M. Schumann, W. Beitzen-Heineke et al. 2016. Development of a CO_2 releasing coformulation based on starch, *Saccharomyces cerevisiae* and *Beauveria bassiana* attractive towards western corn rootworm larvae. *Pest Manag. Sci.* 72:2136-2145.

Vidal, S., U. Kuhlmann and C.R. Edwards. 2005. *Western Corn Rootworm: Ecology and Management.* CABI, Wallingford, Oxfordshire. 310 pp.

Wang, H., B.S. Coates, H. Chen et al. 2013. Role of a gamma-aminobutryic acid (GABA) receptor mutation in the evolution and spread of *Diabrotica virgifera virgifera* resistance to cyclodiene insecticides. *Insect Mol. Biol.* 22(5):473-484.

Wright, R.J., J.F. Witkowski, G. Echtenkamp et al. 1993. Efficacy and persistence of *Steinernema carpocapsae* applied through a center pivot irrigation system against larval corn rootworms. *J. Econ. Entomol.* 86(5):1348-1354.

Zhang, F., S. Toepfer, K. Riley et al. 2004. Reproductive biology of *Celatoria compressa*, a parasitoid of *Diabrotica virgifera virgifera*. *Biocontrol Sci. Technol.* 14(1):5-16.

Conference Notes

Special ESA Pheromone Report

By Joel Grossman

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

Pheromones and Biocontrol Reduce Pesticides

Soybean pod borer, *Leguminivora glycinivorella*, a Tortricidae moth and a major pest of soybeans "is mainly controlled with chemicals in China," said Kuijun Zhao (Northeast Agric Univ, 59 Mucai St, Xiangfang, Harbin 150030, China; kjzhao@163.com). The sex pheromone has become an important monitoring and prevention tool, but pheromone attract-and-kill alone does not reduce soybean pod borers below economic levels.

An IPM approach combines soybean pod borer pheromone monitoring and attract-and-kill with biocontrol by *Trichogramma*. *Trichogramma* egg parasitoids are released five days before peak pod borer flights. This IPM approach reduced chemical use by 25%.

Pheromone-Based IPM in China

Pheromones are a very hot topic in China today, and "many farmers are being trained in pheromone use," said Yinzhong Cui (Pherobio Technol Co Ltd, Bldg 59A, 17 Huanke Mid Rd, Jinqiao Sci Technol Ind Zone, Tongzhou Distr, Beijing, China 101102; sino@aliyun.com). China is using pheromone or kairomone lures for surveillance and mass trapping of over 170 pest species, covering at least 4 million hectares (10 million acres) of crop fields, and mating disruption dispensers are being field tested.

China's large import and export industries result in constant insect outbreaks with big losses along with food safety and environmental problems, leading the government to support increased pheromone use 10 years ago. Initially government and farmers were skeptical of pheromones, wondering about their safety and efficacy. China started its pheromone research in 1966; but a big slowdown occurred during the Cultural Revolution, and pheromone research did not pickup again until 2000.

Pheromones are used to manage longhorn beetles. Longhorn beetles attack tea, cherries, vegetables and other crops. The IPM approach combines pheromone monitoring with mass trapping and mating disruption, reducing crop damage from 30% to 5-8%. Pherobio® pheromone traps with 8 holes caught 400% more tea longhorn beetles than traps with 16 holes. Helicopters delivered encapsulated pheromones.

In 2013-2015, attract-and-kill, mating disruption and botanicals reduced crop field sprays from 8 to 1-2. In a mass trapping study with pheromone monitoring and Pherobio® traps, fruit pest populations fell 80% in 2 years. The 4.5% fruit damage with pheromone-based IPM was similar to that with conventional spray programs; but pesticide spraying was 600% less with no yield difference. Plus farmers commanded 30% higher prices for pheromone-based IPM crops, compared to conventional pesticide crops. China currently has 15 small pheromone companies. Government policy is a 30% reduction in pesticide use by 2020.

Codling Moth Pheromone and Pear Psylla Biocontrol

"Most pear pest management programs rely on multiple, targeted insecticide sprays for pear psylla, *Cacopsylla pyricola*, and other pests including codling moth, *Cydia pomonella*," said Kaushalya Amarasekare (Tennessee State Univ, 3500 John A. Merritt Blvd, Nashville, TN 37209; kaushalya2641@yahoo.com). Codling moth management by pheromone mating disruption slows down the development of insecticide resistance, spares beneficial insects, and improves biological control of pear psylla.

Effects of pesticides can be monitored and evaluated by traps baited with herbivore-induced plant volatiles (HIPV) that attract natural enemies. "These traps are useful for measuring presence and abundance of adult natural enemies that fly away when being sampled with beat-trays."

In the USA Pacific Northwest, codling moth lacks efficient natural enemies on Bartlett pears. However, "pear psylla has many natural enemies including generalist predators such as *Deraeocoris brevis* (a true bug), spiders, *Orius* sp. (pirate bug), Coccinellids (lady beetles) and a specialist parasitoid, *Trechnites insidiosus*, although overwintering, spring and summer psylla are mainly controlled by insecticides," said Amarasekare. "Our results show that codling moth mating disruption can positively influence the abundance of natural enemies in pear orchards. This in turn reduces the amount of insecticides needed to control pear psylla."

"The pear orchard we used for this study was under a codling moth mating disruption program for more than eight years," said Amarasekare. As a result, fewer insecticide applications were needed, protecting natural enemies and minimizing pear psylla outbreaks. Mating disruption codling moth management helped to build up large populations of spiders throughout the orchard. Spiders were the most dominant natural enemy detected irrespective of the method of monitoring used. "We detected negligible abundance of pear psylla throughout the study."

Lower Cost Pine Beetle Lures

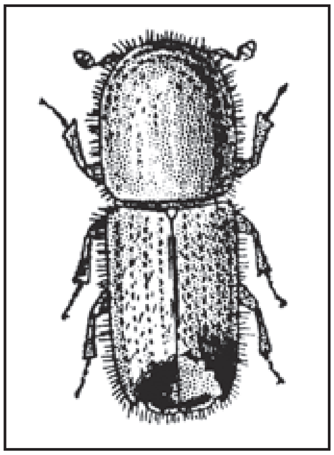
"California five-spined engraver, *Ips paraconfusus*, a Curculionidae beetle attacking many pine tree species, is expanding its range in drought-stressed Washington and Oregon ponderosa pine forests," said Todd Murray (Washington State Univ, POB 369, Stevenson, WA 98648; tmurray@wsu.edu). This rare, long-lasting outbreak became an opportunity to use pheromone-baited Lindgren funnel traps to field test aggregation lure formulations. The goal being to create "a more effective and affordable aggregation lure."

Basically, pure (+)-ipsdienol, an expensive major active aggregation lure component, was compared to a "more biologically relevant" and cheaper to produce "crude, impure ipsdienol" from Synergy Semiochemicals Corp. Standard lures, which contain pure ipsdienol, cis-verbenol and ipsenol, were tested with and without myrtenol. Crude ipsdienol lures, which contain impure ipsdienol, cis-verbenol and ipsenol were tested with and without myrtenol. Traps were placed in the field from early July to mid-August in 2014 and 2015.

Traps captured 45,936 *I. paraconfusus* in 2014 and 7,122 in 2015. "In both years, the peak flight was captured early in the study," and "trap captures were almost completely comprised of *I. paraconfusus*," said Murray. Beetles strongly preferred the impure lure over the standard lure. In 2014, the addition of myrtenol to the standard lure enhanced trap catch, but attraction was still less than the crude lure. In 2015, the addition of myrtenol to the crude lure reduced efficacy, but the crude lure still outperformed the standard one.

Pheromones for Stink Bugs in California

"Brown marmorated stink bug (BMSB), *Halyomorpha halys*, originated in East Asia and has been spread to over 43 states in continental United States including California," where "a significantly large BMSB population was discovered in Midtown Sacramento in early September 2013," said Jhalendra Rijal (Univ California, 3800 Cornucopia Way, Ste A, Modesto, CA 95358; jrijal@ucdavis.edu). BMSB, found in 28 California counties, is established in Butte, Yolo, Los Angeles, Sutter, Sacramento, San Joaquin, Santa Clara, Siskiyou and Stanislaus.



An *Ips* sp. engraver beetle

Since BMSB detections near California's Highway 99 and in a Modesto commercial peach orchard, 9 commercial peach orchards in Stanislaus and Merced Counties were monitored using beat trays, visual samplings and standard 4-foot (1.2-m) tall black pyramid traps baited with aggregation pheromone plus methyl decatrienoate (Trécé, Adair, OK). In 2016, pyramid traps with lures captured 3 BMSB in one peach orchard. In contrast, neither beat trays nor visual sampling captured BMSB. At the original Modesto detection location, pyramid traps with lures caught 21 adults and 4 nymphs per night in September, indicating BMSB populations are increasing.

Pheromones for Stink Bugs in Cotton

In outbreak years such as 2013, "damage to cotton from brown stink bug, *Euschistus servus*, resulted in a 25-30% yield reduction which required repeated pesticide applications," which are costly and "increase the possibility of secondary pest outbreaks," said Vonny Barlow (Univ California, 290 N. Broadway, Blythe, CA 92225; vmbarlow@ucanr.edu). Southern California cotton, typically sprayed 3-4 times, was sprayed 11 times for *E. servus* and sweetpotato whitefly, *Bemisia tabaci* Biotype B, in 2013.

Pheromone traps are more efficient than sweep nets for monitoring *E. servus* in commercial cotton fields. Four-vane yellow or brown corrugated plastic pyramid traps topped with aluminum wire screen funnels utilized *E. servus* aggregation pheromone, methyl-(2*E*-4*Z*)-decadienoate, to monitor commercial cotton fields adjacent to alfalfa. Though not consistent vectors of cotton boll rot bacteria, brown stink bugs migrate into cotton within 24 hours of harvest or senescence of nearby broadleaf weeds, legumes, snap beans, soybean, sorghum, corn, okra and millet. But "pheromone trapping revealed that there did not appear to be a significant aggregation of *E. servus* along cotton field perimeters," said Barlow.

Turf Billbug Pheromones

"Billbug damage is arguably the most misdiagnosed insect-related turfgrass disorder in North America," said Alexandra Duffy (Purdue Univ, 901 West State St, West Lafayette, IN 47907; duffy14@purdue.edu). Bluegrass billbug, *Sphenophorus parvulus*, and hunting billbug, *S. venatus*, are the most widespread and economically important billbug species. Males of these Curculionidae beetles respond to host-plant volatiles from Bermudagrass, *Cynodon dactylon* var. Patriot.

"Females are likely cueing into a male-produced pheromone," perhaps much like the male-produced aggregation pheromone of the closely related sugar cane weevil, *Sphenophorus levis*, said Duffy. Cuticular extracts showed qualitative chemical differences between *S. parvulus* and *S. venatus* females, indicating the possibility that cuticular hydrocarbons could play a role in mate recognition between these closely related sympatric species. Identification of the specific compounds is in progress. Duffy envisions turf IPM programs using pheromones for monitoring lures and billbug mating disruption.

Female Pheromone Autodetection

The female-produced sex pheromone of oriental beetle, *Anomala orientalis*, is a 9:1 blend of (*Z*)- and (*E*)-7-tetradecen-2-one. "The pheromone may impede mating disruption by attracting both males and females," said Robert Holdcraft (Rutgers, 125A Lake Oswego Rd, Chatsworth, NJ 08019; rholdcra@rci.rutgers.edu).

"Multiple studies have evaluated the efficacy of mating disruption for this pest on several blueberry farms in southern New Jersey, using both point-source dispensers and SPLAT™ dollops containing the major pheromone component," said Holdcraft. In all of these studies traps baited with (*Z*)-7-tetradecen-2-one were used to monitor male beetle numbers. In one early study female beetles were observed flying upwind toward dispensers, apparently attracted to the pheromone in a manner similar to males. These unexpected observations suggested that female oriental beetles might possibly have the ability to detect their own pheromone, a phenomenon called Female Pheromone Autodetection.

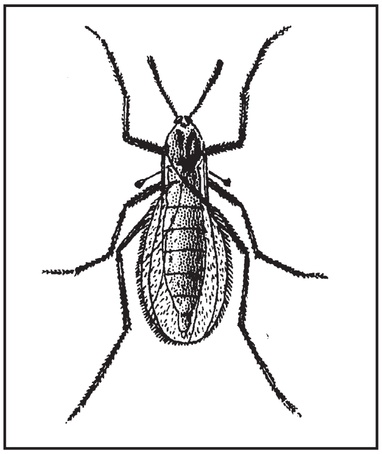
Female arrivals at synthetic pheromone sources may negate some effects of mating disruption, as males attracted to the pheromone are able to find mates. Autodetection may have evolved as a "method for less attractive females to exploit the attractiveness of other females," said Holdcraft. "This behavior has been exhibited by some scarab (beetle) species."

Hessian Fly Pheromone for IPM

Hessian fly, *Mayetiola destructor*, is a key pest of hard-red winter wheat in the USA Southern Great Plains, and no remedial actions can prevent economic loss once a field is infested. As larvae develop behind the leaf sheath, infestations often go undetected until crop damage is evident.

A recently discovered sex pheromone can be useful in baited traps for detection and monitoring, said Allen Knutson (Texas A&M Univ, 17360 Coit Rd, Dallas, TX 75252; a-knutson@tamu.edu).

Pheromone trap (Trécé Inc.) monitoring was tested for three growing seasons in 50 fields at 6 locations along a transect beginning in northcentral Oklahoma, latitude 36°N and ending in southcentral Texas, latitude 31°N. A single pheromone trap was monitored in each field from shortly after fall planting in late September until spring crop maturation (April-June).



Hessian fly, *Mayetiola destructor*

"Results indicate the pheromone is highly attractive and therefore could be useful in quarantine and surveillance programs," said Knutson. Trap captures in the fall or in January and February (southern sites) could alert growers to the risk of damage, and based upon subsequent sampling for larvae, could inform decisions to limit fertilizer, irrigation, fungicides in the spring.

Green Lighting Hessian Fly Pheromones

Hessian fly, the world's number one wheat pest, causes yield- and growth-reducing lodging of wheat plants during outbreak years, though resistant varieties and fly-free planting dates can reduce damage, said Ryan Schmid (Kansas State Univ, 201 Waters Annex, Manhattan, KS 66506; rbschmid@k-state.edu). In 2009, a synthetic Hessian fly pheromone was produced for monitoring, to provide the "when and where" for IPM programs. Traps with female sex pheromone provided good data on male Hessian flies, but lacked consistent correlation with wheat field damage. Adding very high-intensity (16 W/m2), medium green (525 nm) light-emitting diodes (LEDs) can improve monitoring and early detection by attracting female flies.

The existing monitoring strategy of monitoring males with Hessian fly female sex-pheromone is effective, but "monitoring of female Hessian flies is the key to detecting new invasions and incorporating trap captures into management decisions," said Schmid. Hence, the focus on moving green LED pheromone traps from the lab to wheat fields.

Bright Sunlight Dilutes LEDs

Bright sunlight in wheat fields effectively dilutes very bright green LEDs. Thus, another study is comparing green LEDs switched on at night versus daylight hours, as female Hessian flies are nocturnal, flying mostly from 3 a.m. to 6 a.m. in Kansas wheat.

In the 2016/2017 season beginning in October, green LEDs are being compared to white LEDs (control) and blanks in naturally infested Kansas wheat fields. In 7 weeks in heavily infested Kansas fields, white sticky cards and green LEDs provided statistically similar assessments of Hessian fly populations. But green LEDs also attracted many aphids. "The results suggest the potential for incorporation of LEDs into existing Hessian fly female sex pheromone traps to increase trap capture, and ultimately improve monitoring effectiveness," said Schmid.

Comstock Mealybug Sex Pheromone

Comstock mealybug, *Pseudococcus comstocki*, injures pear and many fruit species directly and via sooty mold, and "is difficult to completely control with chemical control because they are settled down at pod part of the branches or not completely exposed to insecticide," said Min Gyu Cho (Chungnam Natl Univ, Daejeon 305-764, South Korea; inception12@nate.com). "Trapping experiments indicate that pheromone-baited traps will be an excellent tool to improve the insect pest management programs in pear yard."

Argentine Ant Pheromones

"Many of the key behaviors and biological processes that underlie the success of Argentine ants, *Linepithema humile*, are regulated by sophisticated chemical signaling," said Neil Tsutsui (Univ California, 137 Mulford Hall, Berkeley, CA 94720; ntsutsui@berkeley.edu). Hydrocarbons such as straight-chain alkanes allow Argentine ants to determine if other ants are not of the colony; and should therefore be attacked or responded to with aggression. Argentine ants also have a trail pheromone with two major components, iridomyrmecin and (*Z*)-9-hexadecenal, which attract foragers. Trail pheromones are being tested to enhance baits in IPM programs.

Peach Bark Beetle Pheromone

Peach bark beetle (PBB), *Phloeotribus liminaris*, a North America native difficult to control because its lifespan is mostly under the bark, attacks black cherry, *Prunus serotina*, a hardwood highly valued for cabinet and furniture veneers, said Matthew Ethington (Purdue Univ, 901 West State St, West Lafayette, IN 47907; methingt@purdue.edu). "In response to attack, black cherry trees produce a defensive compound (gum) which can envelope or push out colonizing beetles." However, "gummosis leads to gum spots in the wood, making it unsuitable for veneer, and decreasing its value up to 90%."

"PBB are attracted to female-infested black cherry, suggesting that females produce a pheromone," said Ethington. Pheromone production peaks at eight days after initial colonization. Peach bark beetle adults are also attracted to a black cherry volatile, benzaldehyde. Lindgren or other trap types can be baited with pheromone or/and benzaldehyde to detect, monitor and manage peach bark beetles in IPM programs.

Gypsy Moth Pheromone Survey

"Synthetic pheromone has been used for monitoring gypsy moth, *Lymantria dispar*, populations for nearly 40 years," said Chelsea Jahant-Miller (State Univ New York, 1 Forestry Dr, Syracuse, NY 13210; cjjahant@syr.edu). Counts of trapped males are used in detection surveys along the leading edge of the invasion front, in eradication operations, as well as for assessing the efficacy of suppression efforts in established areas. In gypsy moth, the adults are non-feeding and thus the morphology of trapped males reflects the environment that they experience as larvae.

The survey forest had not had a gypsy moth outbreak in 20 years, and gypsy moth populations were very low. Each sampling site had a universal Multi-Pher trap baited with commercial disparlure, and was placed 2 m (6.6 ft) above ground and 100 m (328 ft) or more into the forest interior.

Host quality and population size both influenced male moth size. Red oak was a better quality host than maple. But early-season male wing length varied in only one of two survey years. "Male gypsy moth wing length is strongly correlated with pupal mass," said Jahant-Miller. However, "there is a pronounced decline in the size of trapped males through the season even in low density populations."

Calendar

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

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

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

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

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

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

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

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

January 19-21, 2018. NOFA Winter Organic Farming and Gardening Conf. Contact: NOFA, 585/271-1979; www.nofany.org

January 24-27, 2018. 38th Annual EcoFarm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

January 29-February 1, 2018. Annual Meeting Weed Science Society of America. Arlington, VA. Contact: www.wssa.net

February 2018. Annual Conference, Association Applied Insect Ecologists, PO Box 1119, Coarsegold, CA 93614. Contact: 559/761-1064; www.aaie.net

February 22-24, 2018. 29th Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

March 2018. California Small Farm Conference. Contact: www.californiafarmconference.com

March 19-22, 2018. 9th International IPM Symposium. Renaissance Baltimore Harborplace Hotel. Baltimore, MD. Contact: Michelle Marquat, 217-244-8174; mmarqua2@illinois.edu

KEEP OUT OF THE REACH OF CHILDREN
CAUTION

CLIMBUP®
INSECT INTERCEPTOR

DETECTS BED BUGS

- people are the best bed bug bait...use under furniture legs where people are sleeping
- early, reliable detection of bed bugs
- all stages are clearly visible against the white surface
- talc-coated interior makes surface too slick to climb out...it is not acting as a pesticide
- easy to clean and easy to retalc
- bed bugs are attracted to the fibrous exterior surface to climb up
- tells if bed bugs are going to or coming from furniture
- aids in protecting furniture from reinfestation
- Furniture slides easily to reinspect and retreat
- can be reused for months
- made in USA
- patent pending

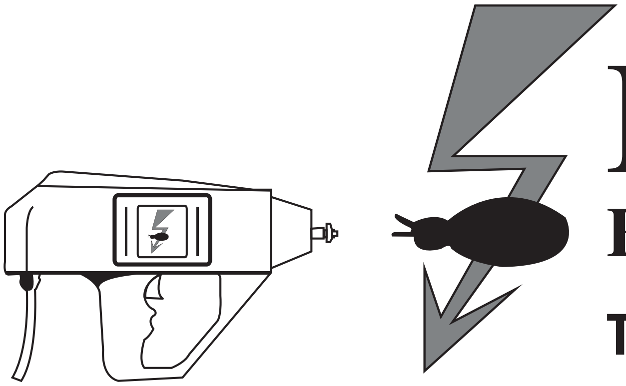
Manufactured by: **Susan McKnight, Inc.**
P.O. Box 11406 Memphis, TN 38111
www.insect-interceptor.com • susan@insect-interceptor.com
901-848-3831

"Pest Controls *Mother Nature* Would Use"
NATURE'S CONTROL

Specializing in Beneficial Insects and Organic Pest Controls for Over 20 Years!

- Ladybugs, Spider Mite Predators, Nematodes, Lacewings, and many more "Hired Bugs".
- Mighty Myco Mycorrhizae.
- Magnifiers, Yellow & Blue Traps.
- Quantity Discounts.
- Orders Arrive in 1-2 Days.
- Live Delivery Guaranteed!
- Friendly, Knowledgable Staff.
- Check our website for the distributor nearest you, or call for your free "Hired Bugs" brochure.

NATURE'S CONTROL
PHONE: (541) 245-6033
FAX: (800) 698-6250
P.O. BOX 35
MEDFORD, OR 97501
www.naturescontrol.com



ETEX®
ELECTRO-GUN®
Termite Treatment System

Your customers are asking for it by name!
Don't delay! Call for your 1st full year discount!

Etex Ltd.
(800) 543-5651
www.etex-ltd.com | salespcoc@etex-ltd.com
Established February 1979
Leased to Licensed Pest Management Companies

MADE IN USA

CA DPR REG #55850-50001-AA

The Ultimate in
Biological Pest Control

Guardian Nematodes™

Lawn Patrol™

(*Steinernema* spp. & *Heterorhabditis* spp. beneficial nematodes)

Application rate: 1 million per 2,000/3,000 sq.ft. of greenhouse
24 million per acre

Pests: Controls over 250 root zone pests including:

* Cutworms	* Fungus gnats	* Corn rootworm
* Black vine weevils	* White grubs	* Thrips
* Sod webworms	* Strawberry root weevil	* Japanese beetle grubs

Other beneficial items: Encarsia formosa, Phytoseiulus persimilis, Mesoseiulus longipes, Neoseiulus californicus, Aphidoletes aphidimyza, Aphidius, Amblyseius cucumeris, Chrysopa carnea (lacewings), Hippodamia convergens (ladybugs), Nosema locustae (Nolo Bait), Orius, Mealybug predators, etc. Sticky ribbons, Sticky cards, Insect Screens and much more!

Call TOLL-FREE 1-800-634-6362
for a FREE Catalog

HYDRO-GARDENS, INC.
Your Total Greenhouse Supplier!
http://www.hydro-gardens.com
email: hgi@hydro-gardens.com

8765 Vollmer Road, Colorado Springs, CO 80908 * FAX 719-495-2266

BioQuip
PRODUCTS

Serving entomology for 69 years
1947 - 2016

BioQuip provides a wide selection of equipment for IPM practitioners including traps, protective clothing, magnifiers & microscopes, forceps, cages, nets, and books, plus live and preserved arthropods. We also provide thousands of other products and books for entomology and related sciences.

Visit our web sites to view products, books, arthropods, and monthly specials.
www.bioquip.com
www.bioquipbugs.com

BioQuip Products
2321 Gladwick St.
Rancho Dominguez, CA 90220
Ph: (310) 667-8800
Fax: (310) 667-8808
Email: bqinfo@bioquip.com

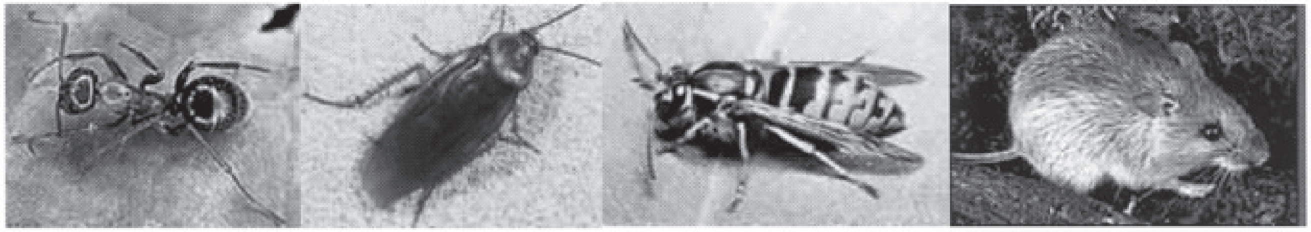
PESTEC

Specialists in Structural IPM

• Consulting

• Exclusion • Sanitation • Steam • Vacuuming • Baits

Call us at 925/757-2945; www.ipmprovider.com



Bio-Integral Resource Center
B • I • R • C
P.O. Box 7414, Berkeley, California 94707

ADDRESS SERVICE REQUESTED

NON-PROFIT ORG.
U.S. POSTAGE
PAID
Berkeley, CA
Permit #442

Please renew your membership and help support BIRC. THANK YOU!

COMMUNITY PRINTERS

Classified Ads

Products	**Products**

Beneficial Nematode Products for:
Lawn & Garden Insects
Greenhouses & Horticultural Insects
Termites, German Roaches
Turf Insects
Bulk Nematodes Available

BioLogic
For full information see
www.biologicco.com

PO Box 177
Willow Hill, PA 17271
Tel. 717-349-2789

RINCON-VITOVA
INSECTARIES, INC.
Biological Solutions Since 1950

Aphid Control *Mealybug Control* *Fly Control*

800-248-BUGS - 805-643-5407 - Ventura, CA - **rinconvitova.com**

Canadian Producer of Nematodes

NIC®
NATURAL INSECT
C•O•N•T•R•O•L

BENEFICIAL NEMATODES
Canadian and "Organic"

BENEFICIAL INSECTS
Distributor for Applied Bionomics
Largest Variety Available

Monitoring Tools and Traps

3737 Netherby Road, Stevensville, ON, L0S 1S0
905-382-2904; 905-382-4418(fax)
nic@niagara.com

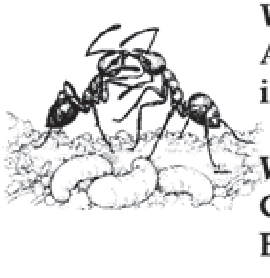
www.naturalinsectcontrol.com

FRESH BENEFICIALS GUARANTEED
Shipping from the Northeastern United States

- Beneficial Insects
- Beneficial Mites
- Beneficial Nematodes

Controlling plant pests & manure pests

IPM Laboratories Inc
ipminfo@ipmlabs.com
315.497.2063
FREE CONSULTATION
www.ipmlabs.com



Want to Order a Back Issue?
A BIRC Publications Catalog
is Online at www.birc.org

Want to Advertise?
Call 510/524-2567 or
Email birc@igc.org

Garlic Barrier
Aphids, Spider Mites, and Earwigs
are quickly controlled by OMRI listed
Garlic Barrier.

See our website:
www.garlicbarrier.com

CLASSIFIED AD RATES—1x rate: $1 per word. 2x-3x: 80¢ per word. 4x or more: 80¢ per word. Write ad, calculate the cost. **BUSINESS CARD AD RATES** (2 x 3.5")—1x rate: $55. 2x-3x: $45 each time. 4x or more $40 each time. Business card ads must be camera-ready; or BIRC will typeset your ad for $40. **ALL ADS MUST BE PREPAID**. Send ads and payment to ***IPMP* Classified Ads**, PO Box 7414, Berkeley, CA 94707. Ads must be received five weeks prior to date of issue in which it is to appear. We reserve the right to refuse materials we feel are inappropriate.