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Genetic Engineering and Pest Control

By William Quarles


Photo courtesy of CDC and James Gathany

Aedes aegypti **mosquitoes, like the one shown here, carry Zika virus and other pathogens. Genetic engineering techniques may be able to eliminate the mosquito, but there are ecological risks.**

About 20 years ago, genetic engineering (GE) techniques were commercially applied to pest control (Fernandez-Cornejo et al. 2014; Quarles 2014a). Transformed insecticidal crops containing genes of *Bacillus thuringiensis* (BT) were released in the U.S. in 1995. These were followed in 1996 by plants that were tolerant to the herbicide glyphosate (Roundup Ready®). Glyphosate resistant crops have changed traditional farming methods. Seeds are drilled into the soil without cultivation. When weeds appear, entire fields are aerially sprayed with glyphosate (Fernandez-Cornejo et al. 2014; Duke and Powles 2009).

There have been unexpected impacts on ecology and the environment from GE crops. Milkweed habitat of the monarch butterfly, *Danaus plexippus*, in the Midwest has been destroyed by glyphosate. The monarch depends on milkweed, and there has been an 81% reduction in Midwest monarch populations (Hartzler 2010; Pleasants and Oberhauser 2012).

Huge Glyphosate Increase

Due to a huge increase in glyphosate, GE crops overall have led to a large increase in pesticide use. About 3 million pounds (1.36 million kg) of glyphosate were applied in 1994, and 280 million pounds (127.3 million kg) were applied in 2013 (Benbrook 2009; USGS 2015). Repeated applications have contaminated soil and water and have probably reduced amphibian populations (Battaglin et al. 2005; Quarles 2015; Wagner et al. 2013; Relyea 2011). Many studies show that buildup of glyphosate in the soil leads to increased soil pathogens such as Fusarium (Johal and Huber 2009; Kremer and Means 2009; Zobiole et al. 2011). As a result of glyphosate saturation, several important weed species have developed resistance (Duke and Powles 2009; Fernandez-Cornejo et al. 2014).

BT Crops

BT crops have also caused problems. BT proteins target specific insects such as European corn borer, *Ostrinia nubilalis*; pink bollworm, *Pectinophora gossypiella* and others. Since insecticidal effects are so specific, BT crops tend to encourage development of secondary pests that are not affected by the pesticide (Tabashnik et al. 2013).

Because pests are constantly exposed, several insect species are now resistant. Insect resistance and invasion of secondary pests have led to treatment of crops with neonicotinoid insecticides that can have toxic effects on bees, birds, and beneficial insects (Goulson 2013; Tabashnik et al. 2013; Quarles 2014b; Hopwood et al. 2012). We are chronically exposed to systemic neonicotinoids, BT insecticide, and glyphosate in GE food (Quarles 2012; FOEE 2013; Arregui et al. 2004; Bohn et al. 2014; Kruger et al. 2014; USDA 2011; Koch et al. 2015).

In This Issue

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.

Update

Transgenes Escape

Transgenes from GE crops escape into the environment. A recent study showed that 27% of feral roadside alfalfa stands in Washington, Oregon, and California contained transgenic alfalfa plants. Bee pollination then allows contamination of conventional crops with the transgene. This gene flow puts the crops of organic farmers in danger of contamination (Greene et al. 2015).

A major problem with GE crops has been consumer resistance. About 90% of people in the U.S. believe that genetically engineered foods should be labeled. Generally, U.S. food corporations have resisted labeling. But the situation may be changing. In January 2016, Campbell Soup announced that it would label its GE products (Quarles 2014a; Campbell Soup 2016).

Despite the unexpected problems with modified plants, the evolving technology has now led to transgenic insects engineered for pest control. Release of these organisms represents a dramatic escalation of potential risks. Organisms transformed so far include mosquitos, flies, and pest moths (Alphey et al. 2007; Alphey 2014; Liu et al. 2014; Harvey-Samuel et al. 2015). This article reviews the successes and failures of the work so far, and the implications of future releases.

Commercial Success

Though they have caused negative environmental impacts, GE crops have been a commercial success in the U.S. In 2013 transgenic pest resistant plants were available for corn, cotton, tomatoes, soybeans, canola, potato, sugarbeet, papaya, rice, squash, alfalfa, plum, rose, tobacco, flax, and chicory. Seeds for herbicide tolerant soybeans, corn, cotton, canola, sugar beets, and alfalfa were commercially available. Insect resistant corn and cotton, and virus resistant squash and papaya were available to consumers in 2013 (Fernandez-Cornejo et al. 2014).

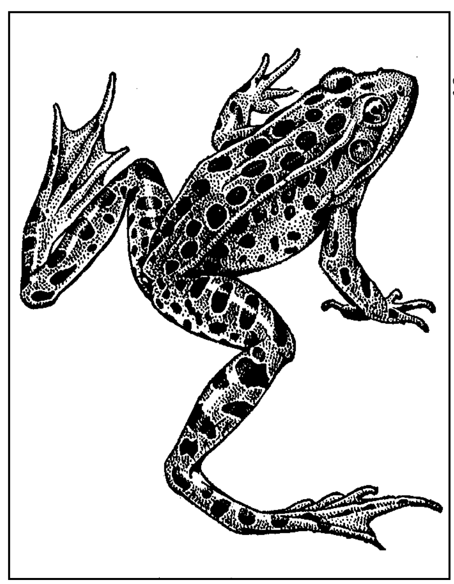
The most successful crops have been transgenic corn, cotton, and soybeans. About 169 million acres

Photo courtesy Glenda Denniston

Milkweed habitat of the monarch butterfly is being destroyed.

(68.4 million ha) in the U.S. were planted to these crops in 2013. Herbicide tolerant soybeans are now 93% of soybeans planted in the U.S. About 85% of U.S. corn acreage is now covered by herbicide tolerant corn. About 82% of U.S. cotton is transgenically tolerant to herbicides. About 76% of U.S. corn, and 75% of the cotton is BT transgenic. Altogether, 90% of cotton, 93% of soybeans, and 90% of U.S. corn is now engineered to help with pest control (Fernandez-Cornejo et al. 2014). About 95% of U.S. sugarbeets, 97.5% of canola, and an increasing amount of alfalfa is transgenic (Owen et al. 2014).

These crops have been successful not because they improve yields, but because they are easier to grow



Drawing from Stebbins 1954

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

and often produce larger profits. But GE crops are not a good agronomic practice, as vast monocultures of one variety puts entire crops at risk from diseases such as Goss's Wilt caused by *Clavibacter* sp. and soybean rust caused by *Phakopsora pachyrhizi.* And pest resistance can eventually make a GE crop useless (Fernandez-Cornejo et al. 2014; Gray 2011; Mortensen et al. 2012).

Genetic Engineering of Crops

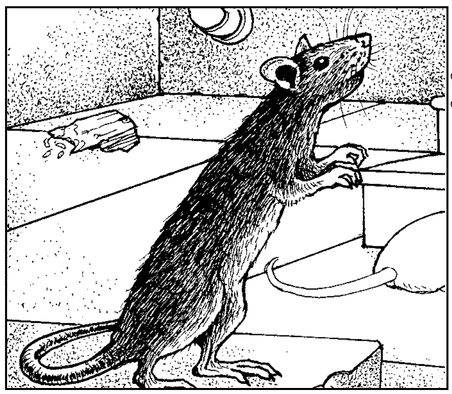
Adding plant protectants to crops through genetic engineering started with the addition of insecticidal BT proteins to tobacco, cotton, and potatoes. Transgenic tobacco was never commercialized. The New Leaf™ potato resistant to Colorado potato beetle, *Leptinotarsa decemlineata*, was commercialized in 1995, but it was withdrawn due to consumer indifference. The first insecticidal crop to find commercial success was BT cotton (Bollgard®) (Fernandez-Cornejo et al. 2014).

At the time, insecticidal cotton seemed like a reasonable use of the technology. Cotton is one of the most intensely sprayed crops, and BT cotton promised a reduction in insecticide applications. Experiments showed BT cotton had low direct impact on beneficial insects, and decline in beneficials was due to reduction of prey. Cotton is not eaten by humans, and edible components such as cotton seed oil are not contaminated with BT. The only major problem predicted was the development of insect resistance. To prevent resistance, plants were engineered to express large concentrations of BT proteins, and a small percentage of the crop was planted to non-BT varieties (Koch et al. 2015; Tabashnik et al. 2013).

Transgenic cotton soon escalated into a continuous flow of transformed plants including corn, potato, soybeans, broccoli, and many other crops. *Bacillus thuringiensis* sprays are used by organic farmers for caterpillar control on food crops. BT has low toxicity to mammals, is quickly degraded, and can be easily washed off fruits and vegetables. But insecticidal BT proteins in transgenic crops are systemic and cannot be removed by washing (Tabashnik et al. 2009; Koch et al. 2015).

Safety of GE Crops

Incorporation of BT into food crops means that humans can have chronic dietary exposure to BT insecticides. Currently, corn and cotton are the major BT crops in the U.S. However, soybean, crucifers, and other crops have been transformed (Tabashnik et al. 2013; Koch et al. 2015).


Drawing by Diane Kuhn

Feeding tests in rats are often flawed and give conflicting results.

According to one review, many short term feeding experiments in rats and other mammals do not reveal toxic problems with BT crops (Koch et al. 2015). However, there are very few long term feeding experiments, and most of these are flawed (Snell et al. 2012). Another question is whether results obtained for healthy rats are 100% transferrable to real human populations. In addition to species differences, we are learning that each human is genetically unique. Children and older people are more susceptible to pesticides, and sick people react differently than healthy ones. For instance, a bad liver means that pesticide metabolism could be impaired (NRC 1993; Quarles 2014a).

Another factor is that rat toxicology may not represent the best case for pesticide evaluation. Cell culture experiments show changes in genetic expression induced by pesticides that are not seen with rat toxicology (Richard et al. 2005; Thongprakalsang et al. 2013). For instance, about 5,000 genes change expression when human liver cell cultures are exposed to DEET and fipronil (Mitchell 2015). And about 4,000 genes in rat liver tissue are affected by exposure to Roundup® at 0.1 ppb (parts-per-billion). Since there is some uncertainty, it would seem best not to feed systemic pesticides to a large portion of the U.S. population (Mesnage et al. 2015ab).

Glyphosate in Food

Glyphosate tolerant food crops contain systemic residues of the pesticide, and glyphosate may not be as benign as we once thought (Bohn et al. 2014; Williams et al. 2000). The International Association for Research on Carcinogens (IARC) has called it a probable human carcinogen (Guyton et al. 2015). The USDA rarely measures glyphosate residues in food, and widescale measurement of glyphosate levels in the general population has not been attempted. We do know that glyphosate appears in the urine of applicators, and a recent study in Europe found that 44% of the population studied had glyphosate in their bodies (Acquavella et al. 2004; FOEE 2013). Another study found glyphosate in the urine of farm animals and human volunteers. Sick people had higher concentrations of glyphosate in urine than healthy ones (Kruger et al. 2014). Some studies show that a number of human diseases have increased in concert with increased glyphosate applications. These correlations are interesting and should stimulate further studies on glyphosate exposures and disease thresholds (Swanson et al. 2014; Samsel and Senhoff 2013ab).

Resistance to BT and Glyphosate

In 1996, organic farmers and others opposed widescale planting of BT crops, arguing that resistance to BT was inevitable when insects were constantly exposed (Tabashnik et al. 2009). To help slow resistance, the EPA required mitigation procedures such as BT refuges—areas where BT susceptible insects could breed. Eight years later field resis-

Resistant horseweed, *Conyza canadensis*, covers millions of acres of GE crops.

tance to BT crops had not developed (Bates et al. 2005).

But there were about 80 million acres (32.4 million ha) of BT crops in the U.S in 2013, and it is hard for insects to avoid them (Fernandez-Cornejo et al. 2014). In 2013, field populations of 5 of the 13 major pest species had developed BT resistance leading to loss of efficacy. Resistance had developed in corn pests such as the corn stem borer, *Busseola fusca*; corn rootworm, *Diabrotica virgifera virgifera*; and fall armyworm, *Spodoptera frugiperda*. Cotton pests such as the budworm, *Helicoverpa zea*; and the pink bollworm, *Pectinophora gossypiella*, had also become resistant. Resistance had developed within 10 years of commercialization (Gassmann 2012; Tabashnik et al. 2013).

The pink bollworm, *Pectinophora gossypiella*, is resistant to BT cotton.

Glyphosate tolerant crops have led to production of resistant weeds. Reliance on one herbicide for weed control has led to glyphosate resistance in 14 important weed species and biotypes in the U.S. (Fernandez-Cornejo et al. 2014; Duke and Powles 2009; Quarles 2012).

Genetic Treadmill

Pesticide applications lead to pest resistance, which leads to increased pesticide use and then to a new pesticide. Van den Bosch (1978) termed this ineffective approach to pest management "the pesticide treadmill." The biotech industry has responded to insect and weed resistance by the genetic treadmill. Genetic engineering is used to fix problems that genetic engineering has caused. For instance, to correct for development of resistant weeds, new transgenic crops have been developed that are tolerant to multiple herbicides (Green et al. 2008).

This genetic treadmill will lead to increased environmental contamination with an increasing variety of pesticides. Near approval is Enlist Duo®, an herbicide containing both 2,4-D and glyphosate. Planting of crops resistant to Enlist Duo on U.S. corn and soybean acreage could triple the amount of 2,4-D used in agriculture. Enlist Duo was first approved by the EPA, then EPA asked the courts to block the decision. When approved, the Agency did not know that the combined effects of glyphosate and 2,4-D could be synergistic (Newman 2015; Quarles 2012; Mortensen et al. 2012).

To compensate for insect resistance to one BT protein, plants have been engineered that simultaneously express multiple BT proteins. These multitrait or stacked trait crops work best when introduced before resistance has developed. So IPM methods have been tossed out the window with the proactive introduction of multitrait crops (Gray 2011; Furlong et al. 2013). Escalation to GE crops producing spider venom has been proposed (Ullah et al. 2015).

Development of insect resistance has also led to another step on the genetic treadmill—development of transgenic insects to mitigate the problem (Alphey et al. 2007).

Genetically Engineered Insects

Genetically engineered insects are now being developed for pest control. Examples include pest moths and flies that spread lethal genes in wild populations, pest mosquitoes that are engineered for population suppression or pathogen suppression (Alphey et al. 2007; Alphey 2014; WHO 2014). The technique involves using genetic transformations that are either self-limiting or sustaining. Self-limiting transgenic insects die out after a few generations. Sustaining transformations involve coupling a transgene with a gene drive that ensures its propagation throughout the entire wild population. Gene drives can be constructed with new genetic technology such as the CRISPR technique (Ganz and Bier 2015; Bohannon 2015). Sustaining transformations could eliminate or transform entire species (WHO 2014).

This is not wild speculation, transgenic *Aedes aegypti*, were released in Brazil in 2012, leading to 95% suppression of a local *A. aegypti* population (see below). Transgenic diamondback moths carrying a self limiting lethal gene are due to be released in the U.S. this year (Carvalho et al. 2015; Harvey-Samuel et al. 2015). Limitations to the technology are that the species has to reproduce sexually, and best results are obtained with fast generation times. Inherited transgenes would spread slowly in human populations (WHO 2014).

Transgenic Diamondback Moth

The diamondback moth (DBM), *Plutella xylostella*, is a monster created by the pesticide industry. Before DDT, it was a minor crop pest. But diamondback moth has enough genetic diversity to quickly adapt to pesticides. Application of pesticides gave it a selective advantage over less hardy insects. It has become resistant to every pesticide used against it. Its success is due to emphasis of pesticide only pest management and decline in the use of IPM methods (Furlong et al. 2013; Bommarco et al. 2011).

Organic farmers use sprays of BT as part of diamondback management, but the pest has become resistant. In fact, DBM was the first crop pest to develop field resistance to the pesticide (Tabashnik et al. 1990). Genetically engineered BT broccoli crops have been developed, but have not been commercialized because of the resistance problem. Resistance to BT can be mitigated by release of beneficial insects and other IPM methods such as trap crops and biopesticides, but this approach has not generally been adopted (Furlong et al. 2013, Liu et al. 2014; Han et al. 2015).

Photo courtesy Lyle Buss, University of Florida

The diamondback moth, *Plutella xylostella*, is resistant to many pesticides. Genetic engineering may be used to mitigate resistance or eliminate the moth.

Lethal Genes

An engineered diamondback moth has been produced that carries a self limiting lethal gene. The technique is called RIDL—Release of Insects carrying a Dominant Lethal gene. Because female moths can lay eggs causing plant damage, the lethal gene is constructed to be female specific, causing deaths only of females (fsRIDL). This is a variant of the sterile insect technique, where sterility is induced by genetics rather than chemicals or radiation (Alphey et al. 2007; Jin et al. 2013).

Transgenic males mate with wild populations, female offspring die during development, and only transgenic males survive. If enough insects are released initially, local populations are exterminated. If the transgenic males released are homozygous for BT susceptibility, releases can also mitigate diamondback moth resistance to BT. Computer modeling shows release ratios of one transgenic to five wildtype moths could mitigate BT resistance, but this estimate is probably optimistic. For pest elimination, much larger release ratios are required (Alphey et al. 2007; Harvey-Samuel et al. 2015).

Large Numbers Released

To have an effect, large numbers have to be reared and released. In cage releases, ratios of ten transgenics to one wildtype led to extinction of diamondback moth in three generations. This kind of effort would probably be better spent on rearing and releasing parasitoids known to be effective for DBM management. But no one has done a comparative analysis of costs (Liu et al. 2014; Furlong et al. 2013).

Though most of the DBM released will stay local, studies have shown that diamondback moth can move from crop to crop and even migrate. So releases may eventually cover wide areas (Furlong et al. 2013). Anything this new comes with unknown risks for the native ecology. Risks are mitigated somewhat by fitness costs—the insects are genetically weakened by the transformation. Experiments show that the gene should be eliminated from wild populations of DBM in about seven generations (Harvey-Samuel et al. 2014).

Releases Opposed

Although developers assure that the proteins produced by the lethal gene of the transgenic are not toxic and are not likely to impact other species, environmental groups are opposing mass releases of the transgenic diamondback moth. One argument is that fields of organic farmers, and possibly organic food, would be contaminated by prohibited transgenic organisms. Problems not explored include possible horizontal transfer of the lethal gene into other insects. Tetracycline is necessary to produce the transgenic, and there are some concerns that releases could spread antibiotic resistance (Harvey-Samuel et al. 2015; GeneWatch 2014). Also, self-limiting releases should probably be viewed as proof of concept, and will likely lead to sustaining releases with a much wider impact (WHO 2014).

Other species engineered with fsRIDL include pink bollworm, *Pectinophora gossypiella*; the olive fly, *Bactrocera oleae*; medfly, *Ceratitis capitata*; fruit fly, *Drosophila melanogaster*, and *Aedes aegypti* mosquitoes (Thomas et al. 2000; Jin et al. 2013; Harvey-Samuel et al. 2015; Alphey 2014). Cage releases of ten transgenics to one wildtype, led to extinction of medfly and olive fly populations in three generations. Populations of *Aedes aegypti* went extinct in five generations (Harvey-Samuel et al. 2015).

Update

Photo courtesy of CDC and James Gathany

If *Aedes aegypti* is eliminated, *Aedes albopictus*, shown here, or another mosquito species may take its place. There are unknown ecological risks from release of transgenic insects.

Modified Mosquitoes and Microbes

Global warming has led to increased pest problems. Mosquito borne diseases such as malaria, dengue, and others are increasing (Quarles 2007). *Anopheles* spp. mosquitoes transmit 200 million cases of malaria causing 800,000 deaths each year. *Aedes aegypti* causes 50-100 million cases of dengue (Wilke and Marrelli 2015). Emerging problems are birth defects that may be associated with mosquito borne Zika virus (CDC 2015; Hayes 2009). Mosquitoes are becoming resistant to pesticides, and pesticides also have environmental consequences. Due to cost, source reduction and other IPM methods may not be an option in developing countries (Baldacchino et al. 2015).

Organisms in development for mosquito control include transgenic microbes and transgenic mosquitoes. Genetically engineered microbes can be introduced into mosquito populations causing mosquitoes to die or resist disease. An early microbe candidate was the bacterium *Wolbachia* (Wilke and Marrelli 2015; McGraw and O'Neill 2013). Mosquito modifications include transgenics carrying either lethal genes or genes that resist disease transmission (Alphey 2014; Kean et al. 2015).

Females Die

The fsRIDL technique has been used to make transgenic mosquitoes. Males carrying a female specific lethal gene are released, these then mate with native mosquitoes. All females produced either die in the pupal stage or develop without wings. This option has already seen field tests with *Aedes aegypti* in Brazil. Releases of about 25,000 male transgenics/ha/week in 2012 led to a transgenic to wild ratio of about 1:1. According to trap data, releases of about 3.5 million transformed mosquitoes over a six month period in an area of 5.5 ha (13.6 acres) led to a 95% local reduction in *Aedes aegypti* (Carvalho et al. 2015; Alphey 2014).

The female lethal technique is self-limiting, and can be driven only by successive releases of transformed mosquitoes. According to GeneWatch, the transformation technique is not perfect, and about 0.02% (200 per million) of the releases are females. So, a few bites from transgenic mosquitoes are possible, with uncertain consequences. There is also some concern that the mass releases will drive wild-type males away from the release area, leading to worsening mosquito problems nearby. Or mosquito populations in the same area might rebound after releases are suspended (GeneWatch 2014).

Gene Drives

Another option is releasing mosquitoes with transformed genes coupled to gene drives to insure that the transgene is permanently established in the wild population. This option is also called the "mutagenic chain reaction," and it has potential earth shaking consequences similar to the chain reaction in a nuclear explosion. This is the most risky approach because it would not be easy to reverse it. In contrast with the self-limiting technique, fewer transgenics would be needed. In theory, one transgenic would be enough. With diligent application, an entire wild species could be eliminated or transformed (Windbichler et al. 2011; Bohannon 2015; Ganz and Bier 2015; WHO 2014).

All these options have risks. Engineered microbes could lead to increased pathogenicity. For instance, *Wolbachia* infection leads to enhanced transmission of West Nile virus by *Culex pipiens* (Wilke and Marrelli 2015). There is a potential risk of horizontal transgene transfer to other populations. There are unknown ecological risks. For example, if we should get rid of *Aedes aegypti* would *Aedes albopictus* take its place? Or if we get rid of all mosquitoes, would non-target populations that depend on them for food be impacted? Or would the ecological niche be filled with a pest that we would like even less than mosquitoes (GeneWatch 2014; WHO 2014).

The Corporate Bee

Release of transgenic insects raises ethical questions and comes with ecological risks that are hard to measure. Release of transgenic crops led to unexpected effects, and likely transgenic insects will also create some problems. The applications considered at the moment are mitigation of pesticide resistance or elimination of pest populations. But the technique could be used in other ways. For instance, should we create bees that are resistant to neonicotinoids? Should we solve a pesticide problem by creating a new species? Changing the genetic identity of wildlife to overcome a pest or pesticide problem starts us sliding down a very slippery slope. Following the Monsanto model, will corporations produce both pesticides and pesticide resistant organisms? Will pesticide resistant beneficial insects be paired with proprietary pesticides?

Conclusion

Genetic engineering techniques are becoming easier to use. At some point, the temptation will be to change the identity of living things rather than change the pesticide intensive cropping methods that led to the problem. Mass releases of transgenic organisms to solve a pest or pesticide problem is a subject too important to be left to corporations and regulators. This topic should be thoroughly debated, because the technique can lead to transformation or elimination of an entire species. Such profound changes in the life forms around us should be a topic considered by the entire society. Once the transgene genie is released, it may be impossible to put it back in the bottle.

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Calendar

January 19-23, 2016. 35th Annual Eco-Farm Conference. Asilomar, Pacific Grove, CA. Contact: Ecological Farming Association, 831/763-2111; info@eco-farm.org

January 16, 2016. NOFA Winter Organic Farming and Gardening Conf. Saratoga Springs, NY. Contact: NOFA, 585/271-1979; www.nofany.org

February 2016. Annual Conference, Association Applied Insect Ecologists, Napa, CA. Contact: www.aaie.net

February 8-11, 2016. Annual Meeting Weed Science Society of America. Lexington, KY. Contact: www.wssa.net

February 25-27, 2016. 27th Annual Moses Organic Farm Conference. La Crosse, WI. Contact: Moses, PO Box 339, Spring Valley, WI 54767; 715/778-5775; www.mosesorganic.org

March 1-2, 2016. Annual Meeting BPIA. Monterey, CA. Contact: www.biopesticideindustryalliance.org

March 2016. California Small Farm Conference. Contact: www.californiafarmconference.com

June 23-25, 2016. Annual Meeting, Pest Control Operators CA, Honolulu, HI. Contact: PCOC, 3031, Beacon Blvd, W. Sacramento, CA 95691; www.pcoc.org

July 30-August 3, 2016. American Phytopathological Society Conference, Tampa, FL. Contact: APS, 3340 Pilot Knob Road, St. Paul, MN 55121; 651-454-7250; aps@scisoc.org

August 7-12, 2016. 101th Annual Conference, Ecological Society of America, Ft. Lauderdale, FL.
Contact: ESA, www.esa.org

September 25-30, 2016. Annual Meeting, Entomological Society of America, Orlando, FL. Contact: ESA, 9301 Annapolis Rd., Lanham, MD 20706; www.entsoc.org

October 18-21, 2016. NPMA Pest World, Seattle, WA. Contact: NPMA, www.npmapestoworld.org

November 6-9, 2016. Annual Meeting, Soil Science Society of America. Phoenix, AZ. Contact: www.soils.org

November 6-9, 2016. Annual Meeting, Crop Science Society of America. Phoenix, AZ. Contact: https://www.crops.org

November 6-9, 2016. Annual Meeting, American Society of Agronomy. https://www.acsmeetings.org

Update

Zika Virus and Microcephaly

By William Quarles

Zika is a flavivirus that originated in Africa in 1947. It is related to viruses that cause dengue, yellow fever, West Nile, and Japanese encephalitis. Humans and monkeys are hosts, and transmission is by mosquitoes, blood transfusions, and possibly sexual activity. Zika has also been found in saliva and urine of infected individuals. It is vectored by *Aedes* spp. mosquitoes, including *Aedes aegypti*, which is the yellow fever mosquito. Symptoms of infection include fever, rash, headache and back pain (Hayes 2009; NYT 2016).

Zika has been spreading out of Africa. In 2007, it spread to Yap Island in Micronesia. In 2015, the first case was reported in Brazil, although it was probably present in 2014. Since then, according to the World Health Organization (WHO), it has spread to 20 countries in the region, and there may be 1.5 million cases in Brazil. It is spreading quickly because the exposed populations have no immunity (Duffy et al. 2009; CDC 2015a).

Up to this year, human Zika infection was considered relatively mild and self limiting. But clinicians in Brazil noticed about 4,000 microcephalic babies were born in 2015. This number was about a 10-fold increase over the previous year. Initial tests showed some of the babies were infected with Zika virus, and Zika was proposed as the cause. The situation has drawn world attention, and WHO declared an International Health Emergency on February 1, 2016.

It is hard to get reliable information, but according to the CDC, microcephaly is known to be caused by infections, genetic abnormalities, and exposure to toxic substances (CDC 2015a). According to the *New York Times*, when about 732 of the birth defect cases were investigated, 462 cases (63.1%) were likely caused by chemicals such as alcohol or drugs, but infections were confirmed in 270 cases (36.8%). Zika virus could be detected in only 6 babies (0.8%). Those supporting the Zika hypothesis say that Zika can be detected only for a short time, and many babies might have been infected 7 months earlier (NYT 2016).

Photo courtesy James Gathany

***Aedes aegypti*, shown here, and other *Aedes* mosquito species are able to transmit Zika virus.**

Agrochemicals Involved?

Another view is that Zika may be interacting with another cause, either another infection, or toxic exposure. In the past, the virus by itself has not been associated with birth defects (NYT 2016; CDC 2015a).

Many cases are in Northeast Brazil in cities such as Recife and Camacari. These cities are close to agricultural areas known for sugarcane and intensive cultivation of GMO soybeans, cotton, and corn in rotation. All of these crops use large amounts of pesticides. According to Reuters, Brazil now buys more pesticides than any country in the world, including 14 pesticides that are banned elsewhere (Prada 2015).

Agrochemicals in Argentina have been reportedly associated with cranio-facial birth defects (Antoniou et al. 2011). According to news sources, there has been a four-fold increase in birth defects in the Chaco agricultural area of Argentina in the 10-year period following intensive GMO plantings (Philpott 2013). But this increase is still much less than the 10-fold increase seen in Brazil. Agrochemicals alone are not likely the cause of microcephaly in Brazil, but there might be an interaction.

Mosquito Vectors

Zika in Brazil is being vectored by the yellow fever mosquito, *Aedes aegypti*. In the U.S., this species has been found in the Southeast, southern Texas and Arizona, and the San Francisco Bay Area. Another U.S. mosquito, the Asian tiger mosquito, *Aedes albopictus*, might also carry the infection. *A. albopictus* has a similar southern range, but can also be found further north in states such as Pennsylvania and Illinois (CDC 2015b).

These mosquitoes breed in containers around dwellings and bite in the daytime. Discarded automobile tires are a favorite breeding spot. They can be controlled by reducing breeding sources, larval control programs, and by the use of repellents.

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Conference Notes

ESA 2015 Annual Meeting Highlights

By Joel Grossman

These Conference Highlights were selected from "Synergy in Science," the Minneapolis, Minnesota (Nov. 15-18, 2015) co-meeting of the Entomological Society of America (ESA), the American Society of Agronomy, the Crop Science Society of America, and the Soil Science Society of America. The next ESA annual meeting in Orlando, Florida, Sept. 25-30, 2016, is a joint meeting with the International Congress of Entomology (ICE). For more information contact the ESA (3 Park Place, Suite 307, Annapolis, MD 21401; 301/731-4535; http://www.entsoc.org).

Neonicotinoids and Sunflowers

Neonicotinoid seed treatments, particularly thiamethoxam and its toxic metabolite, clothianidin, are nearly ubiquitous on commercial crops of sunflowers in the USA, said Michael Bredeson (South Dakota State Univ, Brookings, SD 57006; mmbredeson@jacks.sdstate.edu). But neonicotinoid sunflower seed treatments can have non-target effects on bees, birds and beneficial insects through contaminated nectar and plant tissues, or through predator consumption of tainted prey.

Sunflower seed treatments are also a needless economic expense. Bredeson studied 11 commercial sunflower fields, and found that the seed treatment failed to improve yield or decrease herbivores. Measurable negative impacts included reduced populations of beneficial predators and pollinators.

Drosophila Predators Important

Predators reduce larval and pupal survival of spotted wing Drosophila (SWD), *Drosophila suzukii*, said Jana Lee (USDA-ARS, 3420 NW Orchard Ave, Corvallis, OR 97330; Jana.Lee@ars.usda.gov). In experiments with bagged and unbagged fruit, predators reduced larval survival 19%-34% in strawberries; and 28%-49% in blueberries.

SWD larvae in the fruit and SWD pupae in the soil may have different natural enemies. The pupae are found primarily in the soil: 78%-93% of the time in blueberries; 84%-90% of the time in raspberries.

In experiments with predator exclusion mesh, field predators reduced SWD pupae in strawberry soils by 61%. Predators reduced SWD pupae in blackberry soils by 67%. In blueberries, SWD pupae were placed in sawdust and predator removal was 91%. Lee concluded that "ground predators may be especially important in biocontrol of this pest."

Drosophila Exclusion Netting

"In 2014, spotted wing Drosophila (SWD), *Drosophila suzukii*, caused estimated economic losses of $159 million in U.S. raspberry production," said Heather Leach (Michigan State Univ, 202 CIPS, East Lansing, MI 48824; leachhea@msu.edu). "Growers spray insecticides weekly during harvest, abandoning their sustainable IPM programs...which has created an urgent need to develop practices to decrease insecticide dependence."

Leach deployed fine mesh insect netting in field and high tunnel grown raspberries. In high tunnel tests in 2015, yeast-sugar traps were placed at both ends and in the center of each tunnel. A yellow sticky trap was hung in each tunnel to quantify pests, natural enemies, and pollinators.

On a commercial high-tunnel raspberry farm in 2015, 1 acre (0.4 ha) with five 400 ft (122 m) tunnels cost $6,100. About 38% of the cost was netting; 33% labor; 9% bumblebees; 16% door construction; 4% netting accessories. Exclusion netting significantly reduced all SWD life stages. Pesticide applications were reduced; and there were fewer other pests, fewer natural enemies, and fewer pollinators with the exception of added bumblebees.

"Netting significantly reduces and delays SWD infestation," said Leach. "Complementary control efforts include increasing harvest frequency, which significantly lowers the number of larvae found. Within an existing structure like a high tunnel, netting can be a cost effective tool."

Asian Citrus Psyllid Biocontrol

"*Tamarixia radiata* is a biological control agent of the Asian citrus psyllid (ACP) that is being used as a tool to help reduce psyllid populations in urban environments of citrus growing areas in Texas," said Christopher Vitek (Univ Texas, 1201 W. University Dr, Edinburg, TX 78539; vitekc@utpa.edu).

"In 2010, before we began our releases, we were detecting up to 43 immature psyllids per flush in residential citrus," said Vitek. "Since our field releases began, we have seen the populations gradually decline. In 2015, we are observing 6.5 immature psyllids per flush. This is a reduction of 85% of the psyllid population."

Besides releases at over 2,260 sites in South Texas, *Tamarixia radiata* is being released in Tamaulipas and Baja California, Mexico, Louisiana, Puerto Rico, and Florida in areas where HLB (Huanglongbing) has been detected. Asian citrus psyllid populations have been reduced by 49% in Tamaulipas and 83% in Baja California.

Seed Blend Refuges Speed Bt Resistance

"Seed blend refuge is a pre-mix of a *Bt* corn and non-*Bt* seed at the EPA required proportion of *Bt* to non-*Bt* plants," said Sydney Glass (Univ Minnesota, 219 Hodson Hall, 1980 Folwell Ave, St. Paul, MN 55108; glass151@umn.edu). "With the seed blend refuge, separate planting of block refuge of corn is no longer needed. However, seed blend refuges may be facilitating rather than preventing resistance. Caprio et al. (2015), through quantitative modeling, have shown that pollen contamination in seed blend refuges makes them less durable than block refuges in preventing resistance evolution."

Seed blend refuges have become the preferred refuge type to slow the development of resistance. "However, our results highlight the risk that nearby *Bt* plants will cross-pollinate with non-*Bt* refuge ears, leading to the expression of *Bt* toxins in refuge ear kernels. Seed blend refuge ears are cross-pollinated by *Bt* plants, and express either multiple, single, or no toxins present in kernels creating a mosaic of kernels expressing a lowered dose and greatly increasing the possible development of resistance compared to traditional block refuge."

Fall armyworm and corn earworm larvae avoid feeding on kernels in seed blend refuge ears; and there is a 5-6 day development delay. If they feed, there is significant mortality from feeding on cross-pollinated blend refuge ears, which may accelerate "the rate of resistance evolution over the traditional block refuge strategy."

Chipping Eradicates Lanternfly

Grape, *Vitis vinifera*; and tree-of-heaven, *Ailanthus altissima*, are the preferred hosts of spotted lanternfly (SLF), *Lycorma delicatula*, a pest with a broad host range detected in Pennsylvania in September 2014, said Mariam Cooperband (USDA-APHIS, Buzzards Bay, MA 02542; Miriam.F.Cooperband@aphis.usda.gov). "A chipping study was conducted in Pennsylvania in February 2015 to determine if chipping would be an effective approach for destroying egg masses to treat infested wood in the quarantine zone. Infested *Ailanthus* trees were felled and egg masses were counted. Bolts were either chipped or kept intact. Chipped or intact wood was placed in screened barrels and monitored for emergence."

Mid-winter chipping was 100% effective in destroying SLF egg masses. Plus, "no *L. delicatula* nymphs were found in chipped treatments, as opposed to hundreds found in intact controls," said Cooperband.

Mosquito Avoids Indoor Sprays

"Indoor residual spraying has been implemented on Bioko Island (Equatorial Guinea, Africa) under the Bioko Island Malaria Control Project since 2004," said Zachary Popkin-Hall (Texas A&M, 2475 TAMU, College Station, TX 77843; zpopkinh@tamu.edu). Human landing collections data since 2009 "revealed that the major remaining vector on the island, *Anopheles gambiae* M form, a species that is considered primarily an indoor feeder, predominantly fed outdoors."

"*An. gambiae* likely switched to outdoor feeding as a result of five years of indoor-based vector control," said Popkin-Hall. Analyses of biting rates before and after spray rounds indicate that insecticide repellency is an unlikely explanation for the adaptive shift in mosquito feeding behavior. Popkin-Hall is investigating the genetic basis for the behavior. "These data do raise serious concerns about the future effectiveness of indoor based vector control on the island." Indeed, the "adaptive shift" to outdoor biting may lead to a malaria upsurge.

DEET, Fipronil, and Human Health

"There is an incredibly high exposure rate to the general public of arthropod repellents and toxicants commonly used around the home," said Robert Mitchell (North Carolina State Univ, 2731 Pillsbury Cir, Raleigh, NC 27607; rdmitche@ncsu.edu). One-third of the USA population uses DEET. Fipronil is widely used in gardens; structurally against termites; and persists in high concentrations up to 5 weeks on pets.

"Fundamental molecular human studies are essential," but they are "also greatly lacking for environmental chemicals," said Mitchell. Ethical barriers limit human experiments, and animal models have limits of applicability. However, human hepatocyte cell cultures are remarkably accurate in drug research, both in evaluating drug safety and new drug development; and thus could also be used to evaluate environmental chemicals, including pesticides and repellents. Indeed, human cell cultures could go beyond conventional rodent models and show how environmental chemicals "impact on global cellular function."

For example, RNA-Seq (Illumina) and Ion Torrent (Life Technol) sequencing technology reveal how DEET and fipronil impact human gene expression. The combination of DEET and fipronil up- or down-regulates 5,000 genes. Genes for steroid biosynthesis from cholesterol are in the same biochemical pathway as many enzymes impacted by DEET and fipronil. There may be serious health implications from a 30% increase in altered gene expression. Plus there are epigenetic effects on the chromatin to consider; which can include expression of non-protein coding RNAs and microRNAs. None of this is evident from standard rodent models for chemical testing.

Midwest Cornscape Impairs IPM

Midwest corn IPM needs diversity, but instead the shift is towards landscape simplification with increasing corn acreage, said Jonathan Lundgren (USDA-ARS, 2923 Medary Ave, Brookings, SD 57006; Jonathan.Lundgren@ars.usda.gov). First there was the Freedom to Farm Act which allowed expanded cropping, and then there was the ethanol fuel mandate; all leading to a large-scale shift in land use over the short time period of one decade. The result is a Midwest USA with 14% more corn and a much more simplified landscape that means less biodiversity across many habitats. Wheat acreage is down 21%; hay is down 16%; soybeans down 3%; and other crops down 16%. This means less resilience in the food production system.

Unfortunately, there are no baseline biodiversity inventories for any one crop. It is too labor intensive, necessitating multiple field sites, whole plant counts, vacuuming the soil, and soil cores. Non-*Bt* corn has 107 insects in the crop canopy, of which only 7% are primary pests; and 5 predators per plant, which works out to 137,000 to 167,000 predators per acre (0.4 ha) in the corn canopy alone. Compared to perennial prairie or pasture habitats, corn has only 24-34% the amount of biodiversity.

No Natural Enemies?

The conventional view has long been that there are no natural enemies of larval corn rootworms in the soil. However, gut analysis has recently revealed dozens of predators of larval corn rootworms. Indeed, as total predator populations increase in size and diversity, corn rootworms are more frequently prey, and corn root damage decreases. Something as simple as adding a cover crop to corn fields significantly increases predators and reduces corn rootworm third instar larvae and adult emergence.

Instead of this more holistic biological network approach, we have "a very pest-centric approach" that wastes money on prophylactic corn rootworm treatments and is oblivious to the biological control provided by spiders, pirate bugs, lacewings, lady beetles and other natural enemies, said Lundgren. "Our understanding of species networks primarily comes from simplified systems, and so is not fully relevant to unsprayed corn with numerous beneficial species."

"Practices that increase biodiversity will decrease pest abundance," and result in less pest pressure in corn, said Lundgren. "Bottom line, the pest is not the problem. If you only throw on pesticides or biocontrol agents, it is just a band aid, because you are treating a symptom, not the problem."

Bt Refuge Failures

Large monoculture acreages of solid corn were unknown until 1909, and until 1947 crop rotations were the only corn rootworm control, said Bruce Hibbard (USDA-ARS, Univ Missouri, Curtis Hall, Columbia, MO, 65211; Bruce.Hibbard@ars.usda.gov). By the late 1940s synthetic chemical pesticides targeted rootworms in the soil. By the early 1950s resistance was noticed, prompting a switch to chemicals targeting adult beetles. As early as 1932, there were hints at adaptation to crop rotations. But crop rotations worked remarkably well, with an extended drop in corn rootworm populations until 1965.

Western corn rootworm (WCR), *Diabrotica virgifera virgifera*, is the major pest of continuous corn. It has adapted to corn, soybean crop rotations in Nebraska, Illinois and Indiana. BT corn is now the major protection against corn rootworm. Pyramided *Bt* corn planting comes with government-mandated refuge requirements. But a 1:1 ratio of *Bt*:non-*Bt* corn is needed to make sure it will work, said Hibbard. Non -Bt refuges of 5% are not likely to work; nor even requirements for up to 20% non-*Bt* corn. *Bt* resistance may be a dominant gene trait, not recessive.

Evidence of *Bt* refuge failure is emerging in corn fields. Where refuge rows of non-*Bt* corn are planted, evidence of failure is that the *Bt* fields are treated with Aztec® insecticide and still have 7% damage and 35% lodged plants. By 2017, RNAi biotechnology is expected to be added to pyramided *Bt* corn. But what is really needed is an IPM approach with CO2 attractants, feeding stimulants, corn rootworm biocontrol by entomopathogenic nematodes and other methods.

Soap, Fungi, and Whiteflies

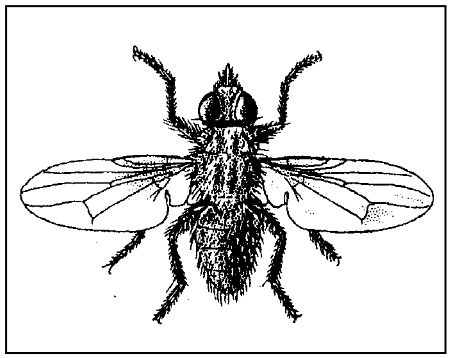
The best biopesticides for sweetpotato whitefly, *Bemisia tabaci*, on greenhouse tomatoes have low reentry intervals, low risk for resistance, and compatibility with pollinators and biological control organisms, said Michelle Samuel-Foo (Univ Florida, Gainesville, FL 32611; mfoo@ufl.edu). Sweetpotato whitefly, a greenhouse tomato pest with an 18 day life cycle from egg to adult, lives up to 2 weeks as an adult in Florida.

In biopesticide trials, untreated control plants had over 200 whitefly nymphs after 3 weeks. Insecticidal soap, M-Pede®, provided whitefly control equal to flupyradifurone (Sivanto™ 200). Mycotrol®, a *Beauveria bassiana* formulation, also provided good whitefly control. BotaniGard® ES, a *Beauveria bassiana* product, showed phytotoxicity as an ES (emulsifiable suspension), and in the future will be used as a WP (wettable powder).

Geraniol and Fatty Acids Reduce Biting

During three southern California summers, the repellents geraniol and straight chain fatty acids (C8, C9, C10) were tested against bloodsucking horn flies on pastured beef cattle, said Bradley Mullens (Univ California, Entomol 268, Riverside, CA 92521; bradley.mullens@ucr.edu). "Each herd over time was sequentially untreated for at least two weeks, treated twice per week with one of two designated repellents (geraniol or a mixture of straight-chain fatty acids) for at least two weeks, and then untreated for at least two weeks. Control herds were totally untreated."

Flies were visually counted twice a week, and "designated flies were tested using a biochemical test to quantify hemoglobin (a measure of blood meal size)," said Mullens. The two repellents were effective for 1-3 days, with much variation among locations and trials. Fatty acids (but not geraniol) also have short-term value as toxicants, as flies dropping to the ground do not recover. In 2011, fatty acids quickly reduced fly numbers on animals; but fly numbers increased again. Besides repellency, there was another nonlethal effect: Bloodsucking female flies (70% of total) took only tiny blood meals, thus reducing blood loss.



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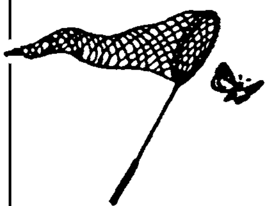

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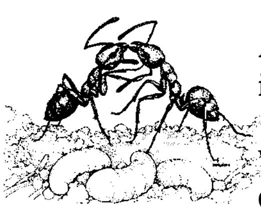

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