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Glyphosate, GMO Soybean Yields and Environmental Pollution

By William Quarles

A repeated mantra of the biotechnology industry is that genetically engineered crops (GMOs) are needed to feed an increasing world population. GMOs are supposed to increase crop yields, and in some cases produce a more nutritious product. These claims have proved to be exaggerated. In the case of GMO soybeans, GMOs have not led to increased yields, but have led to ever-increasing environmental pollution from pesticides and fertilizers (USDA 2007; USDA 2013; USDA 2016ab; NAS 2016).

Farmers have adopted GMO soybeans not because of yields, but because they are easier to grow, and production can be profitable. Instead of labor intensive cultivation, mulches, or herbicide spot treatments, entire fields are aerially sprayed with herbicide, killing weeds, but sparing the resistant crop. Farmers jumped to adopt this easy method of weed control. But the golden promise of better yields with less work has a darker reality—many weed species have become resistant to glyphosate. Resistance has led to increased cultivation, and creation of new herbicide-resistant crops. These stacked trait crops pose their own problems with pesticide pollution that are now becoming evident (Fernandez-Cornejo et al. 2014; NAS 2016; Hakim 2017).

This article briefly reviews effects of GMO soybeans and glyphosate applications on yields, fertilizer and pesticide use, soil microbes, and diseases.

Photo by Ken Hammond courtesy of the USDA

Aerial sprays of glyphosate leave residues in soybeans and contaminate water. Soybean GMOs so far have not increased yields, but require additional fertilizer and pesticide, leading to environmental problems.

Effects on Soybean Yields

The USDA deserves credit for soybean improvement. From 1980 to 1994 it released 66 new soybean varieties. This kind of diligent scientific work led to commercial soybeans with improved crop performance and increased yields. Corporations have taken these high yield varieties and added herbicide resistance and other qualities to them, but these genetically engineered changes generally do not lead to yield improvement (NAS 2016).

A committee convened by the National Academy of Sciences “found little evidence” that GMOs lead to improved yields. Crop yields were increasing each year before introduction of GMOs. According to the committee, “the nationwide data on maize, cotton, or soybean in the United States do not show a significant signature of genetic engineering technology on the rate of yield increase” (NAS 2016). This concept is illustrated in Figure 1.

Figure 1 shows actual annual yields per acre of soybeans in the

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Update

U.S. from 1987 to 2017. The line drawn through the data points represents a statistical best fit estimate of expected yields. If GMOs led to increased yields, the line should have changed slope when GMOs were introduced in 1996. As we see, the slope of the line remains constant as cultivation changed from non-GMO to GMOs (NAS 2016; USDA 2013).

A number of studies have compared genetically engineered glyphosate resistant (GR or GT) soybeans with the near isogenic parent cultivar (Fernandez-Cornejo et al. 2014). "Overall, studies have reported both increases and decreases in yield of GT compared to non-GT soybeans, but the best controlled studies suggest that GT has not increased—and may even have decreased—soybean yield" (Gurian-Sherman 2009).

GMOs are not used in Europe. When U.S. yields of GMO crops are compared with conventional crops grown in France and Germany, the data show that European yields have not suffered. Crops in the U.S. offer no significant yield advantage. In fact, European sugar beet yields are better than those seen in the U.S. (Hakim 2016).

Factors in Crop Yields

There are two kinds of crop yields—potential yields and actual yields. Potential yields reflect maximum output defined by seed genetics and optimal growing conditions. GMOs do not result in increased potential yields of the engineered cultivar (NAS 2016). In fact, GMOs can show yield reduction (yield drag) due to unintended effects on the plant genome introduced during insertion of the transgene. The initial Roundup Ready® soybean cultivar suffered from about a 5% yield drag compared to the near-isogenic parent cultivar (Elmore et al. 2001).

Actual yields reflect crop losses due to pests and unfavorable growing conditions such as drought. GMOs such as BT corn may improve actual yields by protecting the crop from pest loss. But this actual yield improvement can be produced by other pest management methods (NAS 2016).

The dips in soybean yields in 2003 and 2012 shown in the Figure were caused by drought. There are some studies that show that glyphosate sprays on GR soybeans (BRS 242 cultivar) lead to reduced water use efficiency. This effect might lead to greater losses of GR soybeans during drought years (Zobiole et al. 2010a). Glyphosate sprays may also kill earthworms, leading to fewer earthworm tunnels and reduced water infiltration (Gaupp et al. 2015).

Longterm Effects of GMOs and Glyphosate

After introduction of GMO soybeans in 1996, the percentage of GMO soybeans planted increased each year. By 2006, 97% of the soybean crop was GMO and glyphosate resistant (GR). From 2006 to 2012 the number of soybean acres planted each year remained generally stable, ranging from about 75 to 77 million acres. [An exception was a dramatic reduction in 2007 due to increased corn production.] Soybeans are usually planted either on acreage previously used for soybeans or in rotation with another crop, mostly GR corn. Over the period from 2006 to 2012, any trends resulting from glyphosate sprays and GMO agronomy should have become evident (USDA 2007; USDA 2013).

Yields Maintained by Increased Fertilization and Pesticides

As we see in Figure 1, during the period from 2006 to 2012, yields were lower than expected for 5 out of the 7 years. To maintain even these yields, a 51% increase in applied nitrogen (212 to 321 million lbs), 72% increase in phosphorous (P_2O_5) (773 to 1329 million lbs), and a 52% increase in potassium (K_2O) (1455 to 2215 million lbs) was needed (USDA 2007; 2013; 2016). See Table 1. When the numbers are corrected for the slight difference in acreage between 2006 and 2012, the increases are 48% N, 68% P, and 49% K.

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Conversion of cropland from biological nutrient management to synthetic fertilizers during the "green revolution" led to fertilizer increases even in non-GMO crops. And fertilizer application rates per acre to GMOs have not increased (Yamada et al. 2009). But conversion to GMOs has accelerated fertilization needs. As we see in the Table, the percentage of soybean acreage needing nitrogen and phosphorous has approximately doubled since 1994.

Fertilizer increases continued after 97% of the crop was converted to GMO in 2006. About 18% of soybean acres were fertilized with nitrogen in 2006, and 27% were fertilized in 2012. More nitrogen was needed to maintain yields in the GMOs despite the fact that soybeans have rhizobacteria that convert atmospheric nitrogen into fertilizer (USDA 2007; 2013; 2016a).

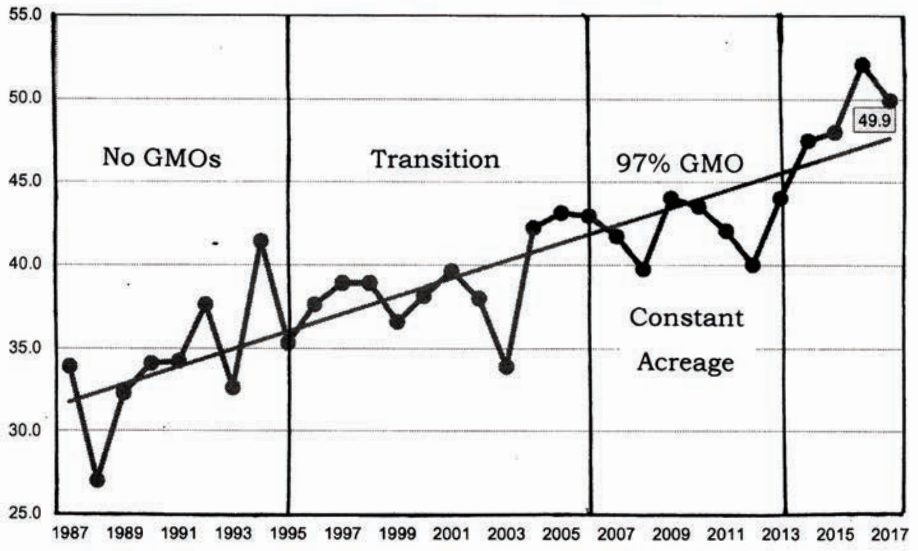
Increased phosphate (P_2O_5) and potassium (K_2O) were also needed. About 23% of soybean acres were fertilized with phosphate in 2006, and 37% in 2012. About 25% of acres were fertilized with potassium in 2006, and 37% in 2012 (USDA 2007; 2013; 2016a).

Glyphosate Effects on Soil Fertility

Why is increased fertilizer needed every year to maintain GMO soybean yields? Plant density should not be a factor, as producers tend to optimize the number of plants per acre and maintain that planting (Bain 2005). The soybean crop pulls nutrients out of the soil, and fertilizer is needed to replace those nutrients. But for similar crop yields (40 bu/acre) the amount of fertilizer needed to replace nutrients should not increase from year to year. Some of this fertilizer may not have been needed, and truly fertilizer pollution and the associated toxic algae blooms in streams and water bodies have been increasing (Dubrovsky and Hamilton 2010).

Another possibility is that glyphosate may have an effect on soil fertility. Soybeans are usually planted either on acreage previously used for soybeans or in rotation with another crop, mostly

Figure 1. Annual U.S. Soybean Yields in Bushels Per Acre*



*from USDA 2017a

Table 1. Fertilizer and Pesticides Applied Annually to Soybeans**

Year	% acres N	% acres P (P_2O_5)	% acres K (K_2O)	Total* N	Total* P_2O_5	Total* K_2O
1994	13	20	25	200	580	1248
1996	15	25	27	232	786	1474
2006	18	23	25	212	773	1455
2012	27	37	37	321	1329	2215
2015	28	39	38	382	1563	2503

*Total fertilizer applied in millions of pounds. Various forms of nitrogen were applied, calculated as N. Phosphorous was calculated as phosphate (P_2O_5), potassium as potash (K_2O).

Year	N lb per acre	P (P_2O_5) lb per acre	K (K_2O) lb per acre	% acres herbicides	% acres insecticides	% acres fungicides	Yield bu per acre	Acres millions
1994	25	47	82	98	1.0	<1	42.0	61.8
1996	24	49	85	98	1.6	<1	37.0	64.0
2006	16	46	80	98	16	4	42.7	75.5
2012	16	49	80	98	18	11	39.3	77.2
2015	17	51	83	96	22	11	47.5	82.7

**From USDA 1995, 1998, 2007, 2013, 2016ab, 2017a

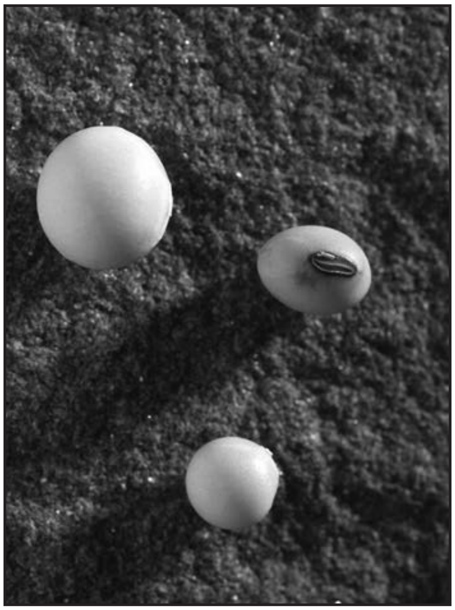


Photo by Scott Bauer courtesy USDA

USDA has developed many successful soybean varieties.

GR corn. In any case, glyphosate would tend to accumulate in areas where GR soybeans are planted. From 2006 to 2012, most corn and soybeans planted were glyphosate resistant. And grain crops used in soybean rotation were sprayed with glyphosate for desiccation (Cessna et al. 1994; USDA 2013; Fernandez-Cornejo et al. 2014; NAS 2016).

Effects of Glyphosate on Nitrogen Fixation

The 48% increase in nitrogen fertilizer use from 2006 to 2012 suggests that either the soil is being depleted of nitrogen, or there is a glyphosate effect on nitrogen fixation or both (USDA 2007, USDA 2013). Experiments to determine glyphosate effects on nitrogen fixation are either conducted in greenhouses or in the field. Variables in greenhouse experiments are easier to control, but relevance to actual growth conditions in field is sometimes unclear. Field experiments are dependent on a large number of factors that are hard to control, sometimes giving contradictory or ambiguous results (Duke et al. 2012).

Since glyphosate is translocated to roots, and the nitrogen fixing bacterium *Bradyrhizobium japonicum* is sensitive to glyphosate, we would expect that root nodulation and nitrogen fixation would be negatively affected. Several experiments have shown this to be true, especially when glyphosate is applied late in the growth cycle (Duke et al. 2012; Zobiole et al. 2012; Zobiole et al. 2010b; Zablotowitz and Reddy 2004; Cerdeira and Duke 2006). For instance, in a field experiment Bohm et al. (2009) found that root nodulation and nitrogen fixation in GR soybeans was depressed by glyphosate. There was no effect on yields because the plants increased their nitrogen uptake from the soil.

But there are other experiments that show glyphosate has no effect on soybean nitrogen fixation. Hungria et al. (2014) found no effect on biological nitrogen fixation or yields in a 3-year field study. Bohm et al. (2014) found no statistically significant effect on nitrogen fixation in a one-year field study in Brazil. Bellaloui et al. (2008) found no effect on nitrogen fixation, but glyphosate interfered with nitrate utilization and changed soybean metabolism, producing more protein and saturated fat. Zobiole et al. (2010d) also found glyphosate effects on soybean nutrition.

These conflicting studies are not too surprising, given the complexity of field experiments. Effects depend on “glyphosate dose, salt, time of application, soybean cultivar, geographical location and environmental conditions, and are accentuated under water stress and in sandy soils” (Hungria et al. 2014). So nitrogen fixation rates may be reduced by glyphosate under some field conditions.

Effects of Glyphosate on Mycorrhizae

Mycorrhizae help plants find phosphorous, generally increase plant access to nutrients, and may reduce nitrogen loss as nitrous oxide (N_2O) (Bender et al. 2016). Adverse effects on mycorrhizae could lead to increased nutrient requirements. Some studies show that mycorrhizae can be affected by glyphosate applications. Druille et al. (2013; 2013a) found that glyphosate killed mycorrhizal spores and reduced root colonization in *Lolium multiflorum*. Zaller et al. (2014) found a 40% reduction of the mycorrhizal fungus *Glomus mosseae* after glyphosate application. Other studies show no effect of glyphosate on mycorrhizae (Powell et al. 2009; Savin et al. 2009).

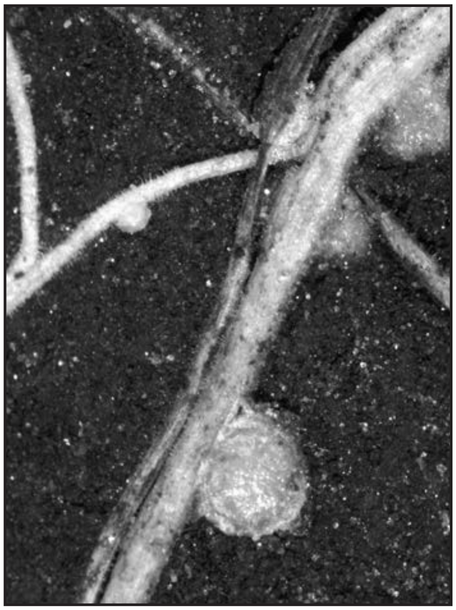


Photo by Markus Dubach courtesy of USDA

Nitrogen-fixing bacteria form nodules on the roots of soybean plants.

Glyphosate Changes Soil Microbiome

Glyphosate is an antibiotic, and longterm cropping with glyphosate resistant (GR) GMO soybeans can change the soil microbiome (Wolmarans and Swart 2014). Applications of glyphosate to soil stimulates microbial activity (Haney et al. 2000; Lancaster et al. 2010), but chronic exposure may lead to elimination of sensitive microbes (Zabaloy et al. 2012). A 10-year field study in Brazil showed no difference in grain yields between the conventional soybean cultivar and a near isogenic GMO. But GMO fields had higher numbers of Proteobacteria, Firmicutes and Chlorophyta. Conventional fields had larger numbers of Actinobacteria and Acidobacteria (Babujia et al. 2016). Actinobacteria include beneficial microbes such as *Streptomyces* that antagonize pathogens (Cha et al. 2016).

Update

In a greenhouse study, Newman et al. (2016) also found that glyphosate applications to GR soybeans led to higher numbers of Proteobacteria, and fewer Acidobacteria in the soil. The authors believed that a decrease in Acidobacteria could "lead to significant changes in nutrient status of the rhizosphere." Decrease in Acidobacteria was especially noticeable in GR corn, and this fact is significant because of the ubiquitous corn-soybean rotation.

In a greenhouse study, Zobiole et al. (2010c) found that glyphosate applications to GR soybeans increased root colonization of *Fusarium* and decreased beneficial fluorescent pseudomonad bacteria in the rhizosphere. Kremer and Means (2009) found that glyphosate decreased pseudomonads and increased bacteria that oxidize manganese (Mn) in the rhizosphere of GR soybeans, leading to reduced plant availability of this essential nutrient.

Effects on Micronutrients

Glyphosate is a chelator, and some studies show that glyphosate can interfere with micronutrients such as Zn, Mn, and Fe in GR soybean crops. Other studies show there is no effect (Wolmarans and Swart 2014). Duke et al. (2012) believe the "contradictory results could be entirely or in part due to due to differences in soils, climatic conditions, and/or GR cultivars used."

Effects on Earthworms

Earthworms burrow through the soil, improving water infiltration and aeration. They ingest soil plant litter, and produce up to 40 tons/ha (16 tons/acre) annually of earthworm casts (excrement) that improve soil fertility. Application of Roundup to soil in a greenhouse experiment led to a 46% reduction in cast production by *Lumbricus terrestris*, and to a 56% reduction in viable eggs for *Aporrectodea caliginosa*. Glyphosate could thus interfere with soil water infiltration and have negative effects on soil fertility due to its effects on earthworms. Whether this happens in field conditions has not been investigated (Gaupp et al. 2015; Zaller et al. 2014).

Photo by Keith Weller courtesy USDA

Glyphosate resistant weeds have led to increased cultivation and production of soybeans resistant to other herbicides.

Better Yields with Acreage Increase

Yields were mostly below expected values when about the same acreage (75-77 million acres) was farmed from 2006 to 2013 (see Figure 1). Soybean yields increased when acreage was expanded to 83 million acres in 2014, and to nearly 89 million acres in 2017. Part of the yield increase might have been due to the introduction of new fields that had not been sprayed with glyphosate or depleted of nutrients by soybean production. Introduction of a GR soybean in 2009 (Roundup Ready 2 Yield®) with less yield drag may have had an effect, and farmers enjoyed good growing conditions from 2014 to 2017. The year 2016, for instance, had optimal rainfall (USDA 2016a; USDA 2017b; Gurian-Sherman 2009).

Increased Herbicide Applications

Not only are increased fertilizers, but increased pesticides are also needed by GMOs. Table 1 shows that the percent of acreage treated with herbicides did not increase from 1996 to 2012. However, GR soybeans led to a large increase in the amount of herbicide applied per acre. USDA statistics show a 43% increase in herbicide use on soybeans between 1996 and 2006, and most of this was glyphosate (Benbrook 2012). One large study of farmers showed GR soybeans led to a 28% increase in herbicides from 1998 to 2011 (Perry et al. 2016).

After conversion of 97% of the crop to GMO in 2006, herbicide use continued to increase. The amount of glyphosate applied increased from 91.9 million lbs on 75.5 million acres in 2006 to 100.4 million lbs on 77.2 million acres in 2012. Glyphosate use increased because increased fertilizer was encouraging weeds, and weeds were becoming resistant to glyphosate. (USDA 2007; USDA 2013).

Glyphosate Resistant Weeds

Because of the widespread use of glyphosate, many weed species have become resistant. Reliance on one herbicide has led to glyphosate resistance in at least 14 important weed species and biotypes in the U.S. Worldwide, there may be 34 resistant species. These include horseweed, *Conyza canadensis*; Palmer amaranth,

Photo courtesy of Bob Williams and Stewart Farm

Resistant horseweed, *Conyza canadensis*, covers millions of acres of glyphosate resistant GMOs.

Amaranthus palmeri; ragweed, *Ambrosia* spp.; Johnsongrass, *Sorghum halepense* and others (Schutte et al. 2017; Fernandez-Cornejo et al. 2014; Duke and Powles 2009; Quarles 2012).

Glyphosate started to lose effectiveness in 2012, and other herbicides were applied at an increased rate. Farmers also increased the use of tillage for weed control, and there was an 8% decline in no-till production (USDA 2014). Because other herbicides were needed, new stacked traits and engineered resistance to other herbicides were developed. Enlist Duo® crops are resistant to 2,4-D and glyphosate. Xtend® crops are resistant to glyphosate and dicamba. Aerial applications of 2,4-D and dicamba along with glyphosate can only increase problems with environmental pollution (Benbrook 2012).

Dicamba Non-Target Effects

Dicamba is already causing problems with non-target crop destruction. When dicamba is applied to resistant crops, it drifts onto non-resistant crops, causing damage. Dicamba also may be volatilizing, then being dispersed in rainfall. Complaints involving 3.1 million acres of damaged soybeans in 30 states have been registered. The State of Arkansas may restrict the product again next year (Hakim 2017). As little as 0.75 g/ha (300 mg/acre) of dicamba applied from a contaminated spray tank can cause damage to glyphosate resistant soybeans (Soltani et al. 2015).

Effects on Insects and Disease

Insecticide and fungicide applications also increased when soybeans were converted to GMOs (see Table 1). In 1994, 1% or less of the acreage was treated. Insecticides were applied to 16% of acres in 2006, increasing to 18% in 2012, and to 22% in 2015. Global warming, increased monocultures, and increased fertilizer may have encouraged insects such as the soybean aphid, *Aphis glycines* (Quarles 2007; Flint 2016). Fungicides surged from less than 1% of the acreage in 1994 to 4% in 2006, and to 11% of acreage in 2012. Fungicides were increased despite the fact that 2012 was a dry year (USDA 2007; 2013; 2014).

More fungicide might have been needed because glyphosate may have encouraged disease. Duke et al. (2012) believe that the consensus of the published literature is that GR soybeans treated with glyphosate are not more susceptible to disease than the near isogenic conventional soybean. However, fungicide applications are clearly increasing in GR soybeans (USDA 2007; USDA 2013). Usually this means there are increasing problems with fungal diseases. And increased problems from seed phomopis (caused by *Phomopsis longicolla*), soybean rust (caused by *Phakopsora pachyrhizi*), and soybean sudden death syndrome (caused by *Fusarium solani*) have been noticed (Njiti et al. 2003; Del Ponte et al. 2006; Johal and Huber 2009).

Glyphosate definitely encourages disease in glyphosate susceptible soybeans. The glyphosate applied translocates to roots and is released in soil. *Fusarium* and other pathogenic fungi accumulate around the roots in order to metabolize glyphosate. Glyphosate also encourages the root rot fungus *Pythium* (Duke et al. 2012; Johal and Huber 2009; Kremer and Means 2009).

Some studies show that glyphosate also may stimulate root pathogens in GR soybeans. Effects are greater if the cultivar used for transgenic conversion is susceptible to *Fusarium*. For this reason, some early GR cultivars were affected by sudden death syndrome caused by *Fusarium solani* (Duke et al. 2012; Njiti et al. 2003). Moisture may be a factor. Means and Kremer (2007) found that *Fusarium* colonization of GR soybean roots increased with the amount of soil moisture.

Environmental Pollution from Fertilizer and Pesticide

Nitrogen fertilizers are converted to nitrous oxide, which is a greenhouse gas that can worsen the effects of global warming. Excess runoff of phosphorous and nitrogen into streams and water bodies causes growth of toxic algae. The combined effects of global warming and fertilizer are causing toxic algae blooms to worsen. Phosphorous fertilizer increases bioavailability of glyphosate, and leads to glyphosate runoff. Nearly every stream, river, and reservoir in heavily farmed regions contain glyphosate and its degradation products (Sasal 2015; Dubrovsky and Hamilton 2010; Chang et al. 2011; Battaglin et al. 2005; Quarles 2016ab).

Aerial sprays of glyphosate are destroying milkweed that provides habitat for the monarch butterfly, *Danaus plexippus*. About 0.7% of glyphosate applied to soil goes airborne and is removed from air by rainfall. Application of glyphosate to GMO crops leaves residues that are found in processed food products. In the U.S. glyphosate has been found in 93% of people tested (Quarles 2016ab; Chang et al. 2011; Pleasants and Oberhauser

2012; Bohn et al. 2014; Detox 2016; Murphy and Rowlands 2016; Bai and Ogbourne 2016; Schutte et al. 2017).

WOTUS Rule

The increased pesticide and fertilizer pollution produced by GMOs has driven the corn and soybean industries to pressure for repeal of the 2015 WOTUS (Waters of the United States) rule. This rule extended protection of the Clean Water Act to headwaters and water sources other than navigable waterways (EPA 2017). The WOTUS rule is needed. In 133 streams sampled from 1992-2004, nitrogen and phosphorous levels were 2-10 times greater than levels known to affect wildlife. Nearly 30% of agricultural streams had nitrate levels higher than the MCL (Maximum Contaminant Level) (Dubrovsky and Hamilton 2010).

Conclusion

GMOs generally do not lead to improved crop yields over a near-isogenic non-GMO cultivar. Continuous glyphosate applications generally do not lead to reduced yields. However, maintenance of yields requires nearly 50-70% increases in applied fertilizer. Some of the fertilizer required is due to nutrient depletion. Some of the added fertilizer may be needed because of glyphosate effects on soil fertility. Some studies show glyphosate may interfere with nitrogen fixation, or nitrogen uptake, requiring more nitrogen. Whether there are soil fertility effects on phosphate and potassium has not been conclusively researched.

Added fertilizer needed to maintain yields may be causing a surge in weeds. Additional glyphosate to control the weed surge has led to resistant weeds. Resistant weeds have led to increases in tillage and new GMOs resistant to other herbicides. Problems have already occurred with dicamba resistant soybeans. New GMOs with resistance to 5 different herbicides will inevitably lead to increased pesticide pollution and pesticide exposures.

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Conference Notes

ESA-ICE 2016 Meeting Highlights

By Joel Grossman

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

Seed Treatment Alternatives

Alternative seed treatments with the plant hormones salicylic acid (SA) and methyl jasmonate (MJ) induced systemic acquired resistance (SAR) in lettuce, *Lactuca sativa*, and rocket/argula, *Diplotaxis tenuifolia*, protecting seedlings from pests such as sweet potato whitefly, *Bemisia tabaci*, said Mengqi Zhang (Ben-Gurion Univ Negev, Sede Boker 8499000, Israel; zhangmengqi614@gmail.com). Treated seeds were germinated in trays, then seedlings were transplanted into pots in a greenhouse at the 2-3 true leaf stage. The natural field-insect population was monitored with sticky traps.

Whitefly development was slower, and whiteflies laid fewer eggs on seedlings grown from seeds treated with the plant hormones. MJ suppressed the development of whitefly nymphs, however, overly high MJ and SA doses inhibit seed germination, more so for lettuce than rocket/argula. Plants grown from treated seeds release volatiles, which may deter whitefly egg laying.

Neonicotinoids in Corn Ecosystems

Only 3.5 parts per billion (ppb) of the neonicotinoids thiamethoxam and imidacloprid are needed to induce adverse effects in honey bees, raising concerns in Canada's Ontario and Quebec provinces, where 100% of the corn seed is neonicotinoid treated, said Nadejda Tsvetkov (York Univ, 4700 Keele St, Toronto, ON M3J 1P3, Canada; nadiats@yorku.ca).

A "field-realistic" risk analysis evaluated timing of honey bee exposure and quantities of 23 pesticides in plant pollens both near and far from corn fields. Tsvetkov suspected synergisms among multiple pesticides including boscalid, a fungicide active ingredient, and the common herbicide linuron. No corn pollen samples and only one soybean pollen sample contained neonicotinoids. However, water-soluble neonicotinoids (possibly from corn fields) were common in clover pollen and willow tree pollen and in bee colonies. Thus, water transport may move neonicotinoids from corn fields to elsewhere in the ecosystem where exposure may occur.

Beneficial Nematodes in IPM

"Beneficial entomopathogenic nematodes (EPNs) are well-adapted to the soil environment and are non-toxic," especially in comparison to soil insecticides, many of which "are either/or highly toxic to humans, have serious other non-target effects, or are banned," said Michael Zellner (Bavarian State Res Centre Agric, Lange Point 10, 85354 Freising, Germany; Michael.Zellner@lfl.bayern.de). This is especially important, as "soil insect pests cause major crop losses as they are difficult to control."

Steinernema feltiae (Nemasys®), an entomopathogenic nematode (EPN), "has been used successfully for the last ten years by (USA) mushroom growers to manage fungus gnats," said Shaun Berry (BASF, 26 Davis Dr, Res Triangle Park, NC 27709; shaun.berry@basf.com). Chrysanthemum and cut flower growers in the Netherlands use the EPN for biocontrol of western flower thrips, *Frankliniella occidentallis*, which has "resistance to the majority of conventional insecticides." EPN soil drenches target thrips pupae in the soil. High water volume sprays target adult thrips. Benefits include no crop reentry intervals, compatibility with most application systems, and effectiveness when used with other biologicals in IPM programs.

Cotton Fleahopper may be Beneficial

Cotton fleahopper, *Pseudatomoscelis seriatus*, a piercing-sucking pest of early season small flower buds and apical meristems in southern USA cotton, is not a pest during the later flowering and boll stages, "but they can persist in fields until dispersing into weedy hosts (e.g. croton) in the fall," said Loriann Garcia (Austin College, 900 N Grand Ave, Sherman, TX 75090; lgarcia@austincollege.edu). Cotton fleahoppers consume eggs of caterpillar pests such as tobacco budworm, *Heliothis virescens*, and beet armyworm, *Spodoptera exigua*. New research shows that cotton fleahoppers also consume neonate caterpillars and whiteflies. Instead of spraying fleahoppers with insecticides, IPM programs can utilize these omnivorous insects for biological control of more damaging cotton pests.

Conference Notes

Collard Companions Depress Pea Aphid

"We examined pea aphid, *Acyrthosiphon pisum*, suppression in response to intercropping the pea aphid host plant, fava beans, *Vicia faba*, with a non-host plant, collards, *Brassica oleracea*," said Kathryn Ingerslew (Univ Missouri, 52 Agri Lab, Columbia, MO 65211; ksiggc@mail.missouri.edu). Pea aphids were reduced in the intercrop, but the reduction could not be explained by plant or herbivore diversity. However, green peach aphid, *Myzus persicae*, and caterpillars of the diamondback moth, *Plutella xylostella*, "feeding exclusively on collards" attracted "a more diverse and abundant community of parasitoid wasps including *Diaretiella rapae* and *Diadegma insulare* to the intercrop."

Although *D. rapae* and *D. insulare* feeding on collard pests are not pea aphid natural enemies, pea aphids instinctively drop off faba bean plants when buzzed by wasps and are effectively removed from the crop.

Cabbage Maggot Exclusion Netting

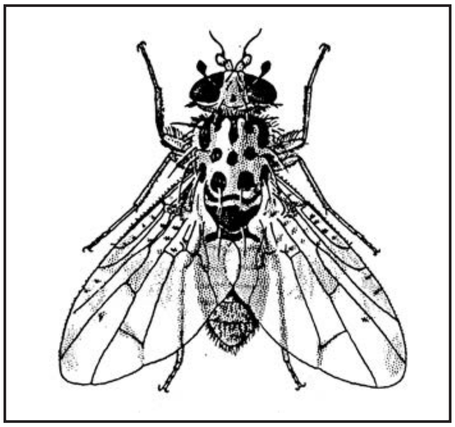
Long-lasting polyethylene insect netting secured at the edges with soil or sand bags is "one of the most promising IPM tools" used worldwide for cabbage maggot (CM), *Delia radicum*, said Carolyn Parsons (Agri-Food Canada, 308 Brookfield Rd, St. John's, NF A1E 0B2, Canada; carolyn.parsons@agr.gc.ca). It currently is used on a large scale in the UK, particularly Scotland.

Long-term field trials using tractor-drawn machinery to mechanically install and remove the netting are underway in Canada. The netting, available in many mesh or gauge sizes, has a high initial cost; but it can be reused over a decade, making the annual cost reasonable.

Even with exclusion netting, an IPM approach with crop rotation, biocontrol and weed management is recommended to prevent CM development under the netting. "Relay cropping (e.g. with lettuce) can be used for first generation CM control in leafy brassicas without causing undue crop competition,"said Parsons. "Of the biopesticides tested, Met52® (*Metarhizium anisopliae* Strain F52) was the most effective with 70% CM mortality in controlled bioassays."

New Jersey Herbal Interplants

"Biological control of *Ostrinia nubilalis*, European corn borer (ECB), is challenging in peppers due to the neonate behavior of boring into the fruit of host plants, where they are protected from predators and parasitoids," said George Condon (Rutgers, 96 Lipman Dr, New Brunswick, NJ 08901; george.condon@rutgers.edu). "Bickerton and Hamilton (2012) demonstrated that intercropping of three flowering insectary plants, dill, *Anethum graveolens*; coriander, *Coriandrum sativum*; and buckwheat, *Fagopyrum esculentum* can provide increased predation of *O. nubilalis* eggs in peppers."



Medfly, *Ceratitis capitata*

Recent New Jersey field trials interplanted coriander, dill and fennel, *Foeniculum vulgare*, alone and in combination between and within pepper rows, with non-intercropped peppers as controls. "Intercropping, the practice of planting secondary crops, and timing transplants to the field so flowering coincides to provide food resources of nectar or pollen," provides microhabitat for natural enemy protection and egg laying, said Condon. The idea is for natural enemies to move from insectary interplants into adjacent primary crops to "enhance biological control of *O. nubilalis* eggs and neonate larvae prior to tunneling into pepper fruits so as to prevent economic damage." In 2015, interplants between rows of peppers reduced fruit damage more effectively than interplants within rows.

Fruit Fly Attract and Kill

"Fruit flies are among the most damaging agricultural pests worldwide," and "most growers rely on organophosphate insecticides" whose overuse is "implicated in secondary pest outbreaks, negative impacts on beneficial insects, environmental contamination, hazards to human health, and resistance development," said Rodrigo Oliveira da Silva (ISCA Tech, 1230 Spring St, Riverside, CA 92507; rodrigo.silva@iscatech.com). "Because attract and kill (A&K) pairs a chemical toxicant with a powerful attractant, only a tiny fraction of the former is required, compared to conventional cover spray applications. ISCA's slow-release matrix anchors the active ingredients in place, reducing the likelihood of environmental degradation or soil or water contamination."

Controlled-release semiochemical formulations resist UV light degradation and rain. Anamed® with spinosad sprayed on mango and citrus leaves subjected to simulated rainfall was superior to GF-120® against South American fruit fly, *Anastrepha fraterculus*, in Brazil. Other desirable properties include biological inertness, biodegradability and sufficient spray flowability for hand, all-terrain vehicle, aerial and other release modes. A&K formulations can also be applied selectively to lure pests away from crops.

Hook ME+CL+TML, an A&K formulation, combines multiple fruit fly attractants: eugenol (ME); the fruit fly parapheromone

Cuelure (CL); and Trimedlure (TML) for Mediterranean fruit fly, *Ceratitis capitata*. Sprayable fruit fly semiochemical attractants with hydrolyzed protein, eugenol (attractant) and spinosad (toxicant), provided 90% mortality of carambola fruit fly, *Bactrocera carambolae*.

Microbial Microbeads

"Solar radiation, UV-A and UV-B, is a major contributor to degradation of fungal activity on plant surfaces, and largely responsible for short field persistence, limiting use" of insect-killing fungi such as *Beauveria* and *Metarhizium* spp. against chewing insects such as the migratory grasshopper, *Melanoplus sanguinipes*, said Stefan Jaronski (USDA-ARS, 1500 N. Central Av, Sidney, MT 59270; stefan.jaronski@ars.usda.gov). "Ecopesticides International Inc. (Santa Fe, NM) developed a method of producing fungal spores coated with a low-cost, proprietary formulation of the UV protectant carbon black combined with alginate polymerization to produce microbeads of 50-100 microns in diameter, suitable for spraying."

The microbeads greatly increased the persistence of both microbials, with a 500% to 1,500% increase in the ED50 (median effective dose) under UV-B exposure. "We believe efficacy of these UV-protected microbeads of fungal conidia is due not to infection via the alimentary system, but rather crushing of microbeads during feeding and percutaneous infection through cuticle around the grasshopper mouthparts and buccal cavity. This phenomena should also be applicable to any chewing insect pest."

Sounds for IPM

Sound can disrupt insect reproduction and reduce population growth. Perhaps the best example comes from vineyards in Italy and Slovenia, where wires transmitting sounds (substrate-borne vibrations) reduce mating frequency 96% in grape leafhoppers vectoring grapevine yellows disease, said Nicholas Aflitto (Cornell Univ, 4138 Comstock Hall, Ithaca, NY 14853; na398@cornell.edu). Bark beetle responses to biologically-relevant sounds vary from species to species. But sound can reduce bark beetle egg laying to zero, and significantly reduce larval gallery tunneling.

In tube and tree entry experiments, southern pine beetle, *Dendroctonus frontalis*, western pine beetle, *D. brevicomis*, and pine engraver, *Ips pini*, were exposed to same-species stress calls, conspecific third party stress calls and noise. Same-species stress calls reduced beetle entry into logs by 71%, an indication stress sounds can be a valid IPM tool.

Commercialization requires further analysis of variables like signal attenuation, tree tissue density, moisture, and effects on predators. Many "weird sounds are found in other pest systems," said Aflitto. Woodpecker sounds may be biologically relevant in woodboring beetle ecosystems, and sound waves are being used to kill mosquito larvae.

Water Hyacinth Biocontrol in California

"Water hyacinth, *Eichhornia crassipes*, native to South America, is an invasive floating aquatic weed in the Sacramento San Joaquin Delta and associated rivers of northern California, as in many tropical and subtropical aquatic ecosystems in the USA, Mexico, Central America, Europe, Africa, Asia, Australia, Indonesia and many Pacific Ocean countries," said Patrick Moran (USDA-ARS, 800 Buchanan St, Albany, CA 94710; Patrick.Moran@ars.usda.gov). "Water hyacinth impedes navigation, blocks water flow for agriculture and human use, and degrades aquatic ecosystems. Prior releases of biological control agents have not led to control in California."

However, a 2011-2013 release of 30,000 planthoppers, *Megamelus scutellaris*, with 4 generations spreading 50 m (164 ft) per year, resulted in 15 insects per plant by 2015; and 27% fewer leaves and 40% less water hyacinth biomass in the release area. More planthoppers are being released adjacent to the Sacramento-San Joaquin Delta.

Dengue Ovitraps

Female *Aedes* mosquitoes vectoring dengue sense the presence of water, and enter traps with domes and funnels covering plastic containers with water for egg laying, said Hidayatulfathi Othman (Natl Univ Malaysia, 50300 Kuala Lumpur, Malaysia; hida@ukm.edu.my). In Malaysia, lethal ovitraps (egg-laying traps) that attract container breeding mosquitoes are designed to blend into neighborhoods. Success can be measured as fewer dengue cases, fewer mosquito eggs per week, or fewer next generation dengue vectors. Ovitraps are inexpensive and require minimal staff labor for placement and servicing.

"In 1997, US Army entomologists Michael Perich and Brian Zeichner submitted their first patent application for a lethal mosquito breeding container, the lethal ovitrap," which was tested in the Florida Keys after a 2010 dengue outbreak, said Rebecca Heinig (SpringStar Inc, PO Box 2622, Woodinville, WA 98072; rheinig@springstar.net). The idea behind lethal ovitraps is to reduce next generation mosquitoes, by eliminating the egg stage.

Commercial versions of the lethal ovitrap, licensed from the U.S. Army, have been registered in Puerto Rico and Trinidad, and are being used with community groups in Hawaii to combat a recent dengue outbreak. In Peru, lethal ovitraps have eliminated indoor dengue vectors, which can breed in a bottle cap with water. Bangladesh also reports significant mosquito reductions. In Brazil, traps reduced dengue vector populations 50% to 90%, depending on the location. Trap-N-Kill® mosquito traps, commercial versions of lethal ovitraps, are now sold in USA big box stores such as Home Depot.

Asian Citrus Psyllid IPM in Florida

Florida's 345,000 ha (850,000 acres) are 70% of USA citrus and 90% of USA oranges, mostly processed for juice and a major source of income and jobs, said

Calendar

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

December 5-8, 2017. Acres USA Annual Conference. Columbus, OH. Contact: 800-355-5313; acresusa.com/events.

January 8-11, 2018. Advanced Landscape IPM Short Course. University of Maryland. Contact: Joshua Kiner, Dept. Entomol., 301-405-3913; email umdentomology@umd.edu

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 Eco-Farm 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

June 20-23, 2018. Annual Meeting, Pest Control Operators of California. Harrah's, South Lake Tahoe, NV. Contact: PCOC, 3031, Beacon Blvd., W. Sacramento, CA 95691; www.pcoc.org

August 5-10, 2018. 102nd Annual Conference, Ecological Society of America. New Orleans, LA. Contact: www.esa.org

Conference Notes

Philip Stansly (Univ Florida, 2686 State Rd 29 North, Immokalee, FL 34142; pstansly@ufl.edu). Most mature trees (>5 years old) are infected with huanglongbing (HLB) vectored by Asian citrus psyllid (ACP), *Diaphorina citri*. Thus, diseased trees are too numerous to rogue (remove). Protecting young trees is "the future of the industry." This necessitates bringing healthy trees into rapid production via clean nursery stock, vector (ACP) control and reduced tree stress.

"Florida citrus production has plummeted by almost 50% in the last 10 years, although many growers maintain yields in spite of HLB by increasing inputs of insecticides and nutrients," said Stansly. Economic thresholds for young citrus trees are lacking. Systemic insecticides, mainly neonicotinoids (thiamethoxam, clothianidin, imidacloprid), protect new growth flushes on "resets" (high-density solid set replantings). IPM measures also include: weed control; soil amendments such as compost; and a white polyethylene mulch with drip irrigation delivery of neonicotinoids to plant roots (cheaper than spraying orchard floors).

Initial trials using fence-hole diggers to transplant trees into UV-reflective mulches "worked very well," said Stansly. The UV-reflective mulches are similar in concept to the silver mulches reflecting UV (ultraviolet) light to repel vectors from vegetable crops. UV is associated with the sky above, confusing insects in flight when reflected from ground level. White mulches vary, some reflecting UV and repelling insects; other whites formulated with titanium dioxide (TiO_2) absorb UV, and neither repel nor stop ACP from landing on plants. Field tests combining drip irrigation insecticide delivery and metalized UV-reflective mulches were "dramatically different visually," and boosted citrus yields 44% compared to insecticide alone.

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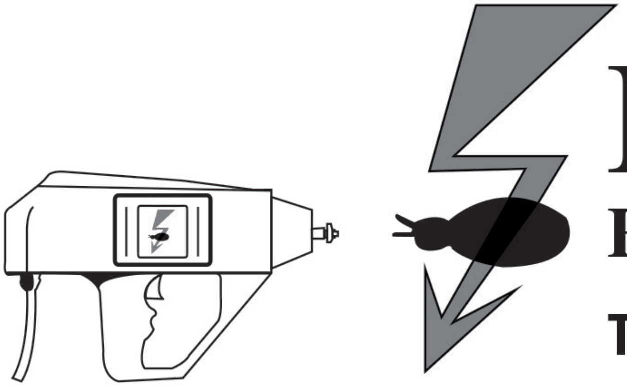

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