The IPM Practitioner
Monitoring the Field of Pest Management
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Special Pheromone Report

Brave New World—Systemic Pesticides and Genetically Engineered Crops

By William Quarles

Photo courtesy Glenda Denniston, UW-Madison Lakeshore Nature Preserve

Glyphosate applications associated with GR crops have destroyed milkweed habitat of the monarch butterfly, *Danaus plexippus*, leading to an 81% reduction of Midwest monarch populations.

Almost overnight, genetically engineered (GE) crops have profoundly changed agriculture in the U.S. Leading the way have been corn, soybean, and cotton crops resistant to the herbicide glyphosate. As a result, traditional farming and IPM methods have been tossed aside and replaced with a simplistic solution. Seeds are drilled into the soil without cultivation. When weeds appear, fields and crops are sprayed with glyphosate, usually by aerial application. Repeated applications are needed, and glyphosate resistant (GR) crops are often grown in the same field, year after year (Duke and Powles 2009; Mortensen et al. 2012).

Glyphosate is systemically absorbed by the crop, and it appears in the food sold for consumption (EPA 2011; Arregui et al. 2004; Duke 2011). Other GE changes include crops that grow their own pesticide. Genes from the bacterium *Bacillus thuringiensis* (BT) are inserted into plant genomes. Each plant cell produces insecticidal proteins, and these insecticides are incorporated into the food (Gassmann 2012).

Genetically engineered foods are not labeled, despite the fact that 90% of Americans support labeling (Acres 2012). Consumers are exposed to these new genetic creations and their systemic pesticides without their knowledge. The effects of longterm, widespread exposure to these products have not been fully investigated, and most of the studies supporting their safety have been produced by industry (Antoniou et al. 2011; Antoniou et al. 2012).

Large Pesticide Increase

Overall, GE crops have caused a large pesticide increase. BT crops have led to less applied insecticide, but GR crops need large amounts of glyphosate. Roundup Ready® GR crops were introduced in 1996, and cumulative pesticide use over 16 years has increased by about 400 million lbs (182 million kg) (Benbrook 2009; Benbrook 2012). These production systems are not sustainable, but agribusiness has bet America's future on GE crops, in exchange for large, shortterm corporate profits.

GE crops are not sustainable because farmers rely on larger amounts of fewer pesticides. Weeds and pest insects then become resistant, and resistance increases pesticide applications (Duke and Powles 2009). GR crops actually reduced herbicide applications over the first three years after their introduction. But rapid emergence of resistant weeds has caused large glyphosate increases each year. For instance, there was a 31% increase

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Update

in glyphosate use from 2007 to 2008 (Benbrook 2009).

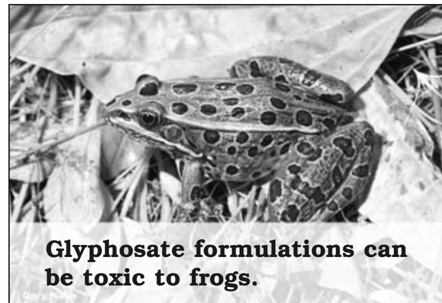
Repeated use of the same pesticides is leading to their buildup in soil and contamination of water and air (Chang et al. 2011; Battaglin et al. 2005). GE crops have caused destruction of habitat for the monarch butterfly and other environmental problems (Hartzler 2010; Pleasants and Oberhauser 2012; Antoniou et al. 2012). Resistance to BT and invasion of secondary pests have led to systemic seed treatments with neonicotinoid pesticides that have toxic effects on bees (Quarles 2011; Hopwood et al. 2012; Krupke et al. 2012). More than 45% of U.S. cropland is now treated with systemic chemical pesticides (Stokstad 2012).

Scope of the Problem

GE canola, sugarbeets, corn, soybeans, and cotton are grown commercially in the U.S. (Duke and Powles 2009). Since most of the acreage is devoted to GE soybeans, cotton, and corn, only these crops will be discussed here. In 2008, herbicide resistant soybeans, cotton, and corn represented 92%, 93%, and 63% of total acres planted to each crop in the U.S., and amount was increasing each year (Benbrook 2009). In 2011, 94% of all U.S. soybeans were GE glyphosate resistant. Since GR soybeans were first planted, there has been a 97% glyphosate increase in soybeans, from 3 million lbs (1.4 million kg) in 1994 to 92 million lbs (41.7 million kg) in 2006 (Pleasants and Oberhauser 2012).

In 2011, about 72% of all U.S. corn was GE glyphosate resistant. There has been a 94% glyphosate increase in corn, from 4 million lbs (1.8 million kg) in 2000 to 63 million lbs (28.5 million kg) in 2010 (Pleasants and Oberhauser 2012).

California has fewer acres of GE crops planted than areas such as the Midwest, but glyphosate use in California has doubled since 1996, the first year that Roundup Ready crops were used. About 4.2 million lbs (1.9 million kg) of glyphosate and its salts were applied in 1996,



Glyphosate formulations can be toxic to frogs.

Photo courtesy Gary Nafis

and about 8.6 million lbs (3.9 million kg) were applied in 2010 (CA DPR 1996; 2010).

In 2008, 57% of the corn acreage and 73% of the cotton acreage in the U.S. had been planted in BT varieties (Benbrook 2009). In 2010, over 58 million acres (23.5 ha) worldwide were planted to BT crops, mostly cotton and corn (Gassmann 2012).

Monarch Butterfly

Habitat destruction of the monarch butterfly, *Danaus plexippus*, represents one of the first large scale environmental catastrophes due to GE crops. The monarch butterfly is one of the best known environmental icons (Brower and Malcolm 1991). Developing caterpillars of the monarch are dependent on wild stands of milkweed, *Asclepias* spp. From the milkweed they obtain the chemicals that give them a bad taste, and thus protect them from predators (Malcolm et al. 1989).

Milkweed is especially sensitive to glyphosate, and stands along crop edges have been destroyed by massive glyphosate applications associated with GE crops. There has been an 81-90% reduction of milkweed on farmland in Iowa. Similar reductions are found throughout the Midwest where GE crops are planted (Hartzler 2010; Pleasants and Oberhauser 2012).

From 1999 to 2010 disappearing milkweed insectary plants have led to an 81% decline in Midwest production of migrating monarchs. Partly due to this reduction, overwintering populations in Mexico have dropped by 65% (Pleasants and Oberhauser 2012; Brower et al. 2012).

Frogs, Pathogens, Nutrients

Pesticides may be one of the causes of widespread amphibian decline seen over the last 30 years. More than one-third of amphibian species are now threatened with extinction. Glyphosate formulations containing various surfactants and inerts may cause amphibian toxicity, including birth defects (Paetow et al. 2012; Paganelli et al. 2010; Howe et al. 2004). Glyphosate formulations are toxic to tadpoles, and some studies have shown that glyphosate formulations kill tadpoles in natural settings (Relyea 2005a; Moore et al. 2012; Williams and Semlitsch 2010). Glyphosate formulations can reduce species diversity of frogs and other species in aquatic communities (Relyea 2005b). (See Box A)

Glyphosate binds to micronutrients in the soil, making them less available for plant nutrition. Low levels of glyphosate reduce root uptake of Fe, Mn, Zn, and Cu, making plants more susceptible to disease. The problem is worsened with the increased glyphosate application seen with GE crops (Johal and Huber 2009). Sprays of glyphosate increase populations of plant pathogens in soil (Cerdeira and Duke 2010; Duke et al. 2007). Roots of GR soybeans and corn are heavily colonized by *Fusarium* (Kremer and Means 2009). Roundup Ready seeds are now being treated with the fungicide pyraclostrobin (Acceleron®) to help deal with the disease problem. In 2010, 11% of corn was treated with fungicides. Less than 1% of corn had been treated in earlier years (Benbrook 2012; Antoniou et al. 2012).

Box A. Glyphosate Problems

Glyphosate herbicide was originally developed by John Franz at Monsanto in 1970. It works by inhibiting a key enzyme needed for plant growth. It is broadspectrum and will affect most higher plants. Differences in damage between plant species is due mainly to differences in absorption (Duke and Powles 2008).

Glyphosate has low acute toxicity, and a generally benign toxicological profile (Duke and Powles 2008; Mink et al. 2011). But some studies have shown that glyphosate or its formulations may cause birth defects and endocrine disruption problems in animals (Richard et al. 2005; Paganelli et al. 2010; Dallegrave et al. 2003). Reduced testosterone and delayed puberty has been seen in rats at relatively low concentrations (Dallegrave et al. 2007; Romano et al. 2010). Most of the controversy coming from these studies is centered on what is an environmentally relevant amount (Antoniou et al. 2011; Williams et al. 2012).

Applicators that use glyphosate often absorb it. One study showed that 60% of farmers that use it have traces of glyphosate in their urine (Acquavella et al. 2004; Battaglin et al. 2005). A large scale epidemiologic study of exposed farmers showed an association with multiple myeloma (de Roos et al. 2005). Another study showed a connection with non-Hodgkins lymphoma (de Roos et al. 2003; Cox 2004).

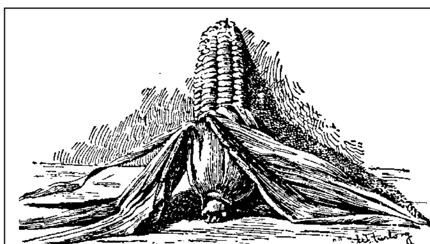
There is a large variation in environmental persistence. The soil half life of glyphosate ranges from 2-197 days, and the soil half life of the degradation product AMPA ranges from 76-240 days. Glyphosate binds to soil, but it still moves out into streams. Phosphate fertilizers displace glyphosate and increase runoff (Cerdeira and Duke 2010). Nearly every stream, river, and reservoir in heavily farmed regions contain glyphosate and its degradation products (Chang et al. 2011). In the Midwest, glyphosate or its degradation products were found in 69% of surface water samples tested. Concentrations measured in streams are low, but direct measurements of runoff from small watersheds can have amounts (5.1 mg/liter) that exceed drinking water standards of 0.7 mg/liter (Battaglin et al. 2005).

Glyphosate was found in 60-100% of rain and air samples tested in Iowa and Mississippi by U.S. Geologic Survey (USGS) (Chang et al. 2011). Glyphosate or AMPA was found in 92% of rain samples in Indiana. Concentrations were low, but maximum concentrations of glyphosate were higher the maximum concentrations of other herbicides tested. About 0.7% of glyphosate applied to soil goes airborne and is removed from air by rainfall (Chang et al. 2011).

Gene Flow and Human Error

One of the problems of GE crops is the flow of the transgenes into the environment, causing genetic pollution. Transgenes can spread through seeds, pollen, and vegetative propagules. As an example, field trials of glyphosate resistant (GR) bentgrass, *Agrostis stolonifera* in Oregon led to gene escape into the wild bentgrass population (Bollman et al. 2012). Three years after the trials, "as much as 62% of the wild bentgrass population in the vicinity possessed the GR trait" (Duke and Powles 2009).

Movement of GE transgenes into organic crops is possible. One study showed half the samples from six conventional soybean cultivars had up to 1% GE contamination. Also, there was up to 1% GE contamination in half the samples from six conventional corn cultivars. GE corn pollen can contaminate nearby fields, but pollution drops with distance. GE transgenes in alfalfa pollen, however, can move 4 km (2.4 mi) or more. In one



GE crops can lead to genetic pollution, causing great economic damage.

study, 22% of seed tested from trap plants 1000 m (0.6 mi) away from alfalfa production fields had the transgene (Mallory-Smith and Zapiola 2008; Snow et al. 2005).

Geneflow is compounded by human error. To farmers and marketers, all corn looks alike. This fact may have led to the illegal sales of Starlink® corn in 2000. The corn was approved for animal use, but not for human food. Starlink was found in taco shells, and the resulting recall cost industry more than $1 billion. Traces of Starlink were still being found in the food supply in 2008. A similar mixup between approved BT11 corn and unapproved BT10 was discovered in 2005 (MacIlwain 2005; EPA 2008). Gene flow and human error may become dangerous with Pharm Crops that have been engineered to produce drugs (Mallory-Smith and Zapiola 2008).

All kinds of genetic traits are being incorporated into crops. But amylase corn may be the first crop that eats itself. As it grows, amylase is secreted that digests the starch produced. The result is a product easier to convert into ethanol. But even low amounts mixed into food supplies could lead to lower quality, such as sticky tortillas and gummy bread (Waltz 2011).

Safety of GE Crops

From the beginning there were regulatory difficulties with the introduction of GE crops. They were clearly novel, and millions of people would be exposed. Regulators had to decide whether GE crops should be treated as food or drugs. The pharmaceutical industry has to show through animal tests and clinical trials that a drug is effective and safe before it can be sold. Yet when the drug is sold, much larger numbers of people are exposed, and sometimes hidden toxic effects appear (Karha and Topol 2004).

The final GE regulatory model involves EPA, USDA, and FDA. Toxic effects of gene products are regulated by EPA. USDA approves production of GE crops. The FDA does a premarket preview of all GE food (Freese 2007). Industry has to show only that the GE food is "substantially equivalent" to the natural product. This is a very vague term. A living body might be "substantially equivalent" to a recently dead one, but there is still an obvious profound difference. Often substantially equivalent means only that nutritional analyses are done, not animal safety tests (Zobiole et al. 2010; Ridley et al. 2011; Antoniou et al. 2012).

A recent publication by Antoniou et al. (2012) reviews GE food safety. Possible food safety issues occur if the transgene product is toxic or allergenic, or if the transformation process itself is mutagenic, causing new toxins or allergens to be produced. According to Antoniou et al. (2012), GE BT crops fed to animals have caused toxic effects to the small intestine, liver, kidney, spleen, and pancreas. There was also reduced weight gain and immune system disturbances. According to Antoniou et al. (2012) animals fed GE soybeans showed "disturbed liver, pancreas and testes function."

Farmers are losing their independence, as traditional seeds are disappearing.

Why are GE Crops Being Planted?

If there are environmental problems and uncertain safety, why are GE crops being produced? GE crops are supported by aggressive marketing, favorable government policy, and some cost advantages. A major problem is lack of traditional seeds. Most seed companies in the 1990s were purchased by pesticide manufacturers, as they saw vast profits could be made by monopolizing both seeds and pesticides. It is not in their interest to produce and promote traditional seeds (Mortensen et al. 2012; Gray 2011).

The simplistic agronomic systems of GE crops can make them easier to grow. Intially, GE crops led to larger profits for farmers. But profits may not be sustainable due to increased seed costs, weed resistance and other problems (Duke and Powles 2009; Gianessi 2008). According to Benbrook (2012), there has been a 30% shift of net income/acre in corn, soybeans, and cotton from farmers to seed and pesticide providers. Net profits in soybean and cotton have dropped since 2004 (Duke and Powles 2009).

Calculations showing the profit advantages of GE crops do not include the economic burden posed by pest resistance (Gianessi 2008; Buman et al. 2005). Glyphosate weed resistance may increase weed control costs in GE crops by $12-$14/acre ($30-$35/ha)(Owen 2010). Profit advantage simulations also do not include some environmental costs, such as loss of the monarch butterfly and reductions in frog populations (Pimentel et al 1992).

Favorable Government Policy

GE crops are being planted because of favorable government policy. From the beginning, the USDA has promoted GE crops. When the National Organic Program was being created, the USDA wanted to include GE products in organic agriculture. The agency relented only after large scale resistance by consumers and organic interests (Quarles 1998). USDA approval and deregulation has been granted to almost every GE crop application. Lawsuits, such as the case of GE alfalfa, are needed to reverse bad decisions (Duke and Powles 2008; Kimbrell 2011).

Update

Government crop insurance programs favor GE crops. In 2008, The USDA's Crop Insurance Board lowered premiums for farmers who would plant at least 75% of their corn to an approved transgenic hybrid (Gray 2011).

As this issue went to press, various amendments were being added to U.S. Farm Bill legislation that would make it easier to get GE crops with multiple herbicide resistant traits (see below) approved. The House Farm Bill contains HR 872, Reducing Regulatory Burdens Act, which stops the EPA from reviewing new and expanded uses of pesticides, and speeds approval of GE crops (Baden-Mayer 2012).

Environmental Benefits

GE crops produce some environmental benefits, mainly due to no-till production, which conserves water and soil. But no-till methods can be used with conventional crops. GR crops have meant fewer applications of other herbicides, such as 2,4-D and atrazine. But this may be a short term phenomenon. Weeds resistant to glyphosate are driving farmers to increase tillage and apply other herbicides. The industry solution is to produce GE crops simultaneously resistant to several herbicides (see below). Due to pesticide pollution, planting of crops resistant to multiple herbicides will likely eliminate any environmental advantage produced by GR crops (Mortensen et al. 2012).

Photo courtesy Virginia Tech Weed ID Guide

Palmer amaranth, *Amaranthus palmeri*, is resistant to glyphosate.

Resistance to Glyphosate

Glyphosate was used for more than 20 years without a report of resistance. Problems started with the introduction of GE glyphosate resistant crops in 1996 and the resulting explosion of glyphosate use (Duke and Powles 2009). Conversion from IPM methods of weed control to no-tillage monocultures maintained by one herbicide has led to a shift in the agricultural weed spectrum in the U.S. Sensitive weeds are disappearing, tolerant weeds are proliferating, and evolved resistance of superweeds is a reality (Owen 2008; Webster and Nichols 2012).

Resistance can build quickly. Resistant waterhemp, *Amaranthus tuberculatus*; and horseweed, *Conyza canadensis*, were seen 2-3 years after the introduction of GR soybeans. Resistant horseweed in cotton is a problem that may require a partial return to tillage (Owen 2008; Heap 2011).

Resistance to glyphosate has evolved in many species and is widely distributed. In 2011, 21 weed species worldwide were resistant to glyphosate. About 8 resistant species have become problems in GR crops in the U.S., and they are listed in Table 1. Leading the list in infested acreage is Palmer amaranth, *Amaranthus palmeri*, and horseweed, *Conyza canadensis* (Owen 2010; Benbrook 2009; Powles 2008; Heap 2011; Riley 2010; 2011).

Photo courtesy of Bob Williams and Stewart Farm

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

Resistant species such as horseweed, *C. canadensis*, are hybridizing and spreading resistance to related species such as hairy fleabane, *C. bonariensis*. Other weeds such as lambsquarters, *Chenopodium album*; pokeweed, *Phytolacca americana*; field horsetail, *Equisetum arvense*; velvetleaf, *Abutilon theophrasti*; tropical spiderwort, *Commelina benghalensis*; wild parsnip, *Pastinaca sativa*; and others are becoming problems because they are either naturally tolerant or are encouraged by no-till production (Owen 2008; Owen 2010; Benbrook 2009; Duke and Powles 2009).

Resistance to BT

Bacillus thuringiensis is one of the most important tools of organic agriculture. It is applied to crops as

Table 1. Glyphosate Resistant Weeds in U.S. Crops

Weed	Scientific Name	Crops
Palmer amaranth	*Amaranthus palmeri*	Corn, cotton, soybean
Waterhemp	*Amaranthus tuberculatus*	Corn, soybean
Common ragweed	*Ambrosia artemisiifolia*	Soybean
Giant ragweed	*Ambrosia trifida*	Cotton, soybean
Horseweed	*Conyza canadensis*	Corn, cotton, soybean
Kochia	*Kochia scoparia*	Corn, soybean
Italian ryegrass	*Lolium multiflorum*	Cotton, soybean
Johnsongrass	*Sorghum halepense*	Soybean

From Owen 2008; 2010. Benbrook 2009

a spray. It leaves no toxic residuals, spares beneficial insects, and generally affects only pests that eat the crop. It degrades quickly in the field, and does not contaminate water (Glare and O'Callaghan 2000).

Several crops have been engineered with transgenes that express

The western corn rootworm, *Diabrotica virgifera virgifera,* is resistant to effects of BT corn.

Photo courtesy Peggy Greb USDA ARS

insecticidal BT proteins. BT corn insecticidal to the European corn borer, *Ostrinia nubilalis*, and the western corn rootworm, *Diabrotica virgifera virgifera*, have been planted. BT cotton insecticidal to the pink bollworm, *Pectinophora gossypiella*, and other Lepidoptera covers more than 6.7 million acres (2.7 million ha)(Benbrook 2009; Naranjo 2011).

Transgenes in BT crops produce insecticidal proteins that differ from the natural product used in organic agriculture. Organic consumers wash off any residual BT, those who buy the GE crop eat insecticidal BT proteins. BT proteins growing in the crops are always there, pests are constantly exposed, making resistance more likely (Benbrook 2008; Benbrook 2009).

Several insect species have developed resistance to BT in the laboratory, and organic farmers objected to BT crops because field resistance was likely (Tabashnik et al. 2009). As a result, the EPA made establishment of BT free refuges a labeled requirement. Up until 2008, BT corn labels required planting of 20% non-BT corn to help prevent resistance. It was a good idea, but grower compliance has been less than 80%, and in 2010 the EPA dropped the refuge requirement to 5% for SmartStax GE corn (Gray 2011).

Despite the general success with refuges, pests are growing resistant. From 1996 to 2006, no resistance was seen. However, seven species have developed resistance within the last four years. These include pink bollworm, corn earworm, *Helicoverpa zea*; fall armyworm, *Spodoptera frugiperda*; corn stalk borer, *Buseola fusca*; cotton bollworm, *H. armigera*; Australian bollworm, *H. punctigera*; and western corn rootworm. In some cases, the BT crop is no more effective than untreated crops (Gassmann 2012).

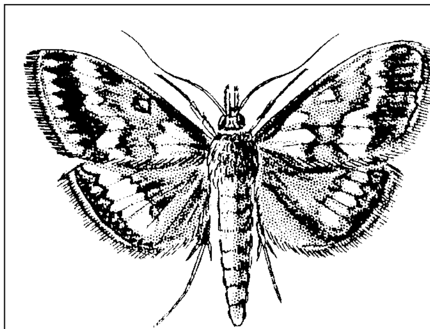
Resistance to BT and invasion of secondary pests not affected by BT have led to widespread seed treatments with systemic neonicotinoid insecticides (Benbrook 2008; Quarles 2011; Stokstad 2012).

BT Effects on Beneficials

According to Naranjo (2011), more than 360 published studies have examined the possible effect of BT crops on non-target organisms. Since beneficial insects do not eat the crop, most of the negative effects are indirect, due to reduced prey or consumption of herbivorous pests full of BT proteins. Thus fewer predators are found in BT cotton

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

Photo courtesy Peggy Greb USDA ARS



European corn borer, *Ostrinia nubilalis*

crops, fewer parasitoids specific for European corn borer are found in BT corn (Marvier et al. 2007; Naranjo 2011).

Secondary pests in BT crops have led to systemic seed treatments. Reduction of the beneficial ground beetle, *Harpalus pensylvanicus*, in BT corn treated with neonicotinoids was due either to direct toxicity from the systemic pesticide or lack of prey due to BT (Leslie et al. 2009).

Stacked Traits and Multiple Herbicides

No lessons have been learned from the past about pesticide treadmills (van den Bosch 1978; Olkowski et al. 1991). To deal with glyphosate resistant weeds, the corporate solution is to engineer crops simultaneously resistant to several herbicides (Green et al. 2008; Benbrook 2009).

One of the first was SmartStax® corn, which was resistant both to the herbicides glyphosate and glufosinate, and simultaneously insecticidal to the western corn rootworm, and various Lepidoptera. Others waiting approval include crops simultaneously resistant to glyphosate, 2,4-D, and dicamba (Gray 2011).

Approval of these "stacked trait" crops with resistance to multiple herbicides will lead to large increases of 2,4-D and dicamba similar to those already seen with glyphosate. One estimate is that herbicide use in soybeans will approximately double by 2020 if these crops are approved (Mortensen et al. 2012).

This might be a conservative estimate. According to the manufacturer, applications of 2,4-D would be 560-2240 g/ha (227-907 g/acre) (Mortensen et al. 2012). Application of the minimum rate of 2,4-D to 54 million acres (22 million ha) of GE corn would be 27 million lbs (12.3 million kg). Application of the minimum rate to 132 million acres (53 million ha) of herbicide tolerant, corn, cotton, and soybeans would be 66 million lbs (30 million kg) of 2,4-D. Total agricultural use now is about 30 million lbs (14 million kg). Crops resistant to 2,4-D could at least triple the amount of 2,4-D applied in agriculture (EPA 2005; Benbrook 2009).

Though there are questions about glyphosate safety, other herbicides may actually be more toxic (see Box B). Water is already contaminated with herbicides, and crops resistant to multiple herbicides will result in major increases (USGS 2008; Benbrook 2012).

Multiple Resistance

Further implementation of this simplistic approach to weed management will lead to multiple herbicide resistance, and other problems. One of the expected problems is misapplication. To a professional applicator, all soybean crops look the same. Unmodified or glyphosate resistant crops may be sprayed by mistake with 2,4 D or dicamba, with resulting crop destruction.

Since herbicides in these crops are applied aerially, another problem will be pesticide drift. After application, pesticides can volatilize, and ester formulations of 2,4-D are especially volatile. These risks might drive farmers to convert to multiple resistant crops in self defense (Mortensen et al. 2012).

Companies promoting multiresistant crops suggest applying glyphosate and other herbicides simultaneously. Repeated application of these other herbicides will lead to the same weed resistance seen with overuse of glyphosate. There are 28 weed species already resistant to 2,4-D. There are 38 weed species already simultaneously resistant to two or more herbicidal modes of action—44% of these have appeared since 2005 (Mortensen et al. 2012).

Box B. Toxicity of 2,4-D

The herbicide 2,4-dichlorophenoxyacetic acid (2,4-D) has been used since 1940. It is more acutely toxic than glyphosate. Subchronic oral exposure causes damage to the thyroid, kidney, adrenal glands, ovaries and testes of laboratory animals. Damage occurs when kidneys are not able to excrete the toxin fast enough. This fact means 2,4-D might be more toxic to older people with impaired renal clearance. Because of the damage to reproductive organs in animals and widespread exposure, 2,4-D is being screened as a possible endocrine disruptor by the EPA. Occupational exposure in humans has been associated with reduced sperm motility and viability. Large doses led to birth defects in rats (NPIC 2012).

There is scientific disagreement about its carcinogenic effects. The EPA classifies it as "not classifiable as to human carcinogenicity." The International Agency for Research on Cancer (IARC) calls it "possibly carcinogenic to humans." One of the confounding problems is that commercial preparations can vary in purity, and older formulations were contaminated with carcinogenic dioxins. Some epidemiologic studies have associated 2,4-D with non-Hodgkins lymphoma (NPIC 2012).

2,4-D is soluble in water. It moves in soil and has been found in surface water and groundwater. The EPA has found traces in 49.3% of finished drinking water samples, but well below the 70 ppb (0.07 mg/liter) maximum contaminant level. Exposure is widespread and "2,4-D was detected in urine samples from all age groups in a large study of the American public." The No Observed Effect Level (NOEL) dose in rats is 5 mg/kg/day. The reference dose (dose below which no toxic effects are expected) in humans is 0.01 mg/kg/day (NPIC 2012; CDC 2005).

About 46 million lbs (21 million kg) a year of 2,4-D are currently applied—30 million lbs (14 million kg) in agriculture. Since 2,4-D is used on lawns as well as agriculture, aggregate exposure is a problem. The Food Quality Protection Act requires that aggregate exposure must be considered. Because of this law, the EPA had to require a reduction in application rates for urban uses in 2005 (EPA 2005). The new and expanded herbicide use proposed for GE crops would normally trigger a re-evaluation. However, as this article went to press, HR 872, Reducing Regulatory Burdens Act, an amendment added to the U.S. Farm Bill, will stop the EPA from reviewing new and expanded uses of pesticides (Baden-Mayer 2012).

Integrated Pest Management

Herbicide resistant crops are not needed to provide effective weed control in agriculture. Weeds can be controlled by using the principles of integrated pest management (IPM) (Stern et al. 1959). A combination of cover crops, competitive cultivars, restricted tillage, and spot treatments with herbicides can produce profits and effectiveness similar to an all herbicide regime (Liebman et al. 2008; Pimentel et al. 2005). For instance, resistant horseweed can be controlled by tillage, crop rotation, and cover crops (Shaner et al. 2012). Even if GE herbicide resistant crops continue to be used, they should be combined in an IPM program with other methods to reduce resistant weeds and maintain a sustainable system (Mortensen et al. 2012).

Conclusion

GE food should have been regulated in the same way as drugs. As it is, GE crop consumption is a vast, uncontrolled experiment, with no oversight, no monitoring for adverse reactions, and no real way to assess liability. Gene flow and genetic pollution can be tracked only after it occurs. If we remember the problems with Starlink corn, the whole industry is one catastrophe away from total meltdown.

If we overlook safety and environmental issues, GE crops have not been used wisely. Monolithic plantings of one cultivar increase the potential for total crop failure. Relying almost entirely on glyphosate and BT for pest management has increased pest resistance, and current GE crops may become ineffective. Seed monopolies are also causing farmers to lose their independence.

We should learn from the pesticide treadmills of the past. GE crops that tolerate several herbicides are not the answer to resistant weeds. The result will be massive applications of herbicides that are more toxic than glyphosate. Weeds will become resistant to multiple herbicides. The answer is a return to IPM principles that allow both sustainable crop production and environmental protection.

For now, the only sure way to avoid eating GE food is to buy organic products. Maybe if more people vote in the marketplace, producers will make some changes.

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