SUPERWEEDS

HOW BIOTECH CROPS BOLSTER THE PESTICIDE INDUSTRY

food&water europe

About Food & Water Europe

Food & Water Europe is the European program of Food & Water Watch, a nonprofit consumer organization based in the United States that works to ensure the food, water and fish we consume is safe, accessible and sustainable. So we can all enjoy and trust in what we eat and drink, we help people take charge of where their food comes from, keep clean, affordable, public tap water flowing freely to our homes, protect the environmental quality of oceans, force government to do its job protecting citizens, and educate about the importance of keeping shared resources under public control.

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Executive Summary

Genetically engineered (GE) crops — usually called "genetically modified" (GM) outside the U.S. — were first approved in the United States in the 1990s, and since then the United States has been the biggest global adopter of this technology. GE crops were supposed to improve yields, lower costs for farmers and reduce agriculture's environmental impact. Yet nearly 20 years after their introduction, genetically engineered crops have not provided the benefits promised by the companies that patented them.

Food & Water Watch examined U.S. Department of Agriculture (USDA) and U.S. Environmental Protection Agency (EPA) data to document the increased use of herbicides that has accompanied the adoption of herbicide-tolerant GE crops. Our analysis looks at the rapid proliferation of GE crops and affiliated pesticides in the United States and points out the interdependent relationship between these two industries that also fuels the crisis of weed resistance. Food & Water Watch evaluated data from the International Survey of Herbicide Resistant Weeds that reveal burgeoning herbicide-resistant weeds caused by the over-reliance on glyphosate for broad control of weeds. These data make it clear that the problem of herbicide-resistant weeds will not be solved with the intensified use of older, more toxic herbicides like 2,4-D and dicamba.

Some of Food & Water Watch's findings include:

- Herbicide use on corn, soybeans and cotton did fall in the early years of GE crop adoption, dropping by 42 million pounds (15 percent) between 1998 and 2001. But as weeds developed resistance to glyphosate, farmers applied more herbicides, and total herbicide use increased by 81.2 million pounds (26 percent) between 2001 and 2010.
- The total volume of glyphosate applied to the three biggest GE crops — corn, cotton and soybeans — increased 10-fold from 15 million pounds in 1996 to 159 million pounds in 2012.
- Total 2,4-D use declined after glyphosate was widely adopted, but its use has increased since glyphosate-resistant crops became widespread, growing 90 percent between 2000 and 2012. 2,4-D application on corn could easily increase by nearly three-fifths within two years of 2,4-D-tolerant corn's introduction. And if just a million dicamba-tolerant soybean acres are planted, it would increase dicamba use 17 times.
- Reports of weeds developing glyphosate resistance are popping up in more and more states. In 2008, glyphosate-resistant waterhemp was reported in five states, but by 2012 it was reported in 12 states. Glyphosate-resistant Palmer amaranth was reported in eight states in 2008 but 17 by 2012. Resistant horseweed spread from 12 states in 2004 to 21 in 2012.
- The International Survey of Herbicide Resistant Weeds found only about one weed infestation per year that was resistant to multiple herbicides between 1997 and 2001, but a decade after GE crops were introduced (2007 to 2011), there were three times as many multiple herbicide-resistant weed infestations.
- Herbicide-resistant weeds' costs to farmers can range from $12 to $50 an acre, or as much as $12,000 for an average-sized corn or soybean farm or $28,000 for an average cotton farm.

More biotech industry-led solutions will only perpetuate agriculture's reliance on chemicals as the end-all-be-all solution to weed and insect management. But this approach drives the rise of superweeds, poses risks to human health and threatens critical habitat for wildlife in the process. Food & Water Watch recommends that:

- The USDA, EPA and Food and Drug Administration (FDA) must work together to thoroughly evaluate the potentially harmful effects of GE crops and linked chemicals before commercialization, to ensure the safety of humans and the environment.
- The USDA should support and encourage cultivation best management practices to prevent weed resistance in the first place.
- The USDA should educate and encourage farmers to adopt non-chemical strategies for long-term weed control. The USDA must dedicate research dollars to developing alternatives for sustainable management of herbicide-resistant weeds.
- The U.S. government must improve the collection and distribution of weed resistance and agricultural pesticide application data.

Introduction

Since the development of the chemical industry after World War II, agriculture has become increasingly reliant on herbicides and insecticides — together referred to as pesticides — to control weeds and pests. Farmers have always battled voracious insects and weeds that crowd cropland, and the chemical industry promised almost miraculously effective and labor-saving solutions.

Farmers quickly adopted the new tools, but the chemicals that killed weeds and insects also posed risks to the environment and farmworkers and can leave dangerous residues on food. Half of the 877 million pounds of pesticides used in agriculture are herbicides designed to kill weeds.[1]

In the 1970s, the United States began to ban or phase out some of the most damaging pesticides, like DDT. But many harmful pesticides remain in widespread use. In the 1990s, chemical and seed companies developed genetically engineered herbicide-tolerant crops. These crops could withstand being sprayed with herbicides that killed weeds. The most common herbicide-tolerant GE crops were designed to be used with Monsanto's herbicide Roundup (known generically as glyphosate).

Monsanto promoted Roundup Ready crops as a way to use a safer and more effective pesticide that could reduce total pesticide use. Theoretically, farmers would make fewer applications without resorting to more dangerous pesticides and could reduce the amount of tillage used to combat weeds on their farms. Farmers rapidly adopted Roundup Ready crops (primarily corn, soybeans and cotton).

But as weeds became almost universally treated with Roundup, they evolved a resistance to the pesticide. Today, some of the most pervasive and damaging weeds can withstand Roundup. As more resilient weeds have invaded more farm fields and suppressed crop yields, farmers have reverted to applying more and more dangerous pesticides that Roundup Ready crops were supposed to let them avoid.

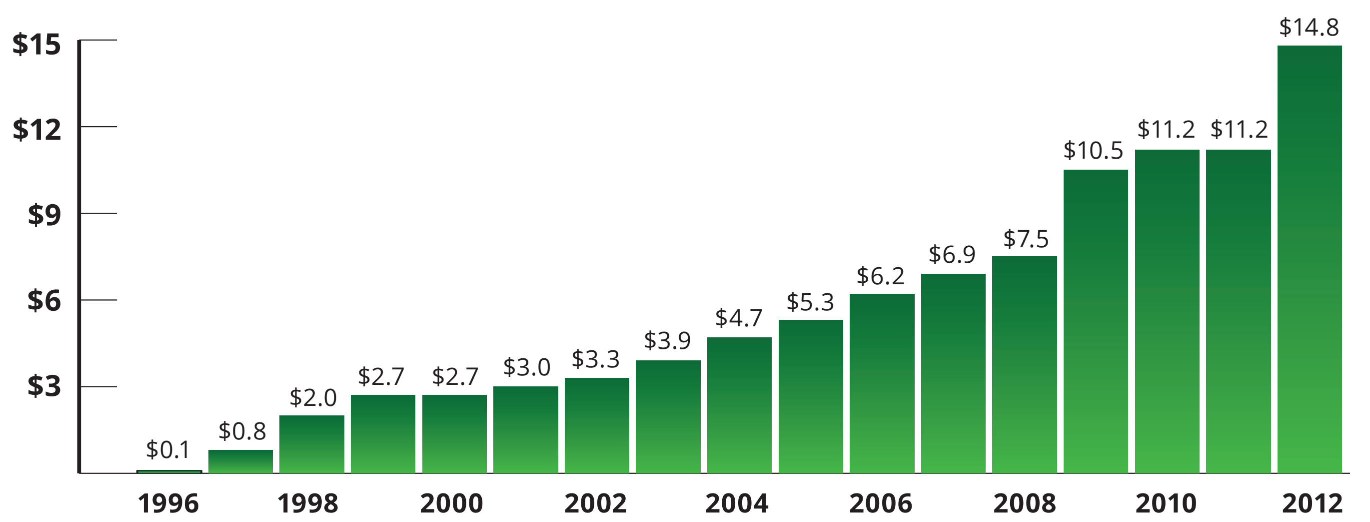
The GE seed companies have a simple solution to Roundup-resistant weeds: introduce new GE crops that are tolerant of different pesticides. Already the chemical and GE seed companies are testing varieties that can withstand more dangerous pesticides, including dicamba, 2,4-D and isoxaflutole.

The biggest beneficiary from the weed resistance epidemic is the "crop protection" industry, including seed and chemical companies. The global crop protection market has tripled from $26 billion in 2001 to a whopping $64 billion in 2012.[2] Herbicides alone account for about half of these sales.[3] The global GE seed market has skyrocketed from $115 million in sales since its inception in 1996 to $15 billion in 2012 — a 130-fold increase.[4] (See Figure 1.)

Monsanto — the largest biotechnology seed company in the world in 2011 — has generated steady earnings, despite its role in creating the glyphosate-resistant weed situation.[5] Monsanto's focus has shifted from chemicals to patented seeds, and since 2000, its seed sales have gone up sixfold from $1.6 billion to $9.8 billion in 2012.[6]

The cycle of herbicide-tolerant GE crops has spawned an agrochemical treadmill. Widespread application

Figure 1. Global Revenue from Sales of GE Seeds (IN $ BILLION)



SOURCE: Food & Water Watch analysis of CropLife International Annual Reports 2002-2006 and the International Service for the Acquisition of Agri-biotech Applications (ISAAA) Annual Reports 2007-2012.

of Roundup creates Roundup-resistant weeds that encourage farmers to increase the application of more dangerous herbicides and create incentives for seed companies to introduce crops that are tolerant of these even more powerful and risky chemicals. Rather than reducing total pesticide use, the GE crops have just accelerated the agrochemical arms race, instigated the rise of superweeds and threatened critical habitat for wildlife and public health.

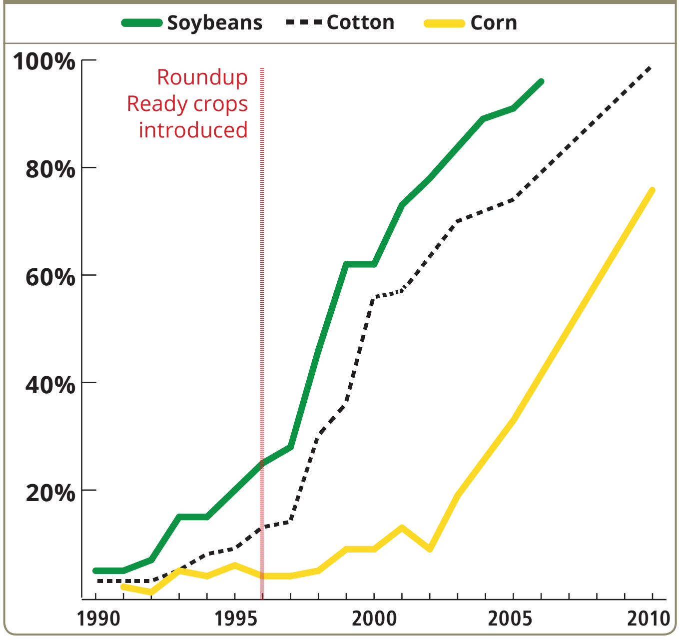
Spread of Weed Resistance

Herbicides first became widely available commercially during the 1950s.[7] So far, chemical companies have introduced 21 different types of herbicide families that act through different mechanisms.[8] But the most significant development for farmers was the approval of glyphosate in 1976.[9] Monsanto's Roundup, the brand name for glyphosate, is a powerful herbicide that kills a wide range of plants by inhibiting an enzyme pathway necessary for the plants to produce proteins required for survival.[10]

Since Roundup Ready crops were introduced, glyphosate has been used more as a post-emergent herbicide, sprayed onto weeds after they sprout. Because farmers apply Roundup to growing crops to kill emerging weeds, the weeds get larger and more difficult to kill before they are sprayed. Infesting weeds can reach sexual maturity, and those that are herbicide-resistant deposit their seeds, propagating the evolution of more herbicide-resistant weeds.[11] The post-emergent application of glyphosate, the limited or non-existent tillage used with the glyphosate system and the fact that some farmers cultivate the same glyphosate-tolerant crop for years at a time (in one case, as many as 14 years) creates the perfect scenario for glyphosate-resistant weeds to thrive.[12]

MARESTAIL PHOTO CC-SA-BY © F.D. RICHARDS / FLICKR.COM

Figure 2. Percentage of U.S. Acres Sprayed With Glyphosate



SOURCE: USDA-NASS Quickstats: Survey, Environmental, Corn, Cotton, Soybean, Application, Percent Area Planted (Average) (Glyphosate).

In the 1990s, Monsanto introduced genetically engineered crops that could survive being sprayed by glyphosate, known as Roundup Ready crops.[13] Farmers were drawn to the ease and versatility of glyphosate for weed control, and Roundup Ready crops were adopted at historic rates during the 1990s.[14] Farmers traditionally combated weeds and insects by rotating their crops and varying the pesticides they used. Because glyphosate was so effective, many farmers solely planted glyphosate-resistant crops and applied glyphosate season after season.[15] Herbicide-tolerant corn and soybean cultivation increased 100 percent from about 45 million acres in 2000 to 90 million acres in 2012.[16] Today, almost all corn, soybean and cotton fields are sprayed with glyphosate (76, 96 and 99 percent, respectively; see Figure 2).[17]

Ubiquitous Roundup application has spawned glyphosate-resistant weeds, driving farmers to apply more-toxic herbicides and to reduce conservation tilling, according to a 2010 National Research Council report.[18] There are 14 weed species resistant to glyphosate in the United States (24 species worldwide), including aggressive weeds like ragweed, horseweed, kochia, Palmer amaranth and waterhemp.[19] The two most pervasive glyphosate-resistant weeds are marestail (horseweed) and Palmer amaranth (pigweed).[20]

The industry currently estimates that 61.2 million acres of cropland now are infested with weeds resistant to glyphosate.[21] More than a quarter (27 percent) of U.S. farmers reported more than one species of glyphosate-resistant weeds in their fields in 2012, almost twice as many as in 2011.[22] Glyphosate-resistant weeds followed the path of GE crop adoption. (See Figure 3.) The first regions that adopted Roundup Ready crops saw the earliest outbreaks of herbicide-resistant weeds.[23]

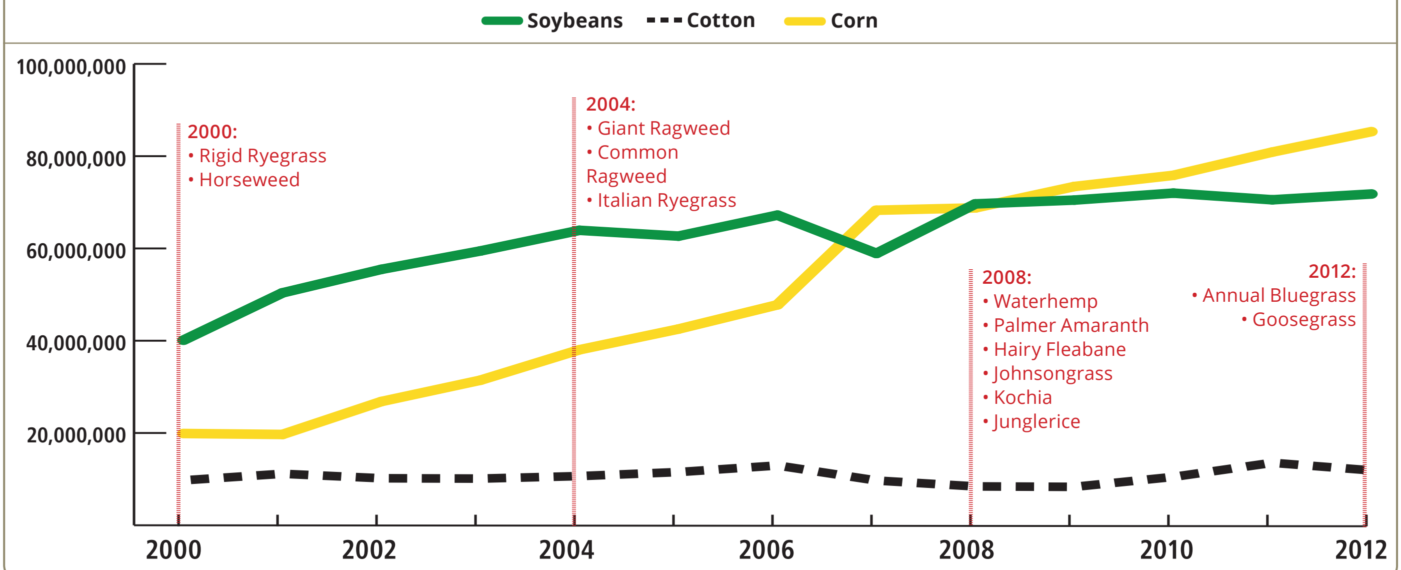
Glyphosate-resistant weeds originated in the South and spread throughout the biggest U.S. corn and soybean regions.[24] In 2012, a staggering 92 percent of surveyed Georgia farmers reported having glyphosate-resistant weeds.[25] In the Midwest, where GE corn and soy dominate agricultural production, the weed problem continues to worsen. In 2012 in Illinois, two out of five farmers (43 percent) had glyphosate-resistant weeds.[26]

Food & Water Watch compared the number of herbicide-resistant weed infestations before and after GE herbicide-tolerant crops were introduced using data from the International Survey of Herbicide Resistant Weeds.[27] The weed scientist survey reports herbicide-resistant weed infestations in a publicly available database.[28] The voluntary infestation reports in the survey represent a conservative estimate, but the rise in the small number of reports illuminates the rapid expansion of herbicide-resistant weed outbreaks. In 2008, glyphosate-resistant waterhemp was reported in five states, but by 2012 it was in 12 states. Glyphosate-resistant Palmer amaranth was reported in eight states in 2008 but 17 by 2012. Resistant horseweed spread from 12 states in 2004 to 21 in 2012. (See Figure 4 below and Appendix A on page 13 for the spread of glyphosate-resistant waterhemp, Palmer amaranth and ragweed.)

Growing weed resistance has increased the total volume of pesticides applied to U.S. farms. A Washington State University study by long-time GE crop and herbicide researcher Dr. Charles Benbrook found that herbicide use has actually increased by 527 million pounds since the introduction of GE crops in 1996, and will only continue to rise with the introduction of new herbicide-tolerant crops.[29] A Penn State University weed scientist predicted that efforts to control newly resistant weeds could increase pesticide use 70 percent by 2015.[30]

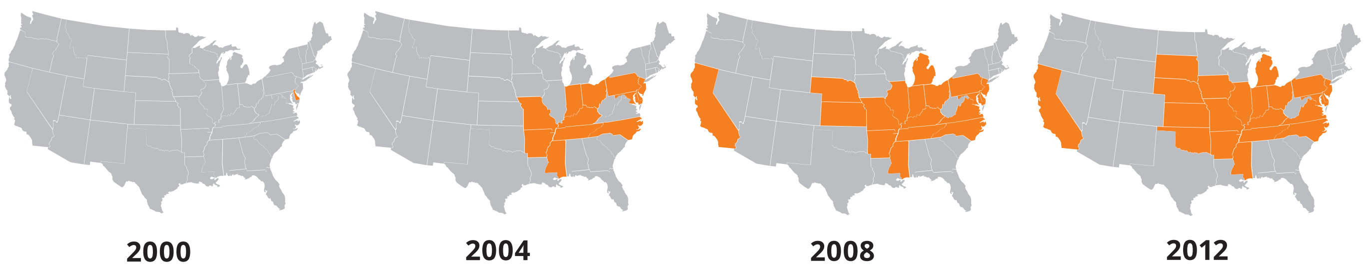
As mixtures of herbicides are used on crops, some weeds are developing multiple resistance — meaning that they can survive being sprayed with two or

Figure 3. Planted GE Acres and Glyphosate-Resistant Weeds



SOURCE: USDA NASS. Quickstats. Agricultural Survey. Planted Acres (Corn, Cotton, Soybean); USDA ERS Data Set for Genetically engineered varieties of corn, upland cotton and soybeans in the United States 2000-2012; Heap, Ian. The International Survey of Herbicide Resistant Weeds. Available at www.weedscience.org/Account/AboutUs.aspx. Accessed April 29, 2013.

Figure 4. Number of States Reporting Glyphosate-resistant Horseweed in Fields (BY YEAR)



SOURCE: Heap, I. The International Survey of Herbicide Resistant Weeds. Available at www.weedscience.com. Accessed March 18, 2013.

more herbicides.[31] Nearly two-thirds of weeds with glyphosate resistance will develop resistance to other herbicides.[32] Prior to the introduction of Roundup Ready crops (1991–1995), the International Survey of Herbicide Resistant Weeds found only about one weed infestation per year (1.2 reports) that was resistant to multiple herbicides. A decade after the GE crops were introduced (2007–2011), the survey found almost three times as many multiple herbicide-resistant weed infestations (3.25 reports annually). Some of the first states to begin to see multiple resistances were Michigan, Ohio and Illinois — all among the first adopters of GE corn and soybeans.[33] Academic experts expect multiple resistances in weeds to occur more frequently as the USDA approves crops engineered to tolerate different herbicides.[34]

What the Data Show: Herbicide-Tolerant Crops Increase Herbicide Use

Food & Water Watch examined the USDA and EPA herbicide data and found that herbicide use has grown steadily since the introduction of GE crops. This analysis elaborates on Dr. Benbrook's research by focusing on other herbicides that will be used in the GE herbicide-tolerant crop pipeline and projecting the increased use under the anticipated cultivation if the USDA approves the crops.

Food & Water Watch's findings contradict the rosy projections of the biotech seed companies that GE herbicide-tolerant crops reduce pesticide use. In 2005, a representative of the Biotechnology Industry Organization testified before a state legislature, "Biotechnology-derived crops have contributed to a substantial reduction in pesticide volumes used in production agriculture."[35] Herbicide use on corn, soybeans and cotton did fall in the early years of GE crop adoption, dropping by 42 million pounds (15 percent) between 1998 and 2001.[36] But as weeds developed resistance to glyphosate, farmers applied more herbicides. Total herbicide use increased by 81.2 million pounds (26 percent) between 2001 and 2010.[37] (See Figure 5.)

Although glyphosate represents half of all herbicides used on corn, soybean and cotton fields, the continued growth of total herbicide use suggests that glyphosate is no longer as effective as it was when it was introduced because of increasing weed resistance.

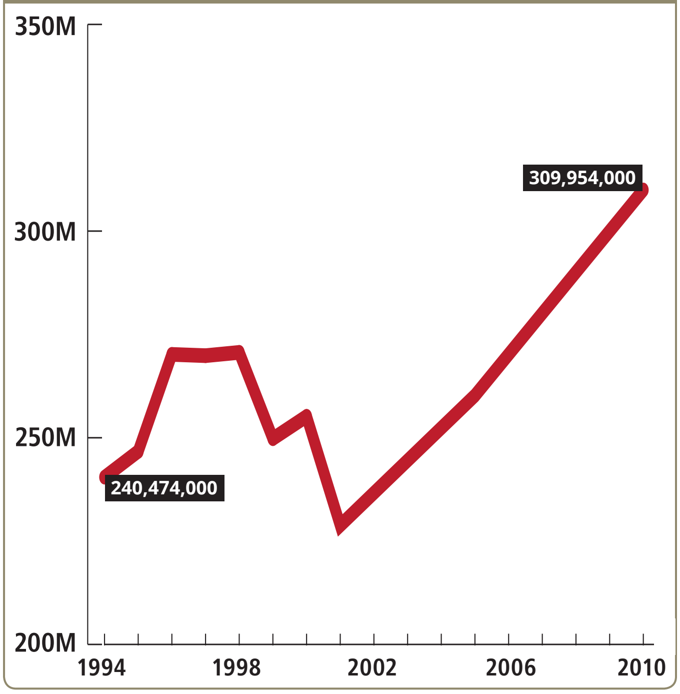
Agrichemical Trends

Atrazine: Atrazine was the most widely used herbicide on agricultural crops from 1987 to 1997, until glyphosate volume surpassed atrazine volume after the introduction of Roundup Ready crops.[38] This chemical is a known endocrine disrupter and a very pervasive pollutant in surface and ground water.[39] In the 1970s, some of the first herbicide-tolerant weeds were resistant to the triazine family of herbicides, a group that includes atrazine.[40] Yet, instead of changing the paradigm for weed control, the chemical industry just added a new chemical.

Although glyphosate has been sprayed on the majority of corn, cotton and soybean acres, the shift to glyphosate has not reduced atrazine use. The percentage of corn acres still treated with atrazine has remained stable.[41] The chemical cycle has now turned full circle, and atrazine is being suggested as a supplement to control glyphosate-resistant weeds, which could cause a resurgence of atrazine use and subsequent water contamination.[42]

Glyphosate (Roundup): The notion of glyphosate's invincibility, its widespread adoption and the way it was applied to fields have facilitated the evolution of resistant weeds.[43] The total volume of glyphosate applied to the three biggest GE crops — corn, cotton and soybeans — increased 10-fold from 15 million pounds in 1996 to 159 million pounds in 2012.[44] (See Figure 6.) Farmers are now resorting to more frequent glyphosate applications to cope with herbicide-resistant weeds. In 1996, farmers typically applied glyphosate to their corn and cotton fields once a season, but by

Figure 5. Total Herbicide Volume Applied to Corn, Cotton, Soybeans
(MILLIONS OF LBS PER YEAR)



SOURCE: USDA-NASS. Quickstats. Agricultural Survey, Chemical Applications, Herbicide Use on Corn, Cotton and Soybeans (Total).

2010, half of cotton farmers applied Roundup twice each season.[45] This happened faster in soybean fields, where half of farmers made two Roundup applications a season by 2006 (the latest available data). Despite the role played by overuse of Roundup in accelerating the chemical treadmill, Monsanto's Roundup Ready manager still considers Roundup the company's "family jewel."[46]

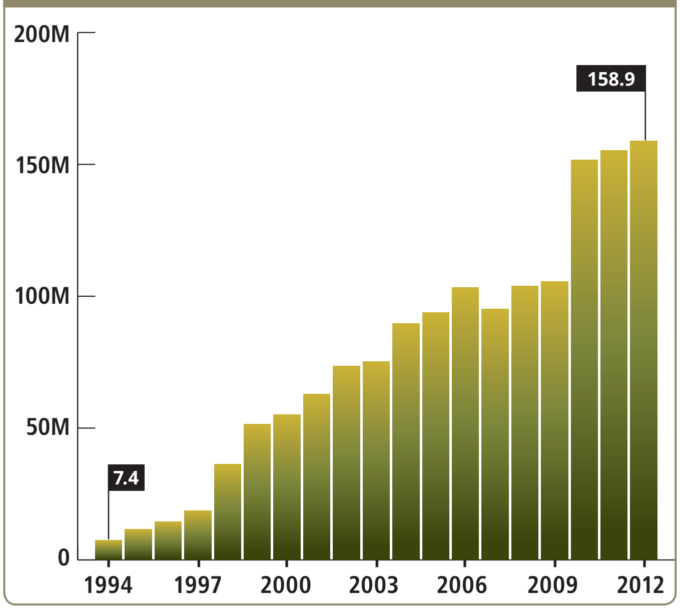
2,4-D and Dicamba: The herbicides dicamba and 2,4-D belong to the synthetic auxins family of herbicides, known for their negative impacts on target and nontarget plant development, causing abnormal growth and death.[47] Since dicamba and 2,4-D are especially prone to drift, any specialty crops — like tomatoes, grapes and potatoes — that are grown near fields sprayed with these herbicides could be damaged by the herbicide, causing yield losses.[48]

A 2004 study modeled that 2,4-D and dicamba had 400 times and 75 times the risk of impacting non-target plants, relative to glyphosate.[49] In 2010, an Indiana farmer testified at a Congressional hearing that dicamba drift destroyed over 20 acres of his tomatoes.[50] An Association of American Pesticide Control Officials survey from 2002 to 2004 found that 2,4-D was the herbicide most commonly involved in drift occurrences.[51] Although Dow claims that its new, pricier formulation of 2,4-D (designed for 2,4-D-tolerant GE crops) is less prone to drift, many farmers will likely continue to use the cheaper generic 2,4-D.[52]

Total 2,4-D use declined after glyphosate was widely adopted, but its use has increased since glyphosate-resistant crops became widespread, growing 90 percent (3.9 million pounds) between 2000 and 2012.[53] (See Figure 7.) Dicamba use slowed down steadily since 1994, but this decline would rapidly reverse if the USDA approves dicamba-tolerant soybeans.[54] The approval of either GE crop that is engineered to work with these drift-prone herbicides could seriously threaten nearby specialty crop growers and any plants and animals that are exposed to higher concentrations of these dangerous chemicals. Steve Smith, Agriculture Director for Red Gold — the largest privately held U.S. canned tomato processing company — stresses that "the widespread use of dicamba herbicide possesses the single most serious threat to the future of the specialty crop [fruit and vegetable] industry in the Midwest."[55]

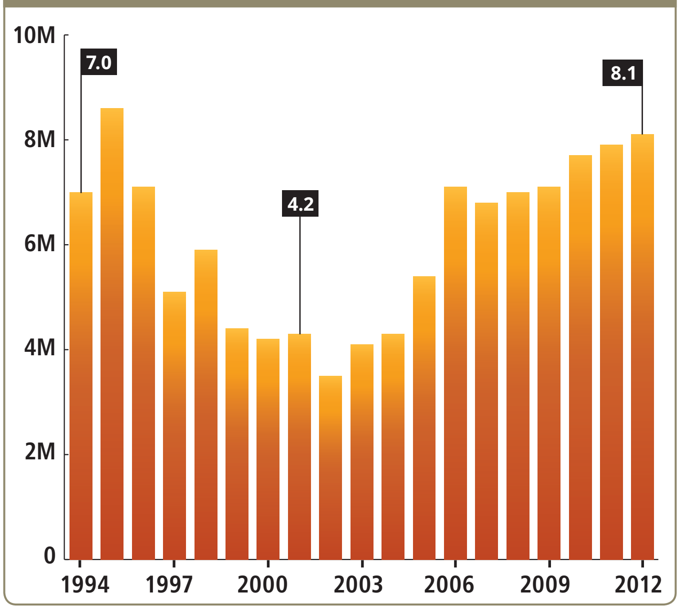
For every 1 million acres of dicamba-tolerant soybeans planted, there could be an additional 2 million pounds of dicamba applied to crops.[56] Even if just a million dicamba-tolerant soybean acres are planted, that would be 17 times the current dicamba volume used on soybeans.[57] And if 2,4-D corn were adopted as quickly as Roundup Ready corn (about 1 million acres a year between 1997 and 2001),[58] 2,4-D application on corn could easily increase by nearly three-fifths from 3.5 million pounds to 5.5 million pounds within two years of 2,4-D-tolerant corn's introduction.[59]

Figure 6. Total Glyphosate Applications on Corn, Cotton, Soybeans (IN MILLION LBS)



SOURCE: Food & Water Watch Analysis of USDA NASS. Quickstats. Agricultural Survey, Chemical Applications, Glyphosate active ingredient (lbs/year), Number of Applications per year, Avg. lbs. per application per year.*

Figure 7. Total 2,4-D Applications on Corn, Cotton, Soybeans (IN MILLION LBS)



SOURCE: Food & Water Watch Analysis of USDA NASS. Quickstats. Agricultural Survey, Chemical Applications, 2,4-D active ingredient (lbs/year), Number of Applications per year, Avg. lbs. per application per year.*

***Figures 6 and 7:** Missing values were estimated using figures from the closest year of data.

Glufosinate (Liberty): Glufosinate, the affiliated herbicide of Bayer's LibertyLink brand of GE corn, cotton and soybeans, has not been used very widely for weed control.[60] In 2010, it was sprayed on just 2 percent of corn and 7 percent of cotton acres, but its use doubled from 525,000 pounds in 2000 to 1 million pounds in 2012.[61] Glufosinate applications will only increase further if the USDA approves any of the five glufosinate-tolerant crops currently in the pipeline to fight pigweed.[62] Between 2009 and 2011, glufosinate pounds applied per acre increased sevenfold.[63] If farmers adopt a million acres of glufosinate-tolerant corn, soy and cotton per year (as they did with Roundup Ready crops), glufosinate use could rise fourfold to 6.5 million pounds in just two years.[64] Currently, ryegrass is the only weed that has developed glufosinate resistance,[65] but more weeds would likely develop resistance if glufosinate use became more widespread.

Isoxaflutole: Bayer has also sought USDA approval for corn with stacked tolerance to isoxaflutole and glyphosate-tolerant soybeans.[66] Already, the volume of isoxaflutole applied to corn has almost doubled since 1999.[67] Isoxaflutole is a restricted-use herbicide that can only be applied to a corn field before planting; its use is discouraged after crops and weeds are already growing because it is toxic to some plants even at low levels.[68] The increased use of this herbicide sprayed on GE crops able to withstand its application postemergence could increase the risk of harming non-target plants.[69]

The Weed Management Pipeline

Although herbicide-resistant weeds emerged from the near-universal application of glyphosate on U.S. farm fields, biotechnology companies are developing new GE crops, resistant to different combinations of more-toxic chemicals, including 2,4-D (an Agent Orange component) and dicamba.[84] The GE seed companies are rushing to petition the USDA for prompt approval of new and controversial varieties. Currently, nearly two-thirds of the GE crops in the pipeline awaiting USDA approval (13 of 20 varieties) are resistant to new herbicide mixes, including 2,4-D-tolerant corn and soybeans, dicamba-tolerant cotton and soybeans, and glyphosate and isoxaflutole-tolerant soybeans.[85]

The USDA is accelerating its approval process for GE crops even as the seed companies hurry the new,

Weeds: Worst Offenders

Horseweed (Marestail): Horseweed, also known as marestail, was one of the first weeds found to be resistant to glyphosate.[70] In 2012, 21 states reported horseweed with glyphosate resistance.[71] It is a hardy weed, thriving even under stressful conditions, and can produce up to 200,000 seeds per plant.[72] Horseweed in a no-till scenario has been found to reduce soybean yield by more than 80 percent.[73] By 2013, the majority of horseweed in Alabama appeared to be glyphosate-resistant.[74] Horseweed is especially problematic in Roundup Ready alfalfa fields because glyphosate-resistant horseweed not only can outcompete crops for light and nutrients, but it also it attracts a pest that afflicts alfalfa specifically — the tarnished plant bug.[75]

TALL WATERHEMP. PHOTO CC-BY © JOHN D. BYRD, MISSISSIPPI STATE UNIVERSITY

Palmer Amaranth (Pigweed): Palmer amaranth is a member of the pigweed family and is related to waterhemp.[76] Each large pigweed plant can produce from 600,000 to 1.6 million seeds, which can travel up to 1,000 feet. According to a University of Arizona extension specialist, just 16 pigweed plants for every 10 feet of crop row can generate 6 billion seeds per acre.[77] It outcompetes corn and soybean for sunlight and nutrients and reduces corn yields by as much as 91 percent and soybean yields by 79 percent, which could be devastating for farmers.[78]

Waterhemp: The first glyphosate-resistant waterhemp was reported in the United States in 2005.[79] Waterhemp seeds can persist in soil for up to four years, and its pollen can travel more than a half-mile in windy conditions.[80] It is one of the most notoriously difficult weeds to eradicate from corn and soybean fields in the Midwest; since waterhemp was the first U.S. weed to develop resistance to up to four herbicide families, it is difficult to combat once it becomes established.[81] Infestations can reduce soybean yields by up to 44 percent and corn up to 15 percent, as waterhemp can grow up to 12 feet tall and outcompete crops for sunlight and nutrients.[82] A 2012 Weed Science Society of America study found that waterhemp in Nebraska has become resistant to 2,4-D.[83]

PALMER AMARANTH IN COTTON (TEST PLOT). PHOTO © UNIVERSITY OF ARKANSAS SYSTEM DIVISION OF AGRICULTURE

untested varieties to market. In November 2011, the USDA unveiled its new streamlined process for GE crop approvals to shorten approval timelines by 13 to 15 months.[86] The USDA claims that the new system will be more collaborative, giving the public more notice and opportunity for more participation in the process.[87] This collaboration could be mostly theoretical given the intense industry pressure on the USDA to approve GE crops more quickly.

If the USDA rapidly approves this next generation of GE herbicide-tolerant crops, it is likely to only speed up the agrochemical treadmill. These crops will likely result in increased herbicide use and the persistence of weeds resistant to many different herbicides, making them harder and harder to manage. Formulating new varieties of crops to withstand applications of harsher chemicals continues to treat one symptom and ignore the underlying disease.

Crop Pests Develop Resistance to Insect-Resistant GE Crops

After herbicide resistance, the second most prevalent GE trait in corn and cotton is insect resistance.[88] The most common variety contains a *Bacillus thuringiensis* (*Bt*) soil bacterium gene, in the tissue of the plant, designed to repel the European corn borer and several cotton bollworms.[89] The amount of *Bt* toxin expressed in insect-resistant corn is actually 19 times the amount of conventional insecticide necessary to target the same pests by applying it to the surface of the plant.[90] Yet, this "plant-incorporated protectant" expressed in every cell of each *Bt* crop is not counted in the USDA and EPA measurements of total insecticide use, which significantly undercounts insecticide applications.[91]

Dr. Benbrook reports that stable declines in insecticide use from the introduction of *Bt* crops are now "in jeopardy" as insects developed resistance to the biotech toxin.[92] A University of Missouri entomologist found that corn rootworms could pass on *Bt* resistance to their offspring.[93] And University of Arizona researchers found that within seven years of *Bt* cotton introduction, cotton bollworms developed *Bt* resistance that they later passed on to offspring, meaning that the resistance was dominant and could evolve rapidly.[94] A 2013 National Academy of Sciences study reported that cotton pests showed "significant" resistance to *Bt* and this resistance was strengthened by GE crops with multiple insect-resistant traits, as is common with stacked *Bt* corn and cotton varieties.[95] This insect resistance will only be exacerbated by continued widespread planting, and stacking, of this GE trait.[96]

Costs Associated With GE Crops and Herbicide-Resistant Weeds

Farmer Costs

Farmers apply herbicides for weed control because of their "economic utility."[97] Yield-depressing weed infestations imperil farm earnings, and herbicides are promoted as a cost-effective approach to combating weeds while continuing to plant the same crop season after season. But with the onslaught of herbicide resistance, the indirect costs of herbicide use are undermining the economic viability of GE herbicide-tolerant crops. Biotech corn seeds already cost nearly $40 more per acre than non-GE seeds, and the cost of biotech corn seeds nearly tripled from $103 per 80,000 seeds in 1998 to $285 in 2013.[98]

Perhaps higher seed costs were justifiable when Roundup always worked, but now that glyphosate-resistant weeds have spread, the higher cost may not be worth it. A 2012 national BASF survey found that 73 percent of farmers surveyed faced reduced yields because of herbicide-resistant weed infestations.[99] And resistance to multiple herbicides in waterhemp could eventually make soybean production an unviable option in parts of the Midwest.[100]

Farmers face significant costs from herbicide-resistant weeds from reduced yields and increased production costs to combat weed infestations. These costs can range from $12 to $50 an acre, or as much as $12,000 for an average sized corn or soybean farm or $28,000 for an average cotton farm.[101] (See Table 1.) In 2010, herbicide-resistant weeds cost farmers $17 an acre from reduced yields.[102] In 2012, 92 percent of surveyed cotton farmers reported that their losses due to weed control were at least $50 per acre.[103] In Tennessee, glyphosate-resistant horseweed has increased soybean farmers' production costs by $12 per acre; and Georgia and Arkansas cotton producers have seen additional costs of $19 per acre due to glyphosate-resistant Palmer amaranth.[104]

Since U.S. farmers have found herbicide-resistant weeds in their fields, they have changed farming methods to control them, resulting in higher weed-control costs and even a return to tillage and hand hoeing.[113] In 2009, farmers in Georgia were forced to weed half of the state's 1 million acres of cotton due to the spread of pigweed, costing $11 million.[114]

Table 1. Farmer Costs of Herbicide-Resistant Weeds

STUDY AREA	YEAR	WEED VARIETY	COST PER ACRE	COMPARISON
National[105]	2010	All	$17	3 percent of value of corn crop[106]
Cotton farmer survey[107]	2012	All	$50	7 percent of value of cotton crop[108]
Tennessee soybean farmers[109]	2005	Horseweed	$12	2 percent of value of soybean crop[110]
Arkansas and Georgia cotton farmers[111]	2011	Palmer Amaranth	$19	5 percent of value of cotton crop[112]

Human Health Costs

Pesticide Exposure: Herbicides are toxic to plants by nature, and some herbicides have been proven to be especially hazardous to humans. The herbicide 2,4-D has been associated with health risks including endocrine disruption in humans.[115] Dicamba is a carcinogenic herbicide that can drift to nearby communities.[116] Isoxaflutole exposure causes developmental toxicity and is a probable human carcinogen, leading to liver tumors and carcinomas in male and female rats.[117] The EPA warns consumers that acute exposure to atrazine can cause organ failure, low blood pressure and damage to adrenal glands, while long-term exposure can damage the cardiovascular system and cause cancer.[118]

Chemical Residues in Food: When Monsanto commercialized its Roundup Ready crops, the company's marketing campaign described glyphosate as being "less toxic to rats than table salt."[119] Company-submitted safety studies highlighted the benign quality of glyphosate, but some of the independent, peer-reviewed research done on glyphosate-tolerant crops has revealed troubling health implications, including deterioration of liver and kidney function and impaired embryonic development in rats fed GE feed.[120] Despite these potential harms, the FDA and USDA's monitoring programs do not test for glyphosate residues on food or crops.[121] As more Roundup was used to cope with glyphosate-resistant weeds, the herbicide residues increased — but the FDA and USDA merely hiked up the permitted residue levels, with the result that glyphosate-resistant crops did not exceed the allowable tolerance levels.[122]

The 2,4-D-tolerant crops in the pipeline — corn and soybeans — could be dangerous to eat because a metabolite of 2,4-D (2,4-Dichlorophenol or DCP) is known to cause skin sores, liver damage and sometimes death in animals.[123] Because of the risks of this byproduct, scientists from the French National Institute for Agricultural Research suggest that crops treated with 2,4-D "may not be acceptable for human consumption."[124] A 2012 study found that individuals with 2,4-DCP present in their urine were more likely to have a diminished tolerance to food and environmental allergens.[125]

Environment and Wildlife: Monsanto has claimed that Roundup "biodegrades into naturally occurring elements" and "will not wash or leach in the soil,"[126] but glyphosate persists in the environment for as long as a year in soil and on sprayed plants, and for more than six months in water.[127] In 2011, the U.S. Geological Survey (USGS) found glyphosate in over 60 percent of air and rain samples taken during the growing season in Mississippi, Iowa and Indiana.[128] Another USGS study demonstrated the persistence of glyphosate in surface waters near agricultural areas, including over half of Iowa water samples and every stream examined in Mississippi over two years.[129]

Drift of 2,4-D can damage ecosystems containing sensitive organisms. According to the EPA, 2,4-D can be "very highly toxic to slightly toxic to freshwater and marine invertebrates."[130] In 2011, the National Marine Fisheries Services issued a final opinion that concluded that registration of pesticides containing 2,4-D is likely to jeopardize the 28 endangered and threatened Pacific salmon species and to adversely modify the designated critical habitat of some of them.[131] Isoxaflutole is moderately toxic to freshwater aquatic organisms and highly toxic to some marine aquatic organisms.[132]

Atrazine is toxic to aquatic invertebrates[133] and has been linked to hormonal problems in frogs and fish that can damage their development.[134] Atrazine was linked to fish in the Detroit River with both male and female sex organs[135] and has been known to turn frogs into "bizarre creatures bearing both male and female sex organs."[136] In 2007 and 2008, the Natural Resources Defense Council (NRDC) monitored atrazine in 20 Midwestern watersheds. Every sampled watershed had detectable levels of atrazine, and more than half had concentrations higher than the 1 part per billion level that begins to damage the function of aquatic plants.[137] The European Union phased out atrazine completely by 2007.[138]

Although the USDA is considering approving GE crops that are resistant to multiple herbicides, the EPA's current surface water standards (or health assessments) do not cover combinations of multiple herbicides or concentration peaks during certain high-use seasons.[139] As a result, the EPA cannot measure or regulate the effects of herbicide loading — made prevalent with stacked GE traits — in waterways, with uncertain effects on wildlife and human health.

Conclusion and Recommendations

Genetically engineered herbicide-tolerant crops have increased the reliance on agrichemicals that threaten the environment, wildlife, human health and farmer incomes. The emergence of herbicide-resistant weeds should cast significant doubt on the biotech seed companies' strategy of developing new varieties of crops that tolerate more dangerous and powerful herbicides. The seed and chemical companies have put farmers on a chemical treadmill, and now they are increasing the pace. It is time for a more rational, systems-based approach, which includes some of the following strategies and policy changes:

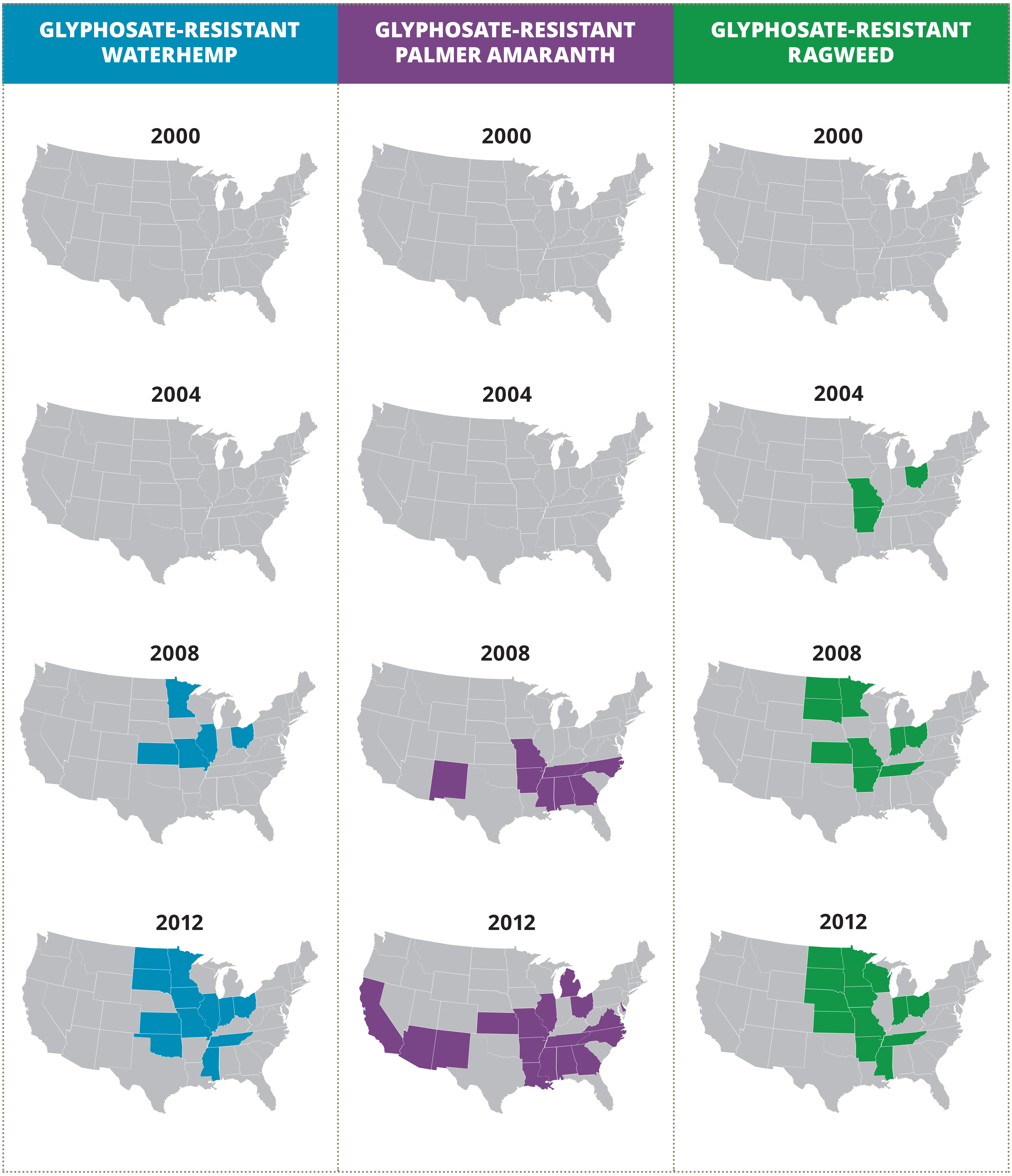
WESTERN CHORUS FROG.PHOTO CC-BY © BENNY MAZUR / COMMONS.WIKIMEDIA.ORG

- **The United States must reform the approval process for biotech crops. The USDA, EPA and FDA should more rigorously evaluate the potentially harmful effects of GE crops and linked chemicals before commercialization, to ensure the safety of humans and the environment.** Until that policy is designed, the United States should enact a moratorium on any new approvals of GE plants and animals, rather than speeding up the approval process.
- **The USDA should support and encourage cultivation best management practices to prevent weed resistance in the first place.** Conservation crop rotation, cover crops, tillage and appropriate use of manure that replaces the no-till, herbicide-based system can reduce soil erosion, sequester more carbon, and improve habitat, biodiversity and water quality.[140] And variety is key. Farmers should expand from the commonplace corn-soy rotation to include additional crops, like wheat or alfalfa, in the seasonal rotation.[141] A long-term 2012 USDA, University of Minnesota and Iowa State University study showed that more diverse cropping systems perform as well and even better than less-diverse systems with fewer chemical inputs.[142]
- **The USDA should educate and encourage farmers to adopt non-chemical strategies for long-term weed control.** Australian farmers developed methods to destroy weed seeds at harvest and maximize crops' seeding rates for increased competition against weedy foes. These

"harvest weed seed control" (HWSC) systems have worked to significantly fight ryegrass populations in Australia.[143]

- **The USDA must dedicate research dollars to developing alternatives for sustainably managing herbicide-resistant weeds.** Even though the cause of herbicide-resistant weeds is the overuse of herbicides, government and industry leaders are promoting the increased use of currently available herbicides as a solution.
- **The U.S. government must improve the collection and distribution of weed resistance[144] and agricultural pesticide application data.** The USDA should collect weed resistance metrics in its annual agricultural surveys and the Census of Agriculture. The EPA should collect data on annual pesticide use rather than relying on private consulting firms to collect the data, as has been the case for years,[145] and make this data publicly available. There has been no EPA data on agricultural pesticide use made public since 2007.[146]
- **In the European Union, Food & Water Europe calls on politicians and regulators to heed the warning that GE crops are an escalation of weed management problems rather than a solution, and to reject all applications for Roundup Ready or other herbicide-tolerant GE crops for import or cultivation.** Growing them on European soil would harm and set back sustainable farming, and importing them would be a tacit approval of a serious problem, and it is no longer acceptable to turn a blind eye by encouraging the cultivation of GE herbicide-tolerant crops outside Europe. The European Union cannot claim to foster sustainable farming or sustainable development if it is exporting the damage caused by its choices to other countries and expecting those communities to pay the price.

Number of States Reporting Glyphosate-Resistant Weeds in Fields (BY YEAR)



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