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Critical Issue Report: The First Thirteen Years

Impacts of Genetically Engineered Crops on Pesticide Use: The First Thirteen Years

by Charles Benbrook

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PREFACE

This report explores the impact of the adoption of genetically engineered (GE) corn, soybean, and cotton on pesticide use in the United States, drawing principally on data from the United States Department of Agriculture. The most striking finding is that GE crops have been responsible for an increase of 383 million pounds of herbicide use in the U.S. over the first 13 years of commercial use of GE crops (1996-2008).

This dramatic increase in the volume of herbicides applied swamps the decrease in insecticide use attributable to GE corn and cotton, making the overall chemical footprint of today's GE crops decidedly negative. The report identifies, and discusses in detail, the primary cause of the increase -- the emergence of herbicide-resistant weeds.

The steep rise in the pounds of herbicides applied with respect to most GE crop acres is not news to farmers. Weed control is now widely acknowledged as a serious management problem within GE cropping systems. Farmers and weed scientists across the heartland and cotton belt are now struggling to devise affordable and effective strategies to deal with the resistant weeds emerging in the wake of herbicide-tolerant crops.

But skyrocketing herbicide use is news to the public at large, which still harbors the illusion, fed by misleading industry claims and advertising, that biotechnology crops are reducing pesticide use. Such a claim was valid for the first few years of commercial use of GE corn, soybeans, and cotton. But, as this report shows, it is no longer.

An accurate assessment of the performance of GE crops on pesticide use is important for reasons other than correcting the excesses of industry advertising. It is also about the future direction of agriculture, research, and regulatory policy.

Herbicides and insecticides are potent environmental toxins. Where GE crops cannot deliver meaningful reductions in reliance on pesticides, policy makers need to look elsewhere. In addition to toxic pollution, agriculture faces the twin challenges of climate change and burgeoning world populations. The biotechnology industry's current advertising campaigns promise to solve those problems, just as the industry once promised to reduce the chemical footprint of agriculture. Before we embrace GE crops as solution to these new challenges, we need a sober, data-driven appraisal of its track record on earlier pledges.

The government has the capability, and we would argue a responsibility, to conduct periodic surveys of sufficient depth to track and accurately quantify the impacts of GE crops on major performance parameters, including pesticide use. While the USDA continued to collect farm-level data on pesticide applications during most of the 13 years covered in this report, the Department has been essentially silent on the impacts of GE crops on pesticide use for almost a decade. This is why the groups listed in the Acknowledgements commissioned this study by Dr. Benbrook, the third he has done on this topic since 2002.

We hope that this report will help trigger new government and academic assessments of the performance, costs, and risks associated with today's GE crops. Without such assessments, American agriculture is likely to continue down the road preferred by the biotechnology industry, a path that promises to maximize their profits by capturing a larger share of farm income, and limit the ability of plant breeders and other agricultural scientists to address other pressing goals of wider importance to society as a whole.

Dr. Margaret Mellon
Director, Food and Environment Program
Union of Concerned Scientists

Mr. Mark Retzloff
Board Chair, The Organic Center
Chairman of Board, Aurora Organic Dairy

ACKNOWLEDGMENTS

This is the third report we have done on the impact of genetically engineered (GE) crops on overall pesticide use in the United States. The first was released as Ag BioTech InfoNet Technical Paper Number 6 in 2003 and covered the first eight years of commercial use of GE seeds. The second report was completed in October, 2004 and analyzed the first nine years of commercial use.[1]

Several people have contributed to this report, as well as to the development and refinement of the model used in all three reports. Thanks to all of them for sharing their expertise and knowledge.

Karen Benbrook compiled and manages the Access database encompassing USDA pesticide use data going back to 1964. This valuable research tool makes it possible to carry out analytical projects drawing on annual USDA pesticide use surveys. Karen also developed the graphics and desk-top published the report.

Karie Knoke, K-Comp Solutions, has contributed to the development and refinement of the Microsoft Excel-based analytical model.

Over the years Dr. Michael Hansen of the Consumers Union, and Dr. Robert Kremer, with the Agricultural Research Service in Columbia, Missouri have provided key information for developing and applying the projection model. Also, thanks to William Freese, Center for Food Safety, for assistance in compiling information on resistant weeds, emerging GE crops, and current developments in the biotechnology industry and regulatory agencies. Bill's attention to detail and depth of knowledge were invaluable as the project unfolded.

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I am grateful for the encouragement, counsel, and technical support of Dr. Margaret (Mardi) Mellon and Dr. Jane Rissler of the Union of Concerned Scientists for my work over the last decade on the impact of GE crops on pesticide use.

I am solely responsible for the analytical approach and model, decisions required to deal with data gaps, the interpretation and communication of findings, and any errors or lapses in judgment.

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[1] Access the October, 2004 report, Ag BioTech InfoNet Technical Paper Number 7, at http://www.organic-center.org/science.latest.php?action=view&report_id=158

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ABBREVIATIONS

AI – Active Ingredient
ALS – Acetolactate synthase, a major herbicide family of chemistry
ARMS - Agricultural Resources Management Survey
AMS - Agricultural Marketing Service
BXN - Bromoxynil Tolerant
Bt – Bacillus Thuriengensis
CWR – Corn Rootworm
ECB – European Corn Borer
EPA - Environmental Protection Agency
ERS – Economic Research Service
GE – Genetically Engineered
GM - Genetically Modified
GR – Glyphosate-Resistant
HT – Herbicide-Tolerant
IPM - Integrated Pest Management
LL – Liberty Link
NAS - National Academy of Sciences
NASS - National Agricultural Statistics Service
NCFAP - National Center for Food and Agriculture Policy
NOP - National Organic Program
PPO - Protoporphyrinogen Oxidase, an enzyme
RR – Roundup Ready
SWCB – Southwestern Corn Borer
USDA – United States Department of Agriculture
WCB – Western Corn Borer

1. Executive Summary

In a recent story tracking the emergence of weeds resistant to glyphosate (Roundup) herbicides, a North Carolina farmer said that "Roundup is the greatest thing in agriculture in my lifetime."

A retired weed scientist admits in the same story "In hindsight, we screwed up. We can't rely on the same thing over and over."

But farmers did, turning glyphosate herbicide and genetically engineered (GE) corn, soybeans, and cotton into the most stunning and profitable market success story in the history of the pesticide and seed industry.

This report documents some of the key impacts of GE crops on their way to market dominance and explains why the total pounds of herbicides applied on GE crops has spiked so sharply in recent years, with more increases to come.

But first, some key terms are defined.

A "pesticide" is a chemical that controls pests. The term encompasses herbicides applied to control weeds, insecticides used to manage insects, and fungicides sprayed to manage plant diseases.

A pesticide "active ingredient" (AI) is the chemical (or chemicals) in a pesticide that is responsible for killing or otherwise controlling target pests.

"Pesticide use" is usually measured as pounds of pesticide "active ingredient" applied per acre, or on a given crop over some period of time.

A "trait" in a genetically engineered crop is the unique characteristic or attribute added to the genetic makeup of the crop using recombinant DNA (gene-splicing) technology. The capacity of a plant to withstand applications of a particular herbicide is an example of a GE crop trait.

"Stacked" GE seeds are those expressing two or more distinct traits.

"Trait acres" are the number of GE crop acres that contain a particular trait. One acre planted to a single-trait GE crop represents one trait acre, an acre planted to a "stacked" crop with two traits is equivalent to two trait acres, and so on. (This is why GE "trait acres" planted exceeds total GE crop acres planted).

GE seeds were introduced commercially in 1996 and now dominate the production of corn, soybeans, and cotton in the United States. GE crops contain one or both of two major categories of traits:

- Herbicide-tolerant (HT) crops are genetically engineered to survive direct application of one or more herbicides during the growing season, chemicals that would otherwise kill or severely stunt the crop. The major HT crops are soybeans, corn, and cotton. Nearly all HT trait acres are planted to "Roundup Ready" (RR) seeds that tolerate applications of Monsanto's glyphosate (Roundup) herbicide, the active ingredient in Roundup herbicide.
- *Bt* crops are engineered to produce toxins derived from the natural bacterium *Bacillus thuringiensis (Bt)* in plant cells. These toxins are lethal to certain agricultural insect pests.

Corn and soybean strip-cropping systems reduce weed and insect pressure and lessen reliance on pesticides and GE crops

A. This Report

This report focuses on the impacts of GE crops on pesticide use, as measured by the total pounds applied on HT and *Bt* corn in contrast to conventional corn, HT soybeans in contrast to conventional soybeans, and HT and *Bt* cotton compared to conventional cotton.

Official U. S. Department of Agriculture (USDA) surveys are the source of most of the data used in this report on the acres planted to each GE trait in corn, soybeans, and cotton. Annual "trait acreage" reports from Monsanto provide more nuanced data on the acres planted to crops with specific traits and trait combinations.

The data in this report on the acres planted to crops with each major GE trait are of high quality and are not controversial.

Pesticide use data come from annual surveys done by the USDA's National Agricultural Statistics Service (NASS). These surveys encompass the percentage of crop acres treated with each pesticide active ingredient, average rates of application, the number of applications, and pounds of active ingredient applied.

NASS pesticide use data are also of high quality and have stood the test of time, but NASS surveys do not report pesticide use separately on crop acres planted to GE seeds, in contrast to acres planted to conventional seeds. Hence, a method was developed for each GE crop and trait to estimate from NASS data how much more or less pesticide was used on a GE acre versus an acre planted with conventional seeds (for more methodological details, see Chapters 2, 4, and 5).

These differences in pesticide use per acre are calculated by crop, trait, and year. The result is then multiplied by the acres planted to each GE crop trait in a given year. Last, the model adds together the differences in the total pounds of pesticides applied across all crops, traits and years, producing this report's bottom line. It's a big number -- an additional 318 million pounds of pesticides were applied due to the planting of GE crops from 1996 through crop year 2008.

B. Key Findings

Farmers planted 941 million acres of GE HT corn, soybeans, and cotton from 1996 through 2008. HT soybeans accounted for two-thirds of these acres.

Bt corn and cotton were grown on 357 million acres, with corn accounting for 79% of these acres.

Thus, about 1.3 billion trait acres of HT and *Bt* crops have been grown between 1996 and 2008. HT crops account for 72% of total GE crop trait acreage. The actual number of acres planted to GE soybeans, corn, and cotton over this period is considerably less than 1.3 billion due to the prevalence of "stacked" versions of GE corn and cotton.

Impacts on Pesticide Use

GE crops have increased overall pesticide use by 318.4 million pounds over the first 13 years of commercial use, compared to the amount of pesticide likely to have been applied in the absence of HT and *Bt* seeds.

The 318.4 million pound increase represents, on average, an additional 0.25 pound of pesticide active ingredient for every GE trait acre planted over the first 13 years of commercial use.

Bt corn and cotton have delivered consistent reductions in insecticide use totaling 64.2 million pounds over the 13 years. *Bt* corn reduced insecticide use by 32.6 million pounds, or by about 0.1 pound per acre. *Bt* cotton reduced insecticide use by 31.6 million pounds, or about 0.4 pounds per acre planted.

HT crops have increased herbicide use by a total of 382.6 million pounds over 13 years. HT soybeans increased herbicide use by 351 pounds (about 0.55 pound per acre), accounting for 92% of the total increase in herbicide use across the three HT crops.

Recently herbicide use on GE acres has veered sharply upward. Crop years 2007 and 2008 accounted for 46% of the increase in herbicide use over 13 years across the three HT crops. Herbicide use on HT crops rose a remarkable 31.4% from 2007 to 2008.

GE crops reduced overall pesticide use in the first three years of commercial introduction (1996-1998) by 1.2%, 2.3%, and 2.3% per year, but increased pesticide use by 20% in 2007 and by 27% in 2008.

Two major factors are driving the trend toward larger margins of difference in the pounds of herbicides used to control weeds on an acre planted to HT seeds, in comparison to conventional seeds:

- The emergence and rapid spread of weeds resistant to glyphosate, and
- Incremental reductions in the average application rate of herbicides applied on non-GE crop acres.

Resistant Weeds

The widespread adoption of glyphosate-resistant (GR), RR soybeans, corn, and cotton has vastly increased the use of glyphosate herbicide. Excessive reliance on glyphosate has spawned a growing epidemic of glyphosate- resistant weeds, just as overuse of antibiotics can trigger the proliferation of antibiotic-resistant bacteria.

The stalk of a mature Palmer amaranth weed can reach six inches in diameter, and can damage mechanical cotton pickers.

GR weeds were practically unknown before the introduction of RR crops in 1996. Today, nine or more GR weeds collectively infest millions of acres of U.S. cropland. Thousands of fields harbor two or more resistant weeds. The South is most heavily impacted, though resistant weeds are rapidly emerging in the Midwest, and as far north as Minnesota, Wisconsin, and Michigan. In general, farmers can respond to resistant weeds on acres planted to HT crops in five ways:

- Applying additional herbicide active ingredients,
- Increasing herbicide application rates,
- Making multiple applications of herbicides previously sprayed only once,
- Through greater reliance on tillage for weed control, and
- By manual weeding.

In the period covered by this report, the first three of the above five responses have been by far the most common, and each increases the pounds of herbicides applied on HT crop acres.

GR pigweed (Palmer amaranth) has spread dramatically across the South since the first resistant populations were confirmed in 2005, and already poses a major threat to U.S. cotton production. Some infestations are so severe that cotton farmers have been forced to abandon cropland, or resort to the preindustrial practice of "chopping cotton" (hoeing weeds by hand).

Resistant horseweed (marestail) is the most widely spread and extensive glyphosate-resistant weed. It emerged first in Delaware in the year 2000, and now infests several million acres in at least 16 states of the South and Midwest, notably Illinois. GR horseweed, giant ragweed, common waterhemp, and six other weeds are not only driving substantial increases in the use of glyphosate, but also the increased use of more toxic herbicides, including paraquat and 2,4-D, one component of the Vietnam War defoliant, Agent Orange.

Growing reliance on older, higher-risk herbicides for management of resistant weeds on HT crop acres is now inevitable in the foreseeable future and will markedly deepen the environmental and public health footprint of weed management on over 100 million acres of U.S. cropland. This footprint will both deepen and grow more diverse, encompassing heightened risk of birth defects and other reproductive problems, more severe impacts on aquatic ecosystems, and much more frequent instances of herbicide-driven damage to nearby crops and plants, as a result of the off-target movement of herbicides.

Figure 1.1 shows the upward trend in the pounds of glyphosate applied per crop year[1] across the three HT crops. USDA NASS data show that since 1996, the glyphosate rate of application per

Farmers have resorted to hand weeding in an attem pt to save cotton and soybean fields heavily infested with glyphosate-resistant Palmer amaranth. Photo by Brad Luttrell (www.bradluttrell.com)

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[1] NASS defines the pesticide "rate per crop year" as the average one-time rate of application multiplied by the average number of applications.

crop year has tripled on cotton farms, doubled in the case of soybeans, and risen 39% on corn. The average ***annual increase*** in the pounds of glyphosate applied to cotton, soybeans, and corn has been 18.2%, 9.8%, and 4.3%, respectively, since HT crops were introduced.

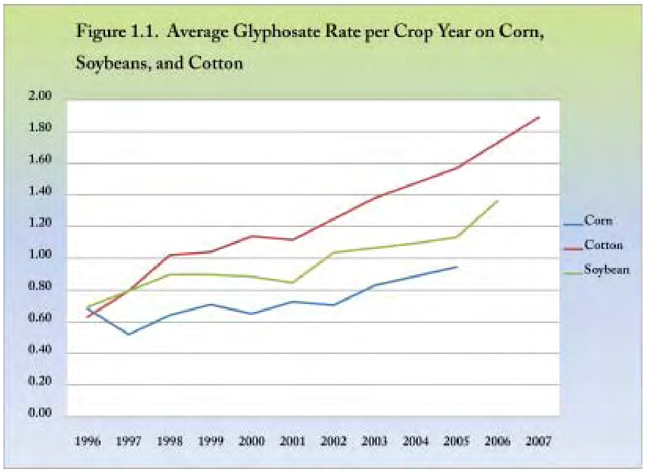
Figure 1.1. Average Glyphosate Rate per Crop Year on Corn, Soybeans, and Cotton

Lower-Dose Herbicides Used with Conventional Crops

The second key factor responsible for the increasing margin of difference in herbicide use on HT versus conventional crops is progress made by the pesticide industry in discovering more potent active ingredients that are effective at progressively lower average rates of application. As a result of these discoveries, the average per acre amount of herbicides applied to conventional crops has steadily fallen since 1996. In contrast, glyphosate/ Roundup is a relatively high-dose herbicide and glyphosate use rates have been rising rapidly on HT crop acres, as clearly evident in the NASS data presented above.

The average rate of herbicides applied to conventional soybean acres dropped from 1.19 pounds of active ingredient per acre in 1996 to 0.49 pounds in 2008. The steady reduction in the rate of application of conventional soybean herbicides accounts for roughly one-half of the difference in herbicide use on GE versus conventional soybean acres. The increase in the total pounds of herbicides applied to HT soybean acres, from 0.89 pounds in 1996 to 1.65 pounds in 2008, accounts for the other one-half of the difference.

A similar trend is evident with insecticides. Corn insecticides targeting the corn rootworm (CRW) were applied at around 0.7 pound per acre in the mid-1990s and about 0.2 pound a decade later. The exception to this rule of dramatically falling pesticide use rates has been cotton insecticides targeting the budworm/bollworm complex. The rate of these products has fallen marginally from 0.56 to 0.47 pounds per acre.

C. The Road Ahead for GE Corn, Soybeans, and Cotton

The vast majority of corn, soybean, and cotton fields in the U.S. in 2010 will be sown with GE seeds. This is not a bold prediction because the non-GE seed supply is so thin now that most farmers will be purchasing GE seeds for the next several years, whether they want to or not.

The GE corn, soybean, and cotton seeds planted over the next five to 10 years will, if current trends hold, contain increasing numbers of stacked traits (usually three or more), cost considerably more per acre, and pose unique resistance management, crop health, food safety, and environmental risks. HT crops will continue to drive herbicide use up sharply, and those increases in the years ahead will continue to dwarf the reductions in insecticide use on *Bt* crop acres.

Tipping Point for RR Crops

Crop year 2009 will probably mark several tipping points for RR crops. The acres planted to HT soybeans fell 1% from the year before, and will likely fall by a few additional percentage points in 2010. Farmer demand for conventional soybeans is outstripping supply in several states, and universities and regional seed companies are working together to close the gap.

Reasons given by farmers for turning away from the RR system include the cost and challenges inherent in dealing with GR weeds, the sharply increasing price of RR seeds, premium prices offered for non-GE soybeans, the poorer than expected and promised yield performance of RR 2 soybeans in 2009, and the ability of farmers to save and replant conventional seeds (a traditional practice made illegal with the purchase of HT/RR seeds).

In regions where farmers are combating resistant weeds, especially Palmer amaranth and horseweed in the South, university experts are projecting increases of up to $80 per acre in costs associated with HT crops in 2010. This increase represents a remarkable 28% of soybean income per acre over operating costs, based on USDA's bullish forecast for 2010 soybean income (average yield 42 bushels; average price, about $9.90).

The economic picture dramatically darkens for farmers combating resistant weeds under average soybean yields (36 bushels) and market prices ($6.50 per bushel). Such average conditions would generate about $234 in gross income per acre. The estimated $80 increase in 2010 costs per acre of HT soybeans would then account for one-third of gross income per acre, and total cash operating costs would exceed $200 per acre, leaving just $34 to cover land, labor, management, debt, and all other fixed costs. Such a scenario leaves little or no room for profit at the farm level.

Resistance Management Still Key in Sustaining *Bt* Crop Efficacy

The future of *Bt* transgenic crops is brighter, but if and only if resistance is prevented. The seed industry, the Environmental Protection Agency (EPA), and university scientists have collaborated effectively in the last 13 years in an effort to closely monitor and prevent resistance to *Bt* crops.

But now, some experts argue that the emphasis on resistance management in *Bt* crops can be relaxed. They point out that the trend in the seed industry toward stacking multiple *Bt* toxins in corn and cotton varieties should reduce the risk of resistance. The EPA has apparently been persuaded by this argument, since it has approved several recent *Bt* crops with substantially relaxed resistance management provisions.

History suggests that lessened diligence in preventing *Bt* resistance is premature. It took 10-15 years for corn and cotton insects to develop resistance to each new type of insecticide applied to control them since the 1950s.

Bt cotton has now been grown for 14 years, but the acreage planted to it did not reach one-third of national cotton acres until 2000. Plus, the first populations of *Bt* resistant bollworms were discovered in Mississippi and Arkansas

Heavy infestations of resistant weeds in cotton fields reduce crop yields and increase costs of production. Resistant populations of weeds can grow as tall, or taller than a hoe handle and produce several hundred thousand seeds per plant.

Farmers will have to diversify weed management tactics and systems to deal with HR weeds. Deep tillage (left photo) buries weed seeds; cover crops (center) can repress weed germination and growth; and mechanized cultivation between plant rows (right) is a proven alternative to herbicides.

cotton fields in 2003, about when experts predicted field resistance would emerge.

Bt corn for CRW control has been planted on significant acreage for only three years (2007-2009). *Bt* corn hybrids for Eastern corn borer (ECB) control are still planted on just a little over one-half national corn acres. For both types of *Bt* corn, and especially in the case of *Bt* corn for CRW control, it is far too early to declare with confidence that resistance is no longer a significant threat.

Future Trends

Agricultural biotechnology firms have thus far devoted the lion's share of their R&D resources to the development of only two biotech traits: herbicide tolerance and insect resistance. Pest control systems largely based on these traits are in jeopardy, biologically and economically, for the simple reason that they foster near-exclusive reliance on single pest control agents – season-long, year after year, and over vast areas of cropland. These are "perfect storm" conditions for the evolution and spread of resistance.

There is no serious dispute that RR crops have been popular, for the most part effective, and about budget-neutral for farmers. But they have fostered unprecedented reliance on glyphosate for weed control, and overreliance has spawned a growing epidemic of glyphosate-tolerant and resistant weeds.

Two major players in the industry – Monsanto and Syngenta – are now offering to pay farmers rebates on the order of $12 per acre to spray herbicides that work through a mode of action different from glyphosate. Monsanto's program will even pay farmers to purchase herbicides sold by competitors, a sign of how seriously Monsanto now views the threat posed by resistance to its bread and butter product lines.

While corn, soybean, and cotton farmers view the spread of resistant weeds as a slow moving train wreck eroding their bottom line, the seed and pesticide industry sees new market opportunities and profit potential arising in the wake of resistant weeds. A large portion of industry R&D investments are going into the development of crops that will either withstand higher rates of glyphosate applications, or tolerate applications of additional herbicides, or both. In short, the industry's response is more of the same.

One major biotech company has applied for and received a patent covering HT crops that can be directly sprayed with herbicide products falling within seven or more different herbicide families of chemistry.[2] These next-generation HT crops will likely be sprayed with two or three times the number of herbicides typically applied today on fields planted with HT seeds, and the total pounds of herbicides applied on HT crops, and the cost of herbicides, will keep rising as a result.

Addressing the rapidly emerging problem of resistant weeds in this way makes as much sense as pouring gasoline on a fire in the hope of snuffing out the flames. Despite these ill-conceived efforts, unmanageable weeds with their roots in the Southeast will almost certainly continue to spread north and west, first into the fringes but eventually throughout the Corn belt.

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[2] Herbicides within a "family of chemistry" work through the same mode of action.

Major weed management problems in the cotton industry in the Southeastern U.S. will not have a dramatic impact on U.S. agriculture or national well being, but what if the same fate lies ahead for corn and soybean producers? It well might in the absence of major changes in weed management systems and regulatory policies.

Instead of just spraying more, farmers must diversify the tactics embedded in their weed management systems, alter crop rotations, scrupulously follow recommended herbicide resistance management plans, and utilize tillage more aggressively to bury herbicide-tolerant weed seeds deep enough to keep them from germinating.

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Sustaining the efficacy of *Bt* crops is both important and possible. The emergence in 2003 of the first, isolated field populations of a major cotton insect resistant to *Bt* is troubling, but also reinforces the importance of today's resistance management plans, which have kept the resistant populations found in Mississippi and Arkansas from spreading. The industry has recently proposed, and EPA has approved, backing away from *Bt* resistance management practices, steps that recklessly place the future efficacy of *Bt* crops and *Bt* insecticide sprays at risk.

Overall pesticide use is bound to continue rising on GE corn, soybeans, and cotton. Even if the new, multiple-toxin versions of *Bt* corn and cotton prove more effective in reducing insect pressure and feeding damage, the reduction in pounds of insecticides achieved as a result will be dwarfed by the continuing surge in herbicide use on HT crops.

The immediate and pressing goals for farmers, scientists and the seed industry include developing weed management systems capable of getting ahead of resistant weeds, assuring no lapse in the commitment to preserving the efficacy of *Bt* toxins, and expanding the supply and quality of conventional corn, soybean, and cotton seeds. The last goal will likely emerge as the most vital, since the productivity of our agricultural system and the quality of much of our food supply begins with and depends on seeds.

Monsanto used this "Roundup Ready Zone" graphic in advertising campaigns to depict an idyllic, orderly vision of rural America where crops are planted to RR seeds. Note the relatively small homesteads, each coupled with three mammoth grain storage bins.

2. Introduction, Data Sources, and Methodology

Weeds, insects, and plant diseases can significantly reduce the yield and quality of crops. Since the dawn of agriculture and around the world, managing pests has been a constant, annual, and unavoidable challenge for farmers. The effectiveness of steps taken to keep pest losses to a minimum has often meant the difference between life and death for families, tribes, communities, and even some civilizations.

Since World War II, pesticides have become the major tool employed by U.S. farmers to combat weed competition and insect damage. The term "pesticide" encompasses any chemical designed to control, manage, or kill a pest. There are three major types of pesticides: herbicides to control weeds, insecticides to manage insects, and fungicides to control plant disease. There are several other types of pesticides including rodenticides, nematicides (nematodes), antibiotics (bacteria), plant growth regulators, and miticides (mites).

All pesticides contain one or more "active ingredients" (AI). These are the chemicals within pesticide products that are responsible for either killing a target pest outright, or undermining the ability of a target pest to thrive or do damage to a growing crop. "Inert ingredients" are added to pesticide products to improve the efficacy and stability of a pesticide.

Pesticides work through many different modes of action. Some modes of action disrupt one or more essential physiological processes within the target pest sufficiently to kill the pest in a short period of time. Other modes of action involve blocking how a pest is able to digest food, impeding growth, or impairing reproduction.

Natural biochemicals like insect pheromones (scents that attract insects), botanicals, bacteria like *Bacillus thuriengensis* (*Bt*), and horticultural oils are also classified by the Environmental Protection Agency (EPA) as "pesticides" because of their ability to help manage pests. Most of these work through a non-toxic mode of action and many are approved by the United States Department of Agriculture's (USDA's) National Organic Program (NOP) for use on certified organic farms.

A. Tracking Pesticide Use and Risk

There are two basic ways to track changes in reliance on pesticides: first, the number of different pesticides applied on a given acre, and second, the total pounds of pesticide active ingredient applied per acre in a given year.

Pesticide use surveys carried out by the USDA (see section below on data sources for details) show that corn fields in the U.S. were treated with an average 1.07 herbicides and 0.39 insecticides in 1971, while in that year 0.72 herbicides were used on soybeans, as shown in Figure 2.1.

Figure 2.1. Corn, Soybean and Upland Cotton: Number of Herbicides Used to Manage Weeds, 1971 - 2008

Figure 2.2. Corn and Upland Cotton: Number of Insecticides Used to Manage Pests, 1971 - 2008

Two decades later in 1991, corn farmers applied on average about two different herbicides per acre. Since 1991 reliance has gradually increased and reached a peak of 2.78 herbicides applied to the average acre in 2001.

Corn growers have been less reliant on insecticides than on herbicides, as clear in Figures 2.1 and 2.2. Between 29% and 39% of national corn acres have been treated with an insecticide since 1971. This lessened reliance compared to herbicides reflects two facts on the ground:

- Weeds are a problem every year in every field, while corn insects are episodic pests that cause problems serious enough to warrant treatments in only some regions and in some years; and

- Planting corn and soybeans in a crop rotation is typically very effective in suppressing most important corn insect pests.

Increasing reliance by soybean farmers over time on a greater number of herbicides is evident in Figure 2.1, until the introduction of Roundup Ready (RR) glyphosate-resistant soybeans in 1996. The number of herbicides applied per acre fell from 2.7 in 1996 to 1.38 in 2005, although the number of herbicides applied on soybean acres is now rising as a result of the emergence of weeds resistant to glyphosate. Very few soybean acres are treated with insecticides.

In terms of the volume, or pounds of pesticide active ingredient applied per acre, there were about three pounds of insecticides applied in 1964 for each pound of herbicide on major U.S. field, fruit and vegetable crops.[1] Just seven years later in 1971, 176 million pounds of herbicides were applied, in contrast to 128 million pounds of insecticides.

Since 1971, the shift to much lower-dose insecticides has reduced the total pounds of insecticides applied to under 40 million in 2004. Herbicide use, on the other hand, rose from 176 million pounds in 1971 to 363 million pounds in 1997, despite the registration of several lower-dose herbicides starting in the early 1980s.

In 2004 across major field crops, the ERS reports that 7.6 pounds of herbicides were applied for each pound of insecticide. **The unmistakable dominance of herbicides in measures of the total pounds of pesticides applied is why the performance of herbicide-tolerant GE crops determines, for the most part, the impact of GE technology on overall pesticide use.**

Table 2.1 provides an overview of the acres planted and pesticide use from 1996 through 2008 for the three major GE crops: corn, soybeans, and cotton. Across these three crops and the 13 years covered in this analysis, 3.8 billion pounds of herbicides were applied, compared to 409 million pounds of insecticides – **9.3 pounds of herbicides for each pound of insecticide.** Cotton is clearly an exception in that insecticide use accounts for 43% of the total pounds of pesticides applied to that crop.

Environmental and public health problems with pesticides began to attract the attention of both scientists and citizens in the 1960s. Rachel Carson's famous 1962 book *Silent Spring* deepened public

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[1] "*Agricultural Resources and Environmental Indicators, 2006 Edition*," edited by Wiebe, K., and Gollehon, N., Economic Research Service (ERS) Information Bulletin Number 16, USDA, July 2006.

Table 2.1. Corn, Soybean, and Cotton Acreage Planted, Average Pesticide Use per Acre, and Total Pounds Applied: 1996 - 2008 (see notes)

	Corn	Soybean	Upland Cotton	Total Three Crops
Total Acres Planted	1,050,099,000	938,854,000	175,695,300	2,164,648,300
Herbicide Pounds Applied	2,337,624,392	1,133,653,162	355,268,782	3,826,546,336
Insecticide Pounds Applied	126,787,180	14,199,081	268,549,750	409,536,010
Total Pounds Applied (Herbicide and Insecticide)	2,464,411,571	1,147,852,243	623,818,532	4,236,082,346
Average Pesticide Use per Acre (Pounds)	2.35	1.22	3.55	1.96
Herbicides as Percent of Total	95%	99%	57%	90%
Insecticides as Percent of Total	5%	1%	43%	10%

Notes: Pesticide use estimates for 2008 are preliminary (see text for approach and assumptions). All use data are from the USDA National Agricultural Statistics Service (NASS) annual surveys of pesticide use and take into account both changes in the one-time rate of application and the average number of applications per crop year. National acres planted to each crop are derived from NASS Crop Production Annual Summary Reports. (http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?doumentID=1047)

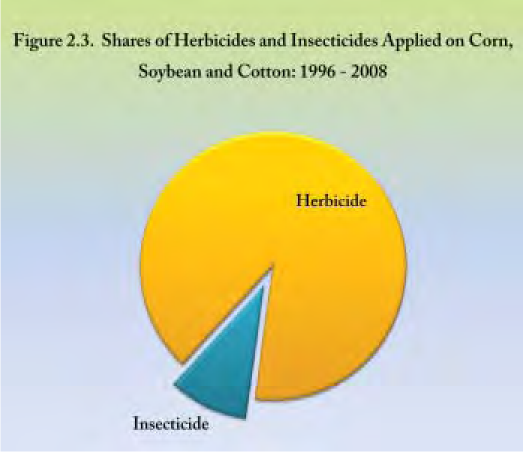
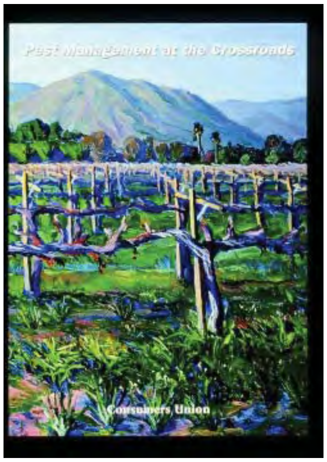


Figure 2.3. Shares of Herbicides and Insecticides Applied on Corn, Soybean and Cotton: 1996 - 2008

awareness and concern over the impact of persistent, chlorinated hydrocarbon insecticides. Government scientists and regulatory agencies focused more attention on pesticide use and risks, both confirming the existence of significant environmental impacts from pesticide use, especially insecticides, and gaining insight into how pesticides were harming birds and other wildlife, as well as people.

As pesticide use grew in the 1970s and 1980s, so did evidence of adverse impacts on exposed wildlife populations and people. The regulation of pesticide use and risks became one of the dominant areas of focus for the EPA and the environmental community in the 1980s and through much of the 1990s. An overview of pest management, pesticide use and risks, and efforts to move toward more prevention-oriented pest management systems is provided in the 1996 Consumers Union book *Pest Management at the Crossroads* (PMAC).[2]

A key theme of PMAC is that changes in crop rotations and other farming practices can sharply reduce pest pressure and reliance on pesticides.



B. Milestones and Major Impacts of GE Crops

The application of recombinant DNA technology in crop breeding, popularly known as genetic engineering, has been promoted by the biotechnology industry as another means to reduce pesticide use. Genetically engingeered (GE) crops were introduced commercially in the U.S. in 1996 and were rapidly adopted by corn, soybean, and cotton farmers.

By 1998, concern and controversy over the health and environmental impacts of GE plants had, for the most part, overshadowed long-

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[2] Benbrook, C., Groth, E., Halloran, J., Hansen, M., Marquardt, S., (1996). *Pest Management at the Crossroads* (PMAC), Consumers Union, PMAC also discusses the likely impacts and problems associated with GE crops, based on what was then known about the technologies.

Table 2.2. Percent of National Acres Planted to Herbicide-Tolerant (HT) and *Bt* Crop Varieties [Combines acres planted to single- and multiple-trait varieties]

	1996	1999	2002	2005	2006	2007	2008
-------------------All Herbicide-Tolerant Varieties-------------------							
Corn	3%	8%	11%	26%	36%	52%	63%
Soybeans	7.4%	55.8%	75%	87%	89%	91%	92%
Cotton	0.2%	44%	74%	81%	86%	92%	93%
-------------------All *Bt* Crop Varieties-------------------							
Corn	1.4%	25.9%	24%	35%	40%	49%	57%
Cotton	12%	31%	39%	60%	65%	72%	73%

Data Source: Supplemental Tables 2-4

standing worries over pesticide use and risk, both in the U.S. and Europe.

In part for this reason, there has been surprisingly little rigourous independent analysis of the pesticide use implications of GE crop technology. This lack of solid data is all the more surprising given that: 1) nearly all commercially grown GE crops have pest management traits that directly impact pesticide use practices; and 2) the technology is being implemented and promoted by agrichemical firms that have acquired a significant share of the world's seed supply.

This report attempts to fill an important gap in understanding of the impacts of GE crop technology by answering the following question: How have GE crops impacted pesticide use in the United States? We begin by providing brief overviews of the two major traits introduced into the three primary GE crops: herbicide tolerance and insect resistance in corn, soybeans, and cotton. **GE crops with these traits comprise roughly 99% of all biotech crops grown (by acreage) in the U.S. from 1996 to 2008.**[3]

Herbicide Tolerance

Herbicide-tolerant (HT) crops are engineered to survive direct "post-emergence" application of one or more herbicides. The herbicide kills or severely stunts all or most growing weeds, while leaving the crop undamaged, or just modestly impacted for a short period of time.

A handful of HT crops was introduced prior to the advent of genetic engineering. The first such crop, canola resistant to atrazine and related triazine herbicides, was commercialized in 1984. Interestingly, it was developed through recurrent backcrossing of canola with a related weed (*Brassica campestris*) from a population that had previously evolved resistance in the field through repeated application of triazine herbicides.[4] Most other non-GE HT crops were developed through use of mutagenesis to be resistant to sulfonylurea and/or imidazolinone herbicides that inhibit the acetolactate synthase enzyme (ALS inhibitors). ALS inhibitor-resistant corn, soybeans, and canola were commercialized in 1992, 1994, and 1997, respectively, followed in the early years of this decade by resistant varieties of wheat, rice and sunflower.[5]

It is worth noting that these crops were endowed with resistance to the two classes of herbicides to which weeds, at the time, had developed the most widespread resistance, in terms of both number of resistant biotypes and acreage infested. The first major wave of herbicide resistance that began in the 1970s involved 23 species of weeds resistant to atrazine and related herbicides of the photosystem II inhibitor class, which have been reported to infest up to 1.9 million acres of cropland in the U.S. The second major wave began in the 1980s, and involves 37 species of weeds resistant to ALS inhibitors. Scientists have confirmed that these resistant weeds now infest up to 152,000 sites covering 9.9 million acres (see Figure 2.4).

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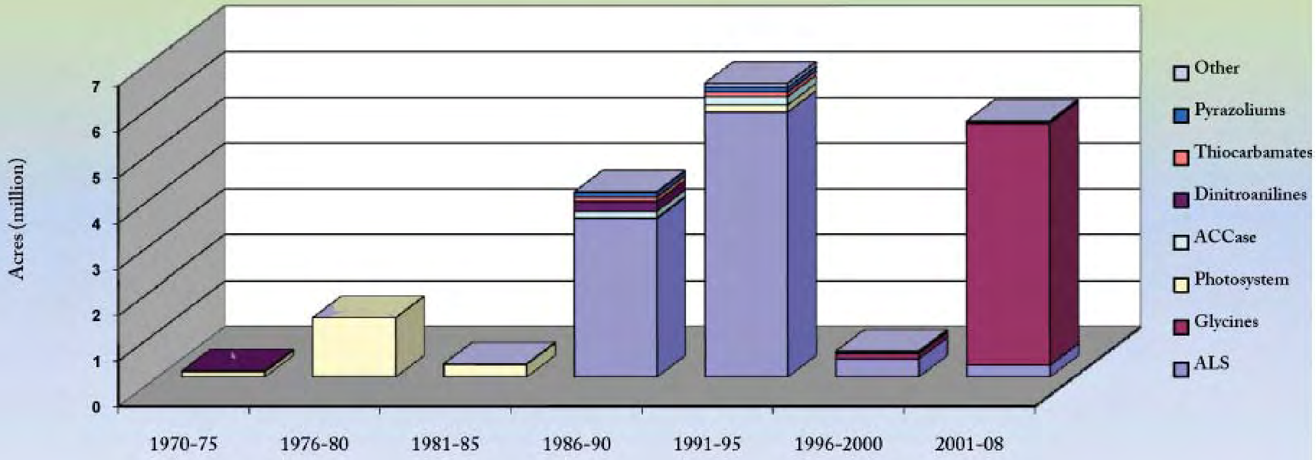
[3] GE canola has been planted on no more than 1 million acres annually; GE papaya is grown only in Hawaii on roughly 1,000 acres (and no where else in the world); the acreage of GE squash is unknown but almost certainly miniscule. GE sugar beets were not planted on a commercial scale until 2009.

[4] Tranel, P. J., and Horvath, D. P., (2009). "Molecular biology and genomics: new tools for weed science," *Bioscience* 59(3): 207-215, p. 208.

[5] Tranel and Horvath (2009), *op. cit.*, Table 1.

Figure 2.4. U.S. Crop Acreage Infested With Herbicide-Resistant Weeds by Class of Herbicide and Year Reported: 1970-2008



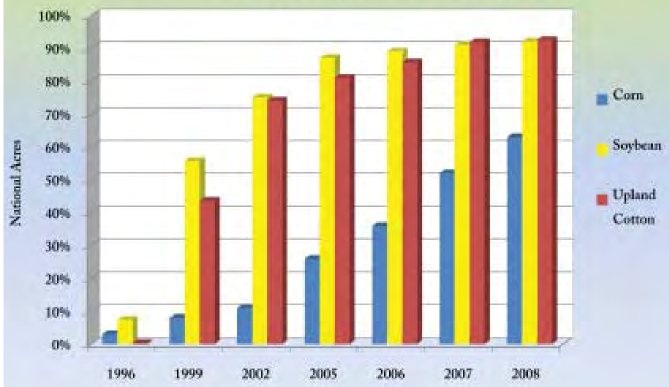
Compiled by Center for Food Safety from reports listed by International Survey of Herbicide Resistant Weeds (http://www.weedscience.org/In.asp), last visited Feb. 3, 2009. Acreage infested figures are reported in ranges due to the difficulty of determining the extent of a resistant weed population. The figures presented here represent aggregate upper-bound estimates. Note that glyphosate is the only member of the "glycines" class of herbicides.

Though acreage figures are difficult to come by, a market research firm recently estimated that non-GE herbicide-resistant crops were planted on roughly 6 million acres in 2007.[6] It was not until the advent of genetic engineering that HT crops became prevalent. This report deals only with GE HT crops.

GE HT soybeans, cotton, and corn were introduced beginning in 1996 on just over 7 million acres, and their use expanded by nearly 20-fold to cover more than 132 million acres by 2008. In 2008, HT soybeans, cotton, and corn represented 92%, 93%, and 63% of total acres planted to each crop, respectively (see Figure 2.5, Table 2.2, and Supplemental Tables 2-4 for details and sources).

The vast majority of HT crops are Monsanto's glyphosate-resistant, Roundup Ready (RR) soybeans, cotton, and corn. GE bromoxynil-tolerant (BXN) cotton was planted on modest acreage from the mid-1990s until 2004, but has since disappeared from the market (see Supplemental Table 4). The only currently grown GE crops resistant to an herbicide other than glyphosate are glufosinate-resistant cotton, corn, and canola, which are sold under the brand name LibertyLink (LL). However, LL varieties are not widely grown, comprising no more than a few percent of U.S. cotton and corn acres.[7]

Figure 2.5. Percent of National Acres Planted to Herbicide Tolerant (HT) Crop Varieties, 1996 - 2008



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[6] Doane Market Research and Biotech Traits Commercialized: Outlook 2010, as cited in USDA APHIS (2008). "Finding of No Significant Impact on Petition for Nonregulated Status for Pioneer Soybean DP-356043-5," USDA's Animal and Plant Health Inspection Service, July 15, 2008, Response to Comments, p. 26. http://www.aphis.usda.gov/brs/aphisdocs2/06_27101p_com.pdf

[7] For LibertyLink cotton, see Supplemental Table 4; for LibertyLink corn, see Chapter 4(B).

A major factor driving adoption of glyphosate-resistant (GR) crops has been the declining efficacy of popular ALS inhibitors. Control problems emerged with ALS inhibitors as a result of the development of resistant weeds beginning in 1987, just five years after the first ALS inhibitor herbicide was brought to market in 1982.[8] As noted above, weeds resistant to ALS inhibitors were more prevalent than any other class of herbicide-resistant weeds in the U.S.

Another reason for the dominance of RR crop systems is ease of use and the efficacy of glyphosate, an herbicide that kills a broad spectrum of weeds including annual and perennial broadleaf and grass species. RR-based cropping systems have been well received by farmers because they are simple, flexible, and forgiving.

Prior to the commercial introduction of RR HT crops, glyphosate use was restricted to either before a crop was planted or new seedlings have emerged, or after a crop was harvested. Any direct applications on a growing crop were certain to cause significant damage. RR technology widened the application window to allow post-emergence applications over the top of growing plants throughout the season, thus leading to dramatically increased use of and reliance on glyphosate-based herbicides. As discussed further below, RR crop systems have fostered a third wave of resistant weeds that poses a serious threat to agriculture, and are also profoundly shaping the biotech industry's product pipeline. As yet, there has been no regulatory response to the growing epidemic of GR weeds.

Insect Resistance

In contrast to herbicides, insecticide use in American agriculture has declined sharply since the mid-1960s as a result of the shift away from chlorinated hydrocarbon and carbamate insecticides applied at about one pound per acre, to synthetic pyrethroid and other insecticides applied at one-half to one-tenth pound per acre, or less.

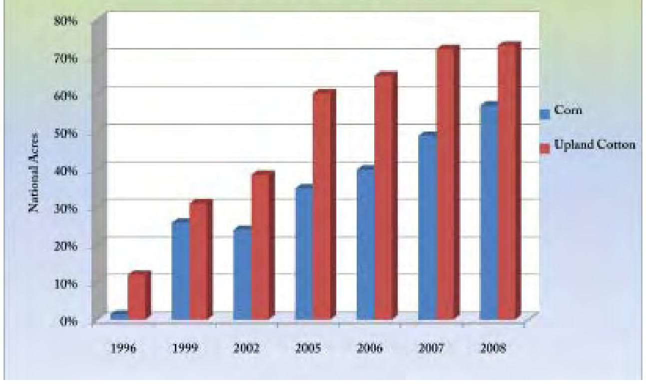
Insect-resistant cotton and corn varieties are genetically modified to produce one or more truncated and activated forms of the toxins (e.g., Cry1Ab) derived from the soil bacterium *Bacillus thuringiensis* (*Bt*). These so-called *Bt* crops were introduced in 1996, and the percentage of national crop acres planted has grown rapidly, as shown in Figure 2.6.

Acreage planted to *Bt* crops grew from 1.8 million acres of cotton in 1996 to 55.8 million acres of corn and cotton in 2008, as shown in Supplemental Table 6. The first *Bt* corn varieties, and all *Bt* cotton varieties, repel above-ground Lepidopteron pests such as the European corn borer (ECB), Southwestern corn borer (SWCB), and cotton bollworm. *Bt* corn to control corn rootworm (CRW) and other soil-borne insects was introduced in 2003.

Bt toxins are biosynthesized continuously throughout the tissues of *Bt* plants, although genetic engineers have some ability to preferentially target (i.e., increase) expression levels in those plant tissues where the toxin is most needed to fend off insect feeding. *Bt* plant-incorporated toxins exert profound selection pressure for development of resistant insects by virtue of the plant's continual production of toxin, in contrast to the intense but short-lived exposure characteristic of *Bt* insecticidal sprays.

The mode of action of *Bt* sprays and toxins is not completely known. Foliar *Bt* sprays contain inactive Cry protoxins (about 130-140 kDa in size) which exist in a crystalline form, when ingested. The alkaline nature of the fore- and mid-gut dissolves the crystal and cleaves it one or two times in the fore and mid-gut to create a truncated, activated toxin (about 60-65 kDa in size). The ***activated*** Cry toxins poke a hole in the gut epithelium, but it is unclear what causes insect death. The two proposed mechanisms are: 1) disruption of the mid-gut epithelium causes insects to stop feeding and starve to death, or 2) extensive cell lysis provides the *Bt* access to the hemocoel, where they germinate and reproduce, leading to septicemia and death.[9]

Figure 2.6. Percent of National Acres Planted to Corn and Cotton Varieties, 1996 - 2008



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[8] Tranel, P. J., and Wright, (2002.), "Resistance of weeds to ALS-inhibiting herbicides: what have we learned?" *Weed Science* 50:700-712.

[9] Broderick, N.A. et al (2006). "Midgut bacteria required for *Bacillus thuringiensis* insecticidal activity." *Proceedings of the National Academy of Sciences*, 103(41): 15196-15199.

The toxicity of *Bt* sprays is limited to those insects with the alkaline gut pH required to cleave and activate the protoxin. In *Bt* plants, the Cry toxins are already activated, increasing the potential for adverse impacts on populations of beneficial insects.[10]

Even before their commercial introduction, many scientists were concerned that *Bt* crops would accelerate the evolution of pest resistance to *Bt* toxins.[11]

In response to such clear warnings from scientists and in the hope of delaying the emergence of resistance, the EPA mandated that *Bt* cotton and corn growers plant blocks of conventional (non-*Bt*) crop "refuges" amidst *Bt* fields to help slow development of resistance. Refuges work by maintaining populations of susceptible insects, some of which will mate with resistant insects, thereby diluting the presence of *Bt*-resistant genes in insect populations. EPA encourages "high-dose" *Bt* crops as another resistance management strategy; high levels of expression of *Bt* toxins lead to a more complete kill of target insects, and hence fewer surviving insects with the potential to pass along resistant genes.

The resistant management plans imposed by EPA on *Bt* cotton and corn have, for the most part, been effective. However, continued vigilance is necessary, given the emergence of isolated populations of cotton bollworms resistant to Cry1Ac in *Bt* cotton.[12]

Seed companies have also begun developing *Bt* crops with multiple *Bt* toxins, both to expand the range of insects controlled and as a resistance management strategy. *Bt* corn with toxins for both ECB and CRW (e.g., YieldGard Plus) were introduced in 2005, and are now widely planted. Cotton with two *Bt* toxins (Bollgard II) was introduced in 2003, and SmartStax corn varieties will be sold for the first time in 2010 expressing six different *Bt* toxins, three for the ECB and SWCB, and three more for the CRW.

New issues arise in assessing risks associated with the stacked versions of crops that have more than one Cry protein. There may be a synergistic effect between the various Cry proteins which could affect the efficacy of the various Cry proteins against their target and non-target organisms. Cross-resistance could emerge as a new challenge in managing resistance. Additional data will also be needed for human toxicity and environmental effects.[13] For instance, the EPA recently funded research to develop an animal model of allergenicity to better assess the potential for *Bt* insecticidal proteins to trigger food allergies.[14]

C. Data Sources and Complications

This report is based on surveys of agricultural chemical use conducted by USDA's National Agricultural Statistics Service (NASS). We chose to base this analysis on USDA data for several reasons. First, NASS supplies highly reliable data through use of transparent, rigorous methods and statistically representative sampling procedures.[15] Second, because the NASS program has collected annual pesticide usage data on soybeans, corn, and cotton for most of the years covered by this report, it offers a consistent dataset that facilitates accurate, year-to-year comparisons. Finally, the public availability of NASS data (free of charge) facilitates open review and criticism of any analysis utilizing them.

NASS data are considered the gold standard of pesticide use information in the U.S. NASS reports provide a solid basis to study trends in the intensity of pesticide use across crops and

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[10] For more on *Bt* modes of action, including differences re: target and non-target species, see: Then, C. (2009), "Risk assessment of toxins derived from Bacillus thuringiensis—synergism, efficacy, and selectivity," *Environ Sci Pollut Res*, Access at: http://www.springerlink.com/content/a42th8677132802g/fulltext.pdf Published online June 26, 2009.

[11] Harris, M. K. (1991). "Bacillus thuriengensis and Pest Control," Letter to *Science*, Vol. 253, September 6.

[12] Tabashnik, B.E., et al (2008). "Insect resistance to *Bt* crops: evidence versus theory," *Nature Biotechnology* 26(2): 199-202.

[13] For a recent report on additional data needs for *Bt* proteins, see http://www.epa.gov/scipoly/sap/meetings/2009/february/022526finalreport.pdf

[14] EPA (2009). "EPA grant to University of Chicago for research on food allergy triggers," EPA Press Release, at http://www.epa.gov/ncer/events/news/2009/07_28_09_feature.html July 23.

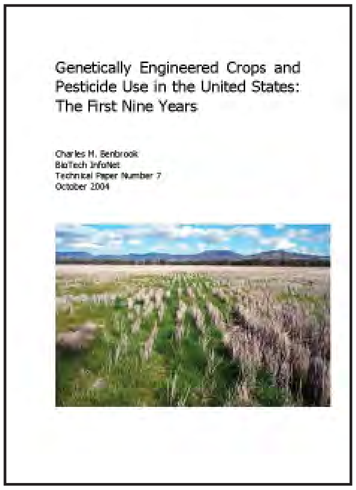
[15] USDA NASS (2006). "Meeting of the Advisory Committee on Agriculture Statistics (ACAS): Summary and Recommendations," USDA National Agricultural Statistics Service, Appendix III, at: http://www.nass.usda.gov/About_NASS/Advisory_Committee_on_Agriculture_Statistics/advisory-es021406.pdf February 14-15, 2006,

regions, among pesticide families of chemistry, and over time. These reports are a valuable resource used by EPA and state pesticide regulatory agencies, farm commodity groups, the food industry, environmental and consumer groups, and the pesticide industry.

Several private firms[16] also collect pesticide use information, under contract with mostly corporate subscribers, such as agrichemical companies. These sources are unacceptable for use in this report for several reasons, including their great expense, the proprietary nature of sampling methodologies, and prohibitions on the use and/or disclosure of purchased data.[17]

Because USDA does not routinely collect separate data for pesticide use on GE and conventional crops, a methodology is needed to estimate average pesticide use on GE and conventional crop acres. Such a methodology was first developed in 2003 and used in the analysis reported in Ag BioTech InfoNet Technical Paper #6, "Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Eight Years."

The method was refined and applied to an additional year of USDA pesticide use data in the October 2004 Ag BioTech InfoNet report "Genetically Engineered Crops and Pesticide Use in the United States: The First Nine Years."[18] The same basic approach has been applied in this analysis covering the first 13 years of commercial planting of GE crops.



Genetically Engineered Crops and Pesticide Use in the United States: The First Nine Years

Charles M. Benbrook
BioTech InfoNet
Technical Paper Number 7
October 2004

USDA has surveyed pesticide use for five decades beginning in 1964. Subsequent national surveys were conducted in 1966, 1971, and 1982. These early surveys covered only a few major crops and collected just basic data like the percentage of acres treated and pounds of active ingredient applied.

From 1991 through 2001, NASS surveyed pesticide use on major field crops including corn, soybeans, and cotton on an annual basis. Annual summary reports have been issued with a set of tables covering pesticide use in all "Program States,"[19] as well as at the national level.

Each standard table for a given crop reports the percentage of acres treated with a specific pesticide active ingredient, the average rate of application in pounds of active ingredient per acre; the average number of applications; the average rate per crop year, which is simply the one-time application rate multiplied by the number of applications; and the total pounds applied.

Benbrook Consulting Services (BCS) and Ecologic, Inc. have moved NASS survey data into a database program to carry out additional computations. For instance, average figures for individual and aggregate pesticide use in the Program States are applied to the small proportion of acres that NASS does not survey to arrive at estimates of total pesticide use for all crop acres in any given year.[20]

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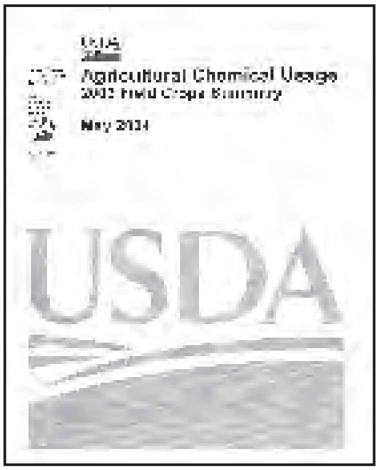
[16] For instance, Doane Marketing Research and Crop Data Management Systems.

[17] USDA NASS (2006), *op. cit.*

[18] Access this 2004 report at http://www.organic-center.org/science.latest.php?action=view&report_id=158

[19] "Program States" are those surveyed that year by NASS, and typically represent 85% or more of the national acreage planted to a given crop.

[20] This is accepted practice, e.g. see "Agricultural Resources and Environmental Indicators: Pest Management Practices," USDA Economic Research Service, Report No. AH722, September 2000, Table 4.3.1, footnote 1, accessible at http://www.ers.usda.gov/publications/arei/ah722/arei4_3/DBGen.htm. "The estimates assume that pesticide use on acreage in non-surveyed States occurred at the same average rate as in the surveyed States."



In years when a given crop was not surveyed by NASS (e.g., cotton in 2006), average values are interpolated between the previous and following year to fill in such data gaps. For corn since 2005, soybeans since 2006, and cotton for 2008, herbicide and insecticide use rates were projected from recent trends and in light of published reports on university websites regarding levels of pest pressure and the emergence of resistant weeds or insects.

Spikes upward in pesticide use are readily apparent in NASS data and have alerted farmers, scientists, and USDA to pest-induced problems in specific crops and regions. Such problems might be triggered by the emergence of resistance to a once-effective pesticide or the introduction of a new invasive species. Likewise, reductions in the frequency and intensity of pesticide use are regarded as evidence that farmers have made progress in adopting prevention-based Integrated Pest Management (IPM), perhaps through the planting of a new crop variety or adoption of a more complex crop rotation.

By combining NASS pesticide use data with EPA data on the toxicological potency of pesticide active ingredients, pesticide risk indices specific to different classes of organisms, like birds or bees, have been calculated by the Economic Research Service (ERS) and other analysts. Such indices provide a useful early-warning system to detect changes in pest pressure, or pesticide efficacy over time and in different regions that may lead to "unreasonable adverse effects on man or the environment," the basic standard embedded in U.S. pesticide regulatory policy.

Scientists studying the emergence of resistance to a specific pesticide, or family of chemicals, rely heavily on pesticide-use data to determine the degree of selection pressure required to trigger resistance.[21] Epidemiologists exploring associations between pesticide use, exposure and patterns in birth defects or cancer often use NASS data in constructing retrospective estimates of exposure levels.

Impacts of USDA Decision to Stop Collecting Pesticide Use Data

NASS has dramatically scaled back its program in recent years. First, NASS replaced its annual surveys of major field crops with less frequent ones beginning in 2002. Then, in the 2007 growing season, data collection was limited to just two crops—cotton and apples. NASS did not collect pesticide use data on any crops during the 2008 growing season, citing a shortage of funds and the availability of private sector survey data as reasons for cutting the program.[22]

Of the three major crops covered in this report, NASS data are available in most years for cotton through 2007, through 2006 for soybeans, and through 2005 for corn.

The absence of a continuous series of NASS data since 2005 for the three major GE crops hampers the ability of independent analysts and government scientists to track the performance and impacts of GE crops. The lack of NASS pesticide-use data covering recent crop years is a special concern, given the dramatic impact of resistant weeds on the number and volume of herbicides applied to HT crops.

USDA's decision to drop the pesticide-use surveys led to strong protests from a wide range of groups, including The Organic Center, Center for Food Safety, Union of Concerned Scientists, Natural Resources Defense Council, and many other organizations, including several with close ties to the pesticide industry.[23] In 2008, the administrator of the EPA voiced concern to the Secretary of Agriculture about the loss of NASS data, joining several government officials at the state and federal levels. In May, 2009, the new USDA leadership announced the reinstatement of the program, beginning with the fruit and nut survey in the fall of 2009.[24]

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[21] For instance, see: Owen, M. D. K., and Zelaya, I. A., (2005). "Herbicide-resistant crops and weed resistance to herbicides," *Pest Manag* Sci 61: 301-311.

[22] Engelhaupt, E. (2008). "Government pesticide and fertilizer data dropped," *Environ. Sci. Techol.* 42(18), 6779-6780, at: http://pubs.acs.org/doi/pdfplus/10.1021/es801937k?cookieSet=1.

[23] For a press release with a link to the letter from 44 organizations to former Secretary of Agriculture Ed Schafer, see http://truefood-now.wordpress.com/files/2009/10/usda-nass-pr-final-without-hyperlinks.doc.

[24] Letter of May 7, 2009 from Katherine Smith, Acting Deputy Under Secretary for Research, Education, and Economics, to Dr. Charles Benbrook, The Organic Center.

D. Methodology

In this report a four-step methodology is used to calculate the differences in the amount of pesticides applied to GE crops versus conventional crops in a given year.

First, the total number of acres of each crop planted to conventional, HT and/or *Bt* varieties is derived from standard USDA sources: NASS for soybeans and corn, the Agricultural Marketing Serviee (AMS) for cotton.

Monsanto's "Biotechnology Trait Acreage" reports are used to disaggregate total *Bt* corn trait acres to those planted to varieties engineered to control the ECB, the CRW, or both.

Second, the average amount of pesticides applied per acre per crop year is estimated for conventional GE crop acreage (detailed results in Supplemental Table 7).

Third and by year, the average amount of herbicides or insecticides applied to an acre planted to a conventional seed variety is subtracted from the corresponding amount for the GE crop.

Finally, in the **fourth** step, the difference in pesticide pounds applied per acre for each GE trait is multiplied by the acres planted to the GE crop in that year (full results appear in Supplemental Table 8). The impacts of herbicide tolerant and *Bt* crops on pesticide use per acre are then added together across the three crops over the 13 years of commercial use, producing the overall impact of today's major GE crops on herbicide, insecticide, and all pesticide use.

Estimating Herbicide Application Rates on Conventional and HT Soybeans, Corn, and Cotton

Because the USDA does not report herbicide-use data separately on acres planted to conventional varieties, in contrast to GE varieties, an indirect method was developed that draws on NASS data. The method involves the use of a standard formula to estimate what is not known, from variables that are known from NASS and other data sources.

The average pounds of herbicides applied on all corn, soybean, or cotton acres in a given year are easily calculated from NASS data. Data are readily accessible on the share of total crop acres in a given year that were planted to conventional crop varieties, as well as the percentage planted to GE varieties. These two percentages add up to 100% and can be used in a weighted-average formula, along with average herbicide use on GE crop acres, to calculate the pounds of herbicides applied on non-HT acres.

The basic weighted average formula, as applied to the pounds of herbicides used in producing HT and conventional acres of crop$_x$, contains the following five data elements, the first four of which are known or can be projected from USDA.

1. Average herbicide use per acre on all acres planted to a crop, from NASS surveys;

2. The percentage of acres planted to HT crops, from ERS and AMS data;

3. The percentage of acres planted to conventional varieties (100% minus number 2);

4. The average pounds of all herbicides applied per acre of HT crop, from NASS surveys and university sources; and

5. The average pounds of herbicides applied per acre of conventional crop, which can be calculated by solving the weighted-average equation for the variable "Ave. Pounds Applied on non-HT acres crop$_x$."[25]

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[25] The weighted-average formula can be used to calculate average herbicide use on conventional crop acres by subtracting the term (% acres planted to HT varieties crop$_x$ x Average Pounds Applied on GE varieties crop$_x$) from both sides of the equation, and then dividing by the percentage of crop acres planted to non-GE varieties.

The basic formula is:

Average Herbicide Pounds Applied per Acre on All Acres of crop$_X$ =
(% acres planted to HT varieties crop$_X$ x Ave. Pounds Applied on HT varieties crop$_X$) +
(% acres planted non-HT varieties crop$_X$ x Ave. Pounds Applied on non-HT acres crop$_X$)

For a given crop and year, we calculated the impact of HT technology on herbicide use by subtracting the average rate applied to conventional acres (number 5 in above list) from the average rate applied to HT acres (number 4 in above list). When this number is negative, HT technology reduced herbicide use in that year for that crop; when it is positive, average herbicide use was higher on HT acres.

Insecticide Application Rates on Conventional and *Bt* Corn and Cotton Acres

In the case of *Bt* corn, two steps are required to estimate the impact of an acre planted to *Bt* corn for ECB/SWCB and/or CRW control on corn insecticide use. First, the average rate of application per crop year must be calculated for insecticides targeting the ECB and the CRW. This process is complicated by the fact that several insecticides are applied for control of both the ECB and CRW. For these insecticides, the portion of acres treated for control of ECB versus the CRW must be estimated. We reviewed pesticide labels, treatments recommended in university spray guides, and consulted with experts in corn IPM in carrying out this step (see Supplemental Table 9 for the share of insecticide acres treated targeting the ECB and Supplemental Table 10 for the share targeting the CRW).

The percentage of national corn acres treated with each insecticide for ECB/SWCB and CRW control was used to calculate a weighted average rate of insecticide application across all corn acres treated per crop year. Based on these calculations, the weighted average rate of insecticides applied on conventional acres for ECB control drops from 0.2 pounds of active ingredient per acre in 1996 to 0.15 in 2005-2008. In the case of CRW, the rate of insecticides applied on conventional acres falls from 0.29 pounds per acre in 2003, the year *Bt* corn for CRW control was commercialized, to 0.19 pounds in 2005-2008. Figure 2.7 shows the weighted-average rate of application for insecticides targeting the ECB and CRW.

The second step in calculating the pounds of insecticides displaced by the planting of *Bt* corn is to estimate the portion of acreage planted to *Bt* corn for ECB and/or CRW control that would have been treated with an insecticide if the corresponding *Bt* crop had not been planted. This step is required since *Bt* corn is now planted on far more acres than were ever treated with insecticides. Historically, USDA data show that before the advent of *Bt* corn, just 6% - 9% of national corn acres were typically treated for ECB/SWCB control, while 27% +/- 4% were treated for CRW control.

Supplemental Table 11 provides the details of this step and the resulting estimates of insecticide use averted through the planting of *Bt* corn for ECB and/or CRW control.

In the case of *Bt* acres targeting the ECB/SWCB, the likely share of acres planted to *Bt* corn that would have been sprayed for ECB control begins at 90% in 1997, the first year of commercial planting, and drops incrementally to 45% in 2008, a year when over half of corn acres were planted to a *Bt* corn variety engineered for ECB control.

The high initial percentage is based on the assumption that early adopters of *Bt* ECB corn were more likely to have been farmers contending with serious ECB and/or SWCB infestations, triggering the need for insecticide applications. The falling percentage reflects the progressively wide adoption of *Bt* corn by farmers with lesser ECB/SWCB problems, many of whom likely did not spray prior to the commercial launch of *Bt* corn.

In the case of *Bt* corn for CRW control, the percentage of acres planted that would likely have been treated with an insecticide targeting the CRW begins at 95% in 2003, the first year of commercial sales, and declines to 60% in 2008, a year when 35% of corn acres were planted to a *Bt* corn for CRW control and another 9% of corn acres were sprayed for CRW control with an insecticide (i.e., about 44% of corn acres were either sprayed or planted to a *Bt* variety for CRW control, well above the 27% +/- 4% level treated with insecticide for CRW from 1964 through 2008).

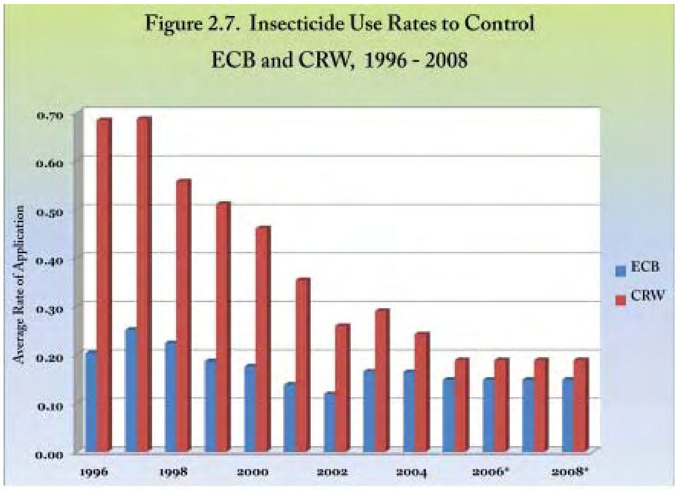

Figure 2.7. Insecticide Use Rates to Control ECB and CRW, 1996 - 2008

This higher projected level of CRW treatment of corn acres is justified in part by the emergence in the late 1990s of a variant of the CRW that learned to overwinter in soybean fields, thus undermining the efficacy of corn-soybean rotations in reducing CRW populations.

Bt cotton targets the budworm/bollworm complex, but does not appear to have significant effects on other insect pests, including the boll weevil, plant bugs, white flies, and stink bugs. Growers typically apply broad-spectrum insecticides to control both the budworm/bollworm complex and other insects. *Bt* cotton will reduce the use of insecticides for budworm/bollworm complex, but not applications of insecticides targeting other insects.

Supplemental Table 12 reports the basis for estimating the pounds of insecticides averted by each acre planted to *Bt* cotton. First, university insect management guides and experts were consulted to estimate the portion of total acres treated with each cotton insecticide for control of the budworm/bollworm complex versus other insects. Then the number of acres treated with each insecticide is calculated from NASS data, as well as the share of total acres treated that was accounted for by a given insecticide.

Finally, weighted average use rates were calculated using the shares of total acre treatments with each individual insecticide. In the case of cotton, this weighted average insecticide application rate falls modestly from 0.56 pounds per acre in 1996 to 0.47 in 2007-2008.

E. Assumptions and Caveats

The methodologies used to project pesticide use on conventional and GE-crop acres require a number of assumptions and projections. Here, a brief description is provided of the major assumptions embedded in the Supplemental Tables that form the operating core of the model used to estimate the impact of GE crops on pesticide use. Each assumption or projection is also assessed in terms of its impact on our analysis of pesticide-use levels.

1. ***Farmers planting GE-crop varieties take advantage of the novel traits they are paying for.***

For example, in the case of herbicide-tolerant plants, it is assumed that farmers build their weed management program around glyphosate herbicide. Likewise, a farmer purchasing a stacked-trait corn or cotton variety will alter both weed and insect pest management systems in accord with the purchased traits.

These assumptions closely reflect reality up to the 2009 crop season, but may not in the future as the seed industry moves toward more multiple-trait stacked varieties.

2. ***A small acreage of corn and cotton planted to GE herbicide-tolerant varieties other than those resistant to Roundup are included in the herbicide-tolerant acreage estimates from the NASS and AMS. Herbicide use on these non-RR acres, however, is analyzed as if the acres were planted to a RR variety.***

Perhaps 15 million acres have been planted to non-RR HT varieties over the last 13 years, a period during which approximately 941 million acres of RR crops have been planted. Accordingly, these non-RR HT acres account for just one out of every 63 acres of HT crops. In addition, the differences in herbicide use on non-RR HT crops, compared to RR crops, are modest. As a result, this assumption has virtually no impact on the outcome of the analysis.

3. ***Bt-crop growers apply no chemical insecticides for the pests targeted by these trait(s): ECB/SWCB and CRW, and the budworm/bollworm complex.***

This assumption assumes close to 100% control of target pests, and overstates efficacy in regions with high pest pressure, especially where multiple generations of target pests are common. As a result, the displacement of insecticide use is likely overstated in the case of some acres planted to *Bt* crops. For example, University of Illinois entomologists have documented spotty performance of *Bt* corn for CRW control, especially under high population pressure, and reported that some growers have applied soil insecticides on *Bt*-corn acres.[26]

In fact, there was so much farm press media attention on the benefits of applying a soil insecticide on corn acres planted to a *Bt* corn for CRW control that the top entomologists in the University of Illinois felt compelled to ask – and answer "No" to - the following question in a widely read bulletin for growers:

> "Does it **always make sense** to use a soil insecticide in conjunction with a *Bt* [CRW] Hybrid?"[27]

Accordingly, this assumption overstates the reduction in insecticide use on some *Bt* corn acres. But because corn insecticides are applied at relatively low rates, the impact of this assumption is modest. This could change dramatically, of course, if resistance emerges to the *Bt* toxins engineered into corn for CRW control, and farmers are forced to apply higher-rate insecticides to prevent serious CRW feeding damage.

> ***4. It is possible to estimate the shares of the pounds applied of a given, broad-spectrum insecticide across multiple target insects, so that these shares can be used in estimating the rate of insecticide applications displaced by a given Bt trait.***

Bt varieties have many complex impacts on insect communities and populations. In some fields, lessened insecticide use allows secondary pests to reach damage thresholds, triggering the need for additional insecticide sprays.[28] In other fields or perhaps in certain years, the reduction in insecticides targeting key Lepidopteron insects creates an opening for populations of beneficial insects, like assassin bugs, to expand, increasing the effectiveness of biological control, and reducing the need for insecticides.

Several different species of assassin bugs attack the large larval stages of lepidopteran insects (e.g., bollworm).

Several broad-spectrum insecticides applied by corn and cotton growers help manage multiple insects, including some which are, and others which are not, the target of the *Bt* toxins engineered into *Bt* corn and cotton varieties. Thus, crediting *Bt* corn for ECB/SWCB control with displacement of all the pounds of organophosphate or synthetic pyrethroid insecticides applied would overstate the impacts of the technology, since a portion of most of these insecticides are applied by farmers for the control of other insects, including the CRW.

Through consultation with insect pest management guides and entomologists, these shares were approximated for the key target pests of *Bt*-crop varieties. In some cases the shares used in the model likely overestimate displacement, while in others, displacement is likely underestimated. Given that most insecticides now applied to corn and cotton acres are low-dose products, discrepancies in these shares will have a modest impact on the pounds of insecticides displaced by *Bt* crops, especially relative to changes in the pounds of herbicides applied on HT acres.

> ***5. Some portion of the acres planted to Bt corn do not displace insecticides because before the commercial availability of Bt-corn seed, farmers were not treating their fields with insecticides.***

Historically, around 35% +/- 4% of corn acres have been treated each year with an insecticide for control of the ECB, SWCB, CRW, and other insect pests. In 2008, 57% of corn acres were planted to a *Bt* variety, including many acres planted to a dual-*Bt* variety. For this reason, crediting each acre of corn planted to a single *Bt* trait with displacement of an insecticide acre treatment would substantially

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[26] Steffey, K., (2007). "*Bt* Corn + Soil Insecticide: What?", *The Bulletin*, University of Illinois Extension, No. 23, Article 4, October 5.

[27] "Preliminary Node-Injury Ratings from University of Illinois Rootworm Product Efficacy Trials Near DeKalb, Monmouth, Perry, and Urbana," , *The Bulletin*, University of Illinois Extension, No. 23, Article 3, October 3, 2008.

[28] Caldwell, D. (2002), "A Cotton Conundrum," Perspectives, OnLine: The Magazine of the College of Agriculture and Life Sciences, North Carolina State University, http://www.cals.ncsu.edu/agcomm/magazine/winter02/cotton.htm Winter 2002,

overestimate the reduction in insecticide use attributed to the technology.

As previously noted, corn insect pressure, however, has also changed in recent years as a result of the emergence of a new subspecies of the CRW that overwinters in soybean fields and disrupts the efficacy of the corn-soybean rotation in reducing CRW populations.

This variant of the CRW was taken into account by increasing the share of *Bt*-corn acres assumed to displace insecticide applications to well above historic levels of insecticide use. The projections of *Bt* corn impacts on insecticide use reflect a near doubling of the percentage of acres that farmers would likely spray with an insecticide, in the absence of *Bt* corn.

Mike Gray, Extension entomologist at the University of Illinois, examines a trap for the presence of CRW beetles in a soybean field.

This assumption likely leads to a modest overestimate of the displacement of insecticide use caused by *Bt* corn, since corn farmers have other proven alternatives to reduce CRW populations through IPM systems. Regrettably, some corn farmers have lost interest in the multi-tactic approaches used in successful IPM systems as one consequence of the planting of *Bt* corn.

6. The Bt toxins manufactured within the cells of Bt crops are not counted as insecticides "applied" on Bt-crop acres.

Clearly, this assumption underestimates the pounds of insecticidal compounds required to manage insects on *Bt* crop acres. Opinions differ among entomologists, the industry, and other experts on whether it is appropriate to count *Bt* toxins manufactured inside GE plants as equivalent to a liquid *Bt* insecticide sprayed on the outside of the plant. Uncertainty over the exact mode of action of *Bt* insecticides and GE toxins is part of the reason for differing opinions.

Those who argue that plant-manufactured *Bt* toxins should not count as equivalent to an applied insecticide assert that a *Bt* variety is just like any other new plant variety that has been bred to express some plant protein or phytochemical useful in combating insect-feeding damage.

Those skeptical of this position point to major differences in the two *Bt* delivery systems and in the source of the *Bt* toxin. *Bt* liquid sprays are applied only when and as needed, consistent with the core principles of IPM. Liquid sprays expose pest populations to short-lived selection pressure, thereby reducing the risk of resistance.

Bt plants, however, produce the toxin continuously during the growing season, not just when needed, and in nearly all plant tissues, not just where the toxins are needed to control attacking insects. In a year with low pest pressure, farmers can decide not to spray insecticides on a corn field, but they cannot stop *Bt* hybrids from manufacturing *Bt* toxins in nearly all plant cells.[29]

There is another key difference that rarely is acknowledged. When plant breeders develop a new variety with a higher level of resistance to a given insect through traditional breeding techniques, they do so by selecting a top-yielding variety to crossbreed with another variety that expresses relatively higher levels of natural phytochemicals that discourage pest feeding, disrupt pest development or reproduction, or in some way reduce the viability of pest populations.

It is extremely rare for a new crop variety developed through conventional breeding to reduce insect feeding damage by killing the target insects. Instead, the elevated levels of phytochemicals in the new variety work through one or more non-toxic modes of action.

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[29] Moreover, from a food safety perspective, *Bt* toxins in liquid sprays break down relatively quickly in the field when exposed to sunlight and hence do not end up in the harvested portion of crops. *Bt* toxins in GE plants are inside plant cells, including the cells of the harvested portion of the crop fed to animals or consumed by people.

This is a second reason why some entomologists reject the notion that there is nothing different between a crop variety genetically engineered to synthesize *Bt* toxins within plant cells, and a new variety from conventional breeders that has improved resistance to an insect pest because of altered levels of natural phytochemicals that work through a non-toxic mode of action.

No resolution is in sight for this complex debate within the entomological community. In addition, no method exists to estimate the pounds of *Bt* toxins produced by a corn or cotton plant during a growing season. Hence, there is no way to project the pounds of *Bt* produced by an acre of *Bt* corn or cotton. Work is needed to develop such a methodology. It will likely show that there is a surprisingly large amount of toxin synthesized by plants during a typical growing season, especially in the new corn varieties engineered to produce six *Bt* toxins.

> ***7. The last NASS survey of soybean herbicide use was in 2006. Glyphosate application rates per crop year on soybeans are projected to increase 5% annually from 2006-2007 and from 2007-2008. Cotton was surveyed last in 2007, and the glyphosate rate was projected to increase 10% from 2007-2008. Corn was last surveyed in 2005, and the glyphosate and total herbicide rates per crop year are projected to increase 5% annually since 2005.***

These assumptions are likely conservative in the case of soybeans and cotton. In soybeans, the glyphosate rate of application per crop year rose 9.8% annually from 1996 through 2006 – almost twice the rate of increase projected in 2007 and 2008.

In cotton, the glyphosate rate per crop year rose 18.2% annually from 1996 through 2007, again well above the 10% increase incorporated in the model's projections of herbicide use on HT cotton acres in 2008.

The corn herbicide rate projections are the most uncertain, given that NASS last surveyed corn in 2005. The percentage of corn acres planted to HT varieties rose from 15% to 26% between 2003 and 2005. In this period, the rate of glyphosate applied per crop year rose on average 7.1% per year. Accordingly, the projected increase of 5% annually in the glyphosate rate per crop year in 2006, 2007, and 2008 is likely conservative. Plus, HT corn has been in widespread use now for about five years – long enough for weed shifts and resistance to begin pushing application rates per crop year upward more sharply than in the first few years of widespread commercial use.

3. Acreage Planted to GE Crop Varieties: 1996-2008

The total number of acres planted to soybeans and corn, as well as the percentage of national crop acres that were planted to an HT and/or *Bt* variety, is derived from annual NASS "Acreage" reports.[1] The USDA's Economic Research Service (ERS) has collated NASS figures on the percentage of crop acres for each GE category from 1996 to present.[2]

In the case of GE cotton, USDA's Agricultural Marketing Service (AMS) has a more accurate breakdown of trait categories by acreage than NASS/ERS. AMS's annual "Cotton Varieties Planted" reports[3] are favored for these data by cotton experts,[4] and also provide figures that are in closer agreement with the information on GE cotton trait acres released periodically by Monsanto.

Supplemental Table 2 reports the ERS data on the percent of corn acres by state and nationally planted to HT varieties, *Bt* varieties, and stacked varieties (one or more *Bt* genes, plus herbicide tolerance). Supplemental Table 3 covers herbicide tolerant soybeans, and Supplemental Table 4 presents both percent of national acres and absolute acreage planted to various GE cotton trait categories.

A. Acres Planted

The percent of national corn, soybean, and cotton acres planted to GE crop traits is presented in Figure 3.1. Soybean and cotton HT seeds were adopted rapidly by farmers. By 1999, 56% of national soybean acres were planted to Roundup Ready (RR) HT varieties. HT corn acres did not reach one-third market penetration until 2006.

Bt cotton reached one-third of national acres in 2000 and is currently planted on close to three-quarters of national cotton acres. It took *Bt* corn for ECB control eight years to reach one-third of national acres in the 2004 crop season. This trait is now planted on close to 50% of national acres. *Bt* corn for CRW control was introduced in 2003 and has now reached about one-third of national acres.

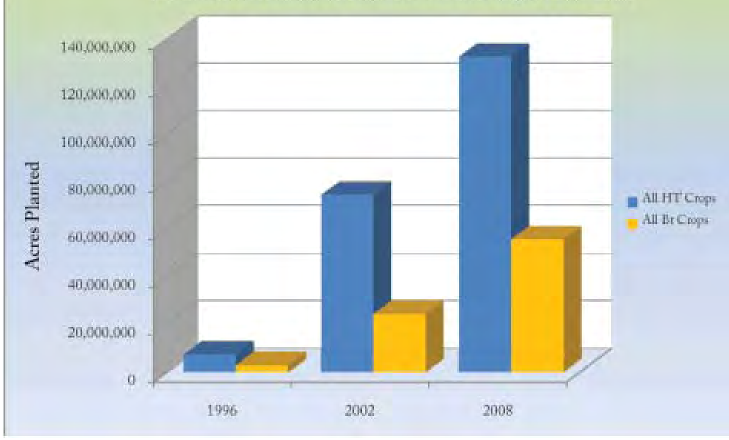

Figure 3.1. Trends in the Percentage of National Crop Acreage Planted to Herbicide Tolerant and *Bt* Crops, 1996-2008

The acreage planted to each GE crop trait by year can be calculated by simply multiplying the percent of national crop acres planted to the GE trait in that year by the total acres of the crop grown. Table 3.1 reports the acres planted to herbicide tolerant and *Bt* transgenic varieties for corn, cotton, and soybeans in 1996, 2002, and 2008; the last column, "Total 1996-2008," includes all 13 years. The data in Table 3.1 come from Supplemental Tables 5 and 6, where HT and *Bt* crop acreage, respectively, is reported for all years.

HT crops clearly account for the lion's share of total GE trait acreage – 72% over the first 13 years of commercial use and around three-quarters in most years. HT soybeans account for almost one-half of all GE trait acres. **This is why HT soybeans are so important in terms of the overall impact of GE crops on the pounds of pesticides applied.**

As discussed in Chapter 2, we assume in this report that when a farmer purchases a variety with a given trait, the farmer relies on that trait in carrying out his/her pest management program. Yet this is not always the case, either because the trait does not perform well enough, or because it is not utilized by the farmer.

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[1] For instance, for 2008, see: http://usda.mannlib.cornell.edu/usda/nass/Acre//2000s/2008/Acre-06-30-2008.pdf.

[2] See spreadsheet at http://www.ers.usda.gov/data/biotechcrops/ for 2000 to present. Click on the graphic for corresponding figures for entire period from 1996 to 2008.

[3] For 2009, see http://www.ams.usda.gov/mnreports/cnavar.pdf.

[4] For instance, see Table 1 in May, O. L. et al (2003). "Challenges in Testing Transgenic and Nontransgenic Cotton Cultivars," *Crop Science* 43: 1594-1601.

Table 3.1. Acreage Planted to Herbicide-Tolerant (HT) and *Bt* Varieties of Corn, Soybean, and Cotton

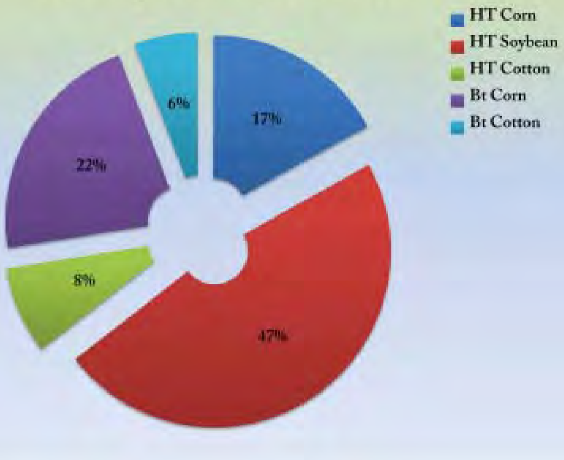
	1996	2002	2008	Total All Years: 1996-2008
HT Corn	2,385,210	8,695,940	54,168,660	219,774,911
HT Soybean	4,751,170	55,442,250	69,660,560	617,386,630
HT Cotton	23,001	10,162,074	8,609,955	104,034,840
ALL HT CROPS	7,159,381	74,300,264	132,439,175	941,196,381
Bt Corn	1,113,098	18,972,960	49,009,740	281,964,269
Bt Cotton	1,725,060	5,293,604	6,787,939	75,321,111
ALL *Bt* CROPS	2,838,158	24,266,564	55,797,679	357,285,380
ALL GE CROPS	9,997,539	98,566,828	188,236,854	1,298,481,761
HT Crops as % All GE Crops	72%	75%	70%	72%
Bt Crops as % All GE Crops	28%	25%	30%	28%

Some traits do not perform well enough to allow the farmer to completely forego pest management measures more typical of the conventional grower. For example, several Midwestern universities have documented the need for insecticide applications to avoid serious root damage in fields planted to *Bt* corn for CRW control, and many farmers are making such applications.[5]

HT crops account for 72% of the total acreage planted to GE crop varieties from 1996 through 2008, and HT soybeans account for almost one-half of total GE acres.

In other cases, superfluous traits go unutilized. For example, corn hybrids engineered to tolerate two different herbicides are on the market, yet only one HT trait will likely be utilized by most farmers.[6] Many corn hybrids express the *Bt* gene for both ECB and CRW control, yet many farmers buying these hybrids face economically damaging levels of only one, or neither, of these insects, in most years.

Figure 3.2. Total Acres Planted to GE Crop Varieties, 1996 - 2008



Why would farmers buy corn seed with unnecessary traits? Because such varieties are the only ones available with other valuable genetic traits matched to a particular farm's soils, maturity zone, and production system.

This tendency to under-utilize GE traits is likely to increase markedly in frequency (i.e., the number of fields impacted)

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[5] Steffey, K., (2007). "*Bt* Corn + Soil Insecticide: What?", *The Bulletin*, University of Illinois Extension, No. 23, Article 4, October 4.

[6] Loux, M. (2009). "Weed Control for Liberty Link vs glyphosate-resistant corn," in: *C.O.R.N Newsletter* 2008-04, Ohio State University, http://corn.osu.edu/print.php?issueID=219&PHPSESSID=eae9fe6fe6e2f9a0b5c0d3d06d47f58b.

and scope (the number of superfluous traits in a purchased bag of seed) as the industry offers more multiple-trait varieties and fewer, and eventually no single-trait seeds. The trend away from single-trait corn and cotton varieties and toward multiple-trait, stacked varieties is already well underway, as evident in Monsanto corn trait acreage figures. In its forecast of 2009 trait acres, Monsanto reported:

> * No acres planted to corn that expresses ONLY the CRW trait;
> * Less than 1 million acres planted to ECB/CRW *Bt* corn **without** the RR trait;
> * Less than 1 million acres of dual-trait corn with Roundup Ready/CRW control; and
> * 32-33 million acres planted to triple-stack corn containing all three traits (RR/ECB/CRW).[7]

Monsanto introduced a limited supply of the first stacked corn seed in 2000 (enough to plant around 100,000 acres). In 2004 Monsanto released the first stacked RR corn expressing the Cry 3Bb1 gene for CRW control. The first dual-*Bt* corn hit the market in 2005.

The first triple-stack corn hybrid was introduced by Monsanto in 2005. It expressed the two *Bt* genes for ECB/SWCB and CRW control, and was also RR. By 2008, double- and triple-stack corn varieties were planted on 57.3 million acres of corn, compared to just 13.6 million acres planted to single-trait GE corn (the vast majority, 11.8 million acres, RR).[8]

The strategy of offering farmers more multiple-trait stacked varieties and fewer single-trait varieties is referred to in the industry as "biotech trait penetration."[9] This strategy is, in turn, driven by the fee-per-trait pricing structure used across the industry. For instance, Monsanto and Dow AgroSciences recently announced a collaboration to develop so-called "SmartStax" corn hybrids that contain eight GE traits stacked together: six different *Bt* insecticides, three for control of ECB/SWCB and similar above-ground pests, three for control of CRW, and two additional traits for tolerance to the herbicides glyphosate and glufosinate. Analysts note that Monsanto encouraged farmers in 2009 to adopt triple-stack corn in order to "create a captive customer base for the 2010 launch of its SmartStax" corn.[10] Over the next few years Monsanto plans to replace the triple-stack corn hybrids sold in 2009 with the eight-stack hybrids coming on the market in 2010.

The commercial introduction of these varieties raises several new issues and questions, some of which are addressed in Chapter 7.

New Challenges in Tracking GE Traits and Acres

The trend toward stacked traits also raises analytical challenges. In corn and cotton, the total number of GE trait acres now far exceeds the total number of acres planted.

According to the June 24, 2009 Monsanto biotechnology trait acreage report, trait acres forecasted for the 2009 crop season include:

- 39 million acres of ECB *Bt* corn;
- 33 million acres of CRW *Bt* corn; and
- 70 million acres of RR corn.

Accordingly in 2009, a projected 142 million GE trait acres of corn was planted, far more than the 87 million acres of corn grown this year. About 73 million acres of corn were planted to a GE crop variety expressing one or more Monsanto traits. Thus, on the average acre planted to GE corn, the variety expressed 1.9 traits, an already significant degree of "trait penetration."
In the case of cotton in 2009, there were 13.4 million

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[7] Monsanto (2009). Monsanto Biotechnology Trait Acreage: Fiscal Years 1996-2009F, updated June 24, 2009. Trait figures reported below also from this report.

[8] Note that Monsanto's figure of 29.9 million acres for total U.S. single-trait corn acres in the trait acreage report referenced above includes 16.3 million acres that are actually double- or triple-stack corn (i.e. they contain only one Monsanto trait – Roundup Ready – but are stacked with competitors' traits).

[9] Monsanto (2006). "Delta and Pine Land Acquisition: Investor Conference Call," Power Point presentation, August 15, 2006, http://www.monsanto.com/pdf/investors/2006/08-15-06.pdf.

[10] Goldman Sachs (2008). "Monsanto Company Update: Trait prices going up along with estimates and price target," June 2, 2008, p. 6.

Monsanto-trait acres and 7.7 million acres of GE cotton grown, for an average of 1.7 traits expressed per acre of GE cotton planted.

The tracking of GE seed traits will be complicated by other factors. As the trend toward more multiple-trait varieties continues, seed companies may begin to neither announce, nor charge, for the presence of certain traits, including those that become obsolete (e.g., the RR trait will become obsolete if and when, and wherever the spread of resistant weeds renders the herbicide ineffective).

In other cases, farmers will be forced by lack of choice to buy a variety that contains traits of little or no use. For this reason, future surveys of GE crop traits will need to explore ways to distinguish between total pest management related trait acres and "functional" trait acres, where a given trait actually changes how the farmer manages pests and the crop.

4. Impacts of Herbicide-Tolerant Crops on Herbicide Use

Curtis Burgess, 16, works with a chopping crew in fields outside of Hughes, Ark. Cotton farmers have resorted to hand weeding to save crops infested with glyphosate-resistant "pigweed". This field is clearly in serious jeopardy. Photo by Brad Luttrell, www.bradluttrell.com

Glyphosate herbicide, marketed as Roundup by Monsanto, has been and remains the backbone of HT cropping systems. The efficacy of RR technology was excellent in the first few years of commercial use. A single application was often all that farmers needed for season long control in corn and soybeans. Typically, an additional application of Roundup or another herbicide was necessary in cotton growing areas, because of the longer growing season and many aggressive weed species in cotton country.

Shifts in weed communities favoring those species not as fully controlled by Roundup started occurring after just a few years of use on the same acre of cropland. After four to six years of applications, such weed shifts to more glyphosate-tolerant species had led to higher rates of Roundup and/or additional applications. In areas where farmers grew RR crops in rotation, like RR soybeans followed by RR cotton, weed populations resistant to Roundup began to emerge and spread.

These changes in weed communities – shifts to more GT species and evolution of glyphosate-resistant biotypes – have driven the incremental increases in both the rates and number of applications of glyphosate and other herbicides required on HT acres.

The title of a recent university extension report to Illinois farmers about the utility of glyphosate-based weed management systems states: "Turn Out the Lights – The Party's Over."[1] In the article, Aaron Hager asserts that:

> "The rapid adoption of glyphosate-resistant corn hybrids and weed spectrum changes in response to near-ubiquitous use of glyphosate in soybean suggests the following theses: *the ability of glyphosate to be a stand-alone herbicide for weed management in soybeans*

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[1] Hager, A., "Turn Out the Lights – The Party's Over," *The Bulletin*, University of Illinois Extension, No. 3 Article 4, April 10, 2009.

Table 4.1. Changes in the Pounds of Glyphosate Applied per Acre per Crop Year on Corn, Cotton, and Soybeans: 1996-2007

Crop and Period	Glyphosate Rate in 1996	Total Increase (Pounds a.i. per Acre)	Percent Change	Average Annual Percent Change in Period Noted
Corn (1996-2005)	0.68	0.27	39%	4.3%
Cotton (1996-2007)	0.63	1.26	199.8%	18.2%
Soybean (1996-2006)	0.69	0.67	97.6%	9.8%

Note: All use data is from the USDA National Agricultural Statistics Service (NASS) annual surveys of pesticide use, and take into account both changes in the one-time rate of application and the average number of applications per crop year. Corn was last surveyed by NASS in 2005, Cotton in 2007, and Soybeans in 2006.

> *will (continue to) decline.* In other words, the 'simplicity' of glyphosate as a stand-alone weed management tool soon will be relegated to the annals of history." [Emphasis in original]

This ecological adaptation to the RR system was predictable and openly discussed well before the first RR crop was planted. A publication issued in 1990 by the Biotechnology Working Group focused on the impacts of HT crops on sustainable agriculture. It stated nearly 20 years ago that:

> "If a shift to herbicide-tolerant crops led to greater use of certain herbicides,... problems associated with resistant weeds would likely increase." [2]

In the 1996 Consumers Union book *Pest Management at the Crossroads (PMAC)*,[3] the "special caution" needed in managing GE crops was highlighted. After discussing the possibility that gene flow could create "super" HT weeds,[4] the report warns that:

> "A more widespread concern with herbicide tolerant plants is the likelihood they will accelerate the emergence of resistant weed species…
>
> "Gaining the ability to apply the herbicides more frequently or possibly at higher rates is the major reason farmers are willing to pay the higher cost for transgenic seed. ***Such changes in the pattern of herbicide use, though, are almost custom-made for accelerating resistance.***" (page 220, emphasis added)

Glyphosate use on cotton rose from 0.63 pounds in 1996 to 1.89 pounds in 2007, or 18.2% per year as a result of the introduction of RR cotton.

The impact of shifts to weed species more tolerant of glyphosate and the evolution and spread of GR populations is unmistakable in USDA pesticide use data over the last 13 years. Table 4.1 summarizes the changes in glyphosate application rates per crop year for corn, soybeans, and cotton that have occurred since 1996, before the widespread planting of HT varieties. Supplemental Table 16 is the source of Table 4.1, and reports full details on glyphosate rates for the three crops.

The first column in Table 4.1 presents the glyphosate application rate per crop year in 1996 and the next column reports the increase from 1996 through the most recent NASS survey (2005 for corn; 2006 for soybeans; 2007 for cotton). The increases take into account both changes in the one-time rate of application, as well as the average number of applications made in a crop season. The third column reports the overall percentage increase and the last column shows the average annual percentage increase in glyphosate rates per crop year.

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[2] Goldburg, R., Rissler, J., Shand, H., and Hassebrook, C. (1990). "Biotechnology's Bitter Harvest: Herbicide-Tolerant Crops and the Threat to Sustainable Agriculture," A Report of the Biotechnology Working Group.

[3] Benbrook, C. et al., (1996). *Pest Management at the Crossroads*, Consumers Union.

[4] Herbicide-tolerant gene flow is a process whereby a resistance gene engineered into a HT crop moves (usually via pollen flow) to a weed species that is genetically related to a GE plant and capable of cross-fertilization with the GE plant.

In cotton, the average rate of glyphosate rose from 0.63 pounds in 1996 to 1.89 pounds in 2007 — clearly good news for the manufacturers of glyphosate herbicides, but bad news for farmers and the environment. Most of this increase was driven by the need to make additional Roundup applications. One application of glyphosate brought about adequate control in 1996 on most cotton farms. Just two years later, 1.5 applications were necessary. By 2003, an average of two applications were made, and by 2007, 2.4 applications. During this time period, the average one-time rate of application went up by 25%, from 0.63 to 0.79 pounds per cotton acre. Glyphosate use on cotton per crop year rose 18.2% per year from 1996 to 2007 as a result of the introduction of RR cotton.

Roundup is a relatively high-dose herbicide. It is applied at around three-quarters of a pound of AI per acre, compared to many other cotton herbicides applied at rates below 0.1 of a pound.[5] The need to make 2.4 applications of glyphosate to control weeds in HT cotton fields in 2007, compared to the just one in 1996, is obviously going to drive up total herbicide use, especially compared to fields planted to conventional cotton, where very low-dose herbicides are among the market leaders.[6]

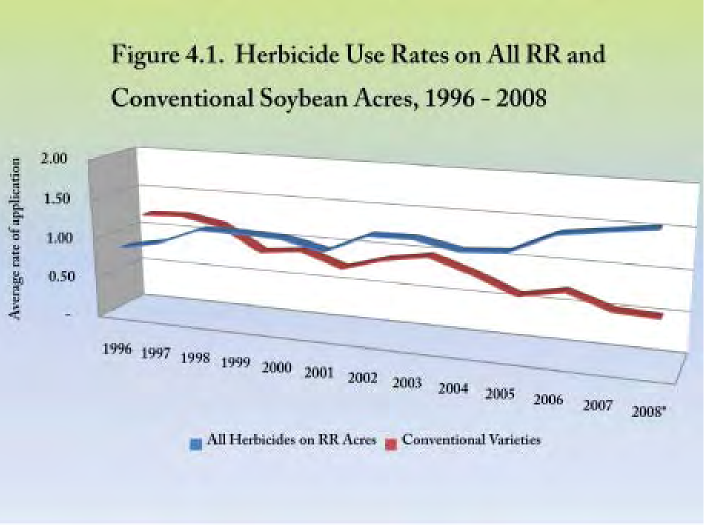

Figure 4.1. Herbicide Use Rates on All RR and Conventional Soybean Acres, 1996 - 2008

The soybean glyphosate rate per crop year increased from 0.69 pounds per acre in 1996 to 1.36 pounds in 2006, or 9.8% per year. The average one-time rate of application rose 27% from 1996 through 2006, while the number of applications rose from 1.1 to 1.7, or 55%.

In corn, the pounds of glyphosate applied rose “only” 4.3% per year. The reason is clear -- RR corn was adopted much more slowly than HT cotton and soybeans. Market penetration did not reach a third of national corn acres until 2006. Accordingly, corn farmers are just now entering the time period when substantial increases are likely in glyphosate application rates, unless farmers switch to other herbicides and weed management technology.

A. Herbicide-Tolerant Soybeans

The general procedure for estimating herbicide use on conventional and GE acres was described in the methodology section in Chapter 2. Here, the methodology is briefly summarized and issues specific to each crop are discussed.

The average number of pounds of herbicides applied to HT acres is composed of the volume of Roundup applied plus an estimate of the pounds of other herbicides needed to achieve effective control.

Total herbicide applications on acres planted to conventional seeds is calculated by use of a weighted-average formula computing the average pounds of herbicides applied on all acres from the pounds applied on conventional and GE acres, coupled with the shares of acres planted to HT and conventional varieties.

The average pounds applied on acres planted to conventional seeds is then subtracted from the average pounds applied to HT acres, producing the difference in herbicide use on an acre of HT crop, in contrast to acres planted to conventional varieties.

Herbicide use rates on all soybean acres, HT acres, and conventional acres are computed in Supplemental Table 15 and are displayed graphically in Figure 4.1.

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[5] NASS data show that there are a half-dozen cotton herbicides applied at rates below 0.01 pound per acre of active ingredient, and another three applied at rates between 0.01 and 0.1 pound per acre.

[6] The cotton herbicide pyrithiobac-sodium was applied to 10% of cotton acres in 2007 at the rate of 0.052 pounds per acre; pyraflufen-ethyl was applied to 8% of acres at 0.003 pounds per acre.

The values in the line "Glyphosate on RR Acres" in Supplemental Table 15 are directly from NASS reports. A small portion of glyphosate applications are made preplant or at planting time to kill weeds that have germinated.

Some of these acres might be planted to conventional varieties. Still, the average rate of glyphosate application does not differ markedly between a preplant and postemergence application over the top of most RR crops.

Total herbicide and glyphosate application rates per crop year were projected to increase 5% from 2006 to 2007, and 5% again from 2007 and 2008. These rates of increase are one-half the 9.8% annual rate of increase in the glyphosate use per crop year from 1996 through 2006 (last column, Table 4.1). This assumption is conservative (understates glyphosate use), especially in light of the continuing emergence of weeds less susceptible or resistant to glyphosate.

The variable "Other Herbicides on RR Acres" in Supplemental Table 15 is estimated from NASS data taking into account changes from year to year in overall herbicide use, changes in the glyphosate rate per acre, an upsurge in use of non-glyphosate herbicides to control resistant weeds, and recent trends in the rate of herbicides applied to conventional acres.

Despite the growing trend to utilize more non-glyphosate herbicides on RR soybean, the amount of such herbicides applied on RR soybean acreage has trended downward, reflecting the shift toward low and very low-dose herbicides. For instance, NASS reports 17 herbicides that were applied on soybean acres in 2006 with application rates below 0.1 pound per acre. Dozens of combinations of two or three of these herbicides could be applied without exceeding a total of 0.15 pounds of active ingredient applied per acre.

The Supplemental Table 15 line "All Herbicides on RR Acres" is simply the sum of glyphosate and other herbicides applied per acre of HT soybeans. The weighted average formula is then used to calculate the rate per acre for "Conventional Varieties." This value drops gradually from 1.19 pounds per acre in 1996 to 0.49 pounds in 2008, again reflecting the transition toward heavier reliance on low-dose soybean herbicides.

In the first two years of commercial adoption, RR technology reduced herbicide use by 0.3 and 0.23 pounds per acre, as shown in the last line in Supplemental Table 15. But by 1998, the rate of glyphosate per crop year had increased enough to push the average rate on HT acres above the conventional crop rate by 0.07 pounds. A high level of confidence can be placed on this estimate for 1998 because of a special analysis carried out by the USDA's ERS (described below).

From 1998 on, the difference between average herbicide applications rates per crop year on RR soybean acres compared to conventional acres gradually rises over the next 10 years, reaching 1.16 pounds per acre by 2008. The increase in this differential is driven in large part by the 9.8% annual increase in glyphosate use per acre. The most dramatic increases in glyphosate use came between crop years 2001 and 2002, and 2005 and 2006, when the glyphosate rate per crop year rose about 20% in a single year.

Special ERS Tabulation in 1998

The ERS carried out a series of special tabulations of herbicide use data on HT and conventional soybean acres drawing on crop sample points in the 1998 Agricultural Resource Management Survey (ARMS). This tabulation was requested and paid for by Benbrook Consulting Services. In this tabulation, ERS analysts divided all soybean acres into four categories:

* Conventional varieties, no glyphosate applied;
* Conventional varieties, glyphosate applied (mostly on no-till acreage);
* RR varieties; and
* Other HT varieties.

From the ARMS soybean dataset, ERS calculated both the percent of total soybean acreage by category, as well as the average number of herbicides and pounds of herbicides applied in each category. This information was used to calculate total herbicide use per acre on conventional and HT soybeans in 1998, using the weighted average formula described previously, as shown in Table 4.2.

The rates and percents of acres planted to conventional varieties

Table 4.2. Difference in Herbicide Application Rates per Acre on Herbicide-Tolerant (HT) Versus Conventional Soybeans in 1998, Based on a Special Tabulation of ARMS Data, Carried Out by the ERS

	Percentage Area Treated	Acres Planted	Average Number Herbicides Applied per Acre	Average Pounds Herbicides Applied per Acre
Conventional Varieties, No Glyphosate Applied	47.9%	34,470,555	2.7	1.08
Conventional Varieties, Glyphosate Applied	8.0%	5,733,955	3.2	1.45
Total Conventional Varieties		40,204,509		
RR Varieties	38.8%	27,928,106	1.4	1.22
Total HT Varieties	5.4%	3,892,385	2.8	1.06
All Soybeans	100%	72,025,000		
Weighted Average Rate on Conventional Acres	**1.13**			
Weighted Average Rate on HT Acres	**1.20**			
Difference Between Conventional and HT Varieties	**0.07**			

Source: Percent area treated, number of applications, and pounds applied per acre by type of seed are from special tabulations done by the Economic Research Service for Benbrook Consulting Services. Calculations of rates of application on conventional and HT soybeans by Benbrook Consulting Services.

treated and not treated with glyphosate were used to calculate the overall conventional soybean rate of 1.13 pounds per acre. Conventional acres treated with glyphosate were planted using either no-till or conservation tillage systems in which the glyphosate is applied before soybean seeds germinate.

The average rate of all herbicides applied on HT acres was calculated at 1.2 pounds per acre. Accordingly, the average acre of HT soybeans in 1998 required 0.07 pounds more herbicide than the average acre of conventional soybeans.

B. Herbicide-Tolerant Corn

Adoption of HT corn increased more slowly than HT soybeans and cotton, in large part because of several cost-effective, herbicide-based weed management alternatives. By 2001, 68% of soybeans and 74% of cotton acres were planted to HT varieties, whereas just 8% of corn acres were planted to HT seeds.

Farmers were slower to adopt the higher cost HT corn varieties because, in general, corn weed management is simpler than soybean or cotton weed management. Corn germinates and grows quickly, producing a "closed canopy" earlier in the crop season than in soybean and cotton fields. A crop has a "closed canopy" when the foliage of the crop fully shades the ground from direct sunlight. Weed germination and growth slow dramatically once a crop canopy is closed.

As in the case of soybeans, projections of herbicide use on HT corn acres are based on the performance of the RR system. NASS data on corn herbicide use suggest that between 2% and 5% of corn acres in some years were treated with glufosinate, the active ingredient associated with HT LibertyLink corn varieties. An unknown portion of these corn acres was planted to HT varieties. On these glufosinate HT acres, the average rate of herbicide use was likely somewhat lower than on the average RR acre, because glufosinate is applied at about one-half the glyphosate rate. Still, LibertyLink acres have had a very modest impact on overall HT corn herbicide use.

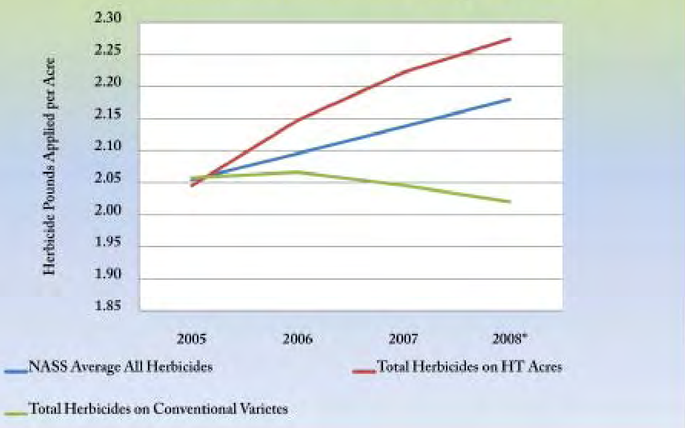
On HT acres, the rate of glyphosate per crop year is taken directly from NASS data, or extrapolated from NASS data since 2005, as shown in Supplemental Table 13. NASS surveyed corn acres in 2003 and 2005, the period during which the percent of corn acres planted to HT varieties rose from 15% to 26%. In this period, the rate of glyphosate applied per crop year rose on average 7.1% per year. Accordingly, and to be conservative, increases of 5% in the glyphosate rate per crop year and were assumed to occur in 2006, 2007, and 2008.

The volume of herbicides other than glyphosate applied to HT corn acres was estimated from university weed management recommendations. The volume of "Other Herbicides on HT Acres" decreased modestly from 1.2 pounds per acre in 1996-1997 to 1.1 in 2005. The volume applied then increases about 7% over three years to 1.18 pounds in 2008 as a result of changes in weed communities and the growing presence of resistant weeds.

From 1996 through 2008, total herbicide use on HT corn acres rose from 1.88 pounds of active ingredient to 2.27, a 21% increase. During this period, glyphosate use is projected to increase from 0.68 pounds per acre to 1.09 pounds, a 60% increase (five percent per year).

Total herbicide applications on conventional and other non-HT[7] corn acres trended downward from 1996 through 2008, falling from 2.67 to 2.02 pounds per acre, reflecting the gradual shift to lower-dose herbicides, as well as regulatory limits on the rate of atrazine that can be applied. The registration of s-metolachlor also contributed to a reduction in average corn herbicide application rates. This product is a more active stereoisomer of metolachlor, and is effective at an application rate about 35% below metolachlor's typical rate of application.

Figure 4.2. Trends in Herbicide Pounds Applied per Acre to Conventional and HT Corn, 2005-2008



Overall, herbicide use per acre on all corn acres also trended downward during this period from 2.65 pounds in 1996 to 1.9 pounds in 2002. Herbicide use per acre then began rising, from 1.9 pounds in 2002 to 2.05 pounds in 2005, the last year NASS surveyed corn pesticide use. During this three-year period, average use per acre rose 2.7% annually. From 2005 through 2008, total herbicide use was projected to increase 2% per year. Herbicide use per crop year for all corn, HT, and conventional corn varieties is shown in Figure 4.2., covering the full thirteen year period. The difference in total herbicide use on HT corn acres, compared to conventional corn acres, gradually changes from a reduction of 0.79 pounds per acre in 1996 to an increase of 0.25 pounds per acre in 2008. This shift from a significant reduction per acre of HT corn to a moderate increase in herbicide use is driven by a combination of factors:

* Increased average annual glyphosate use rates on HT acres;
* An approximate 30% increase in the average number of applications; and
* Steady reductions in the average pounds of herbicides applied on conventional corn acres.

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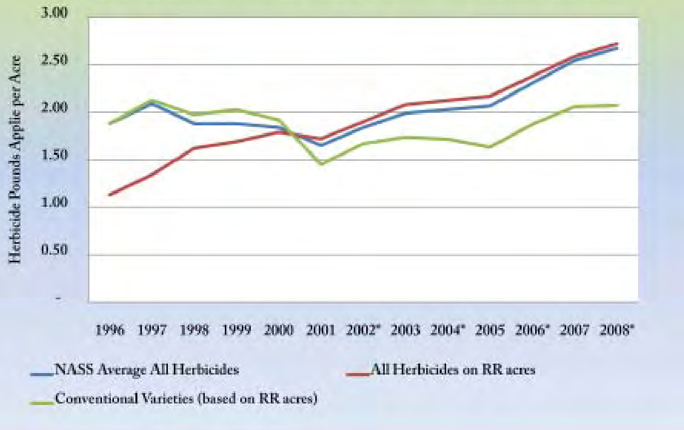
[7] Note that single trait *Bt* corn without herbicide tolerance is treated as "conventional" for the purposes of this HT corn discussion.

C. Herbicide-Tolerant Cotton

Of the three crops covered in this report, cotton farmers face the most difficult challenge in managing weeds. The space between cotton rows is greater than in corn and soybeans fields. The canopy closes more slowly in cotton fields, and sometimes never fully closes. The cotton growing season is longer than corn and soybeans, giving weeds an extended window of opportunity to germinate and grow. This requires conventional farmers to make more applications of generally longer-acting herbicides.

In the case of cotton, NASS pesticide use data are available through crop year 2007, as shown in Supplemental Table 14. Total herbicide use on all cotton acres rose from 1.88 pounds of active ingredient in 1996 to 2.55 in 2007, or 35% (a modest 3.2% per year). The rate of increase shot up dramatically between 2005 and 2007. Total herbicide use per acre rose 11.6% annually in this period.

Figure 4.3. Trends in Herbicide Pounds Applied per Acre to Conventional and HT Cotton, 1996 - 2008



The increase in glyphosate use per crop year was sizable from 2005 to 2007 – 0.32 more pounds per acre, or an annual 10.2% increase. Between 2007 and 2008, the increase in glyphosate use is conservatively estimated to rise by just 7%, and the total pounds of herbicides applied per acre is projected to increase less sharply, at a rate of 5% (compared to 11.6% annually from 2005-2007). Figure 4.3 displays these trends in cotton herbicide use graphically.

On conventional cotton acres, total herbicide use declined in most years between 1996 and 2001, but has increased steadily since that time, reaching 2.07 pounds per acre in 2008. The increase in the total pounds of herbicides used on conventional cotton acres is driven in large part by shifts in weed communities and the emergence of weeds that are tolerant or resistant to various herbicides. Tough-to-control weeds in the cotton belt that have emerged as a result of heavy reliance on RR technology include horseweed (also called marestail), Johnsongrass, and pigweed (Palmer amaranth).

During the first five years of use, HT upland cotton reduced the total volume of herbicides used per acre, an outcome brought about by the high degree of efficacy of glyphosate in the early years of HT crops. By crop year 2001, each acre of HT cotton required more herbicide than the average conventional cotton acre. The margin of difference rose incrementally over the next decade, reaching 0.65 pounds per acre in 2008.

D. Impacts of Resistant Weeds on Herbicide Use and Risks

The Weed Science Society of America (WSSA) and the industry-sponsored Herbicide Resistance Action Committee maintain a registry of resistant weed species around the world (accessible at www.weedscience.org). The WSSA defines weed resistance as "the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type."

Scientists use a simple test to screen for levels of resistance. The amount of herbicide required to reduce plant growth by 50% is measured, producing a value called the GR50, for "Growth Reduction by 50%." A case of resistance is regarded as clear cut when the GR50 herbicide dose in a weed population is at least 10-fold higher than the GR50 in a susceptible weed population.

Widespread use of HT technology has turned the U.S. into the resistant weed epicenter of the world. The WSSA records 125 resistant biotypes of 68 weeds, infesting up to 18 million acres in the U.S., while Australia is a distant second with 53 resistant biotypes.

The actual number of resistant weed populations and the acreage infested with them are likely higher, since the WSSA

Table 4.3. Estimates of Acres Infested with Glyphosate Resistant Weeds in 2008, by Type of Weed

Common Names	Species	Maximum Acres	Crops Infested
Common Ragweed	*Ambrosia artemisiifolia*	150	Soybeans
Common Waterhemp	*Amaranthus rudis*	10,700	Corn, Soybeans
Giant Ragweed	*Amobrosia trifida*	12,550	Cotton, Soybeans
Hairy Fleabane	*Conyza bonariensis*	Unknown	Roadsides
Horseweed (Marestail)	*Conyza canadensis*	3,333,210	Corn, Cotton, Rice, Soybeans, Roadsides, Nurseries
Italian Ryegrass	*Lolium multiflorum*	10,005	Cotton, Soybeans, Orchards
Johnsongrass	*Sorghum halepense*	Unknown	Soybeans
Palmer Amaranth	*Amaranthus palmeri*	2,000,500	Corn, Cotton, Soybeans
Rigid Ryegrass	*Lolium rigidum*	10,000	Almonds

Source: Weed Science Society of America survey of resistant weeds, www.weedscience.org

system is a passive reporting system that depends on academic weed scientists to upload their data on resistant populations. WSSA also has strict standards that must be met for verifying resistance before a resistant weed report is listed, which in some cases may delay or prevent likely cases from being reported.

In addition, WSSA does not report cases of ecological weed shifts – the selection and increasing predominance of weed species that are naturally more tolerant of an intensively used herbicide. For instance, a number of GT weed species are becoming more prominent in GR cropping systems, including common lambsquarters, velvetleaf, Asiatic dayflower and tropical spiderwort, among others.[8] Some weed scientists have called for more active and intensive surveillance of resistant weeds in HT cropping systems.[9]

Dramatic Increases Reported in Glyphosate Resistance

Glyphosate was first introduced in 1974, and for the next 22 years there were no confirmed reports of GR weeds. A few isolated populations of resistant weeds – mainly rigid and Italian ryegrass and goosegrass – emerged in the late 1990s, attributable to intensive glyphosate use in orchards (e.g., Malaysia, Chile, and California) or in wheat production (Australia). The vast majority of GR weed populations have emerged in RR cropping systems since the year 2000. Today, the WSSA website confirms that populations of 16 weed species are resistant to glyphosate in one or more countries, and of these, biotypes of eight species are also resistant to herbicides in one or two other families of chemistry.[10]

The first GR weed population confirmed in the U.S., reported in 1998, was rigid ryegrass, infesting several thousand acres in California almond orchards. Beginning in the year 2000 in Delaware, GR marestail (horseweed) rapidly emerged in RR soybeans and cotton in the East and South. Less than a decade later, GR biotypes of nine species are now found in the U.S., and infest millions of acres of cropland in at least 22 states (see Table 4.3).

The emergence of glyphosate resistance has accelerated in recent years. As of November 2007, the WSSA system

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[8] Owen, M. D. K., (2008). "Weed species shifts in glyphosate-resistant crops," *Pest Manag Sci* 64: 377-387. Owen also cites reports of truly glyphosate-resistant lambsquarters, which however are not listed by WSSA.

[9] GAO (2008). "Genetically engineered crops: Agencies are proposing changes to improve oversight, but could take additional steps to enhance coordination and monitoring," Report to the Committee on Agriculture, Nutrition, and Forestry, U.S. Senate, U.S. Government Accountability Office, GAO 09-060, Nov. 2008, pp. 30-31.

[10] See http://www.weedscience.org/Summary/UspeciesMOA.asp?lstMOAID=12&FmHRACGroup=Go, last visited Nov. 3, 2009.

recorded eight weed species resistant to glyphosate, covering up to 3,200 sites on up to 2.4 million acres. By early 2009, as many as 14,000 sites on up to 5.4 million acres were documented to be infested by populations of nine glyphosate-resistant weeds. This represents more than a four-fold increase in the number of sites, and roughly a doubling of acreage, plagued by resistant weeds.[11]

Most resistant weed populations thus far have been driven by intensive glyphosate use associated with RR soybeans and RR cotton, which are often rotated. However, adoption of corn with the RR trait has increased sharply in recent years, from 20% to over 60% of national corn acres from just 2004 to 2008. The increasing reliance on glyphosate associated with the growing use of RR soybean/RR corn rotations is likely responsible for the rapid emergence of resistant weeds in the Midwest and Northern Plain states. This troubling trend can only accelerate in the future, absent serious resistant weed management programs.

The emergence and rapid spread of GR weeds has driven rising herbicide use in all three HT crops, especially in recent years. Increasing glyphosate application rates and/or the number of applications will usually buy a little time, but invariably accelerates the emergence of full-blown resistance. This is the classic definition, and regrettable outcome, of what scientists call the "pesticide treadmill."

Below, we present case studies of three particularly troubling GR weeds: Palmer amaranth (pigweed), horseweed, and giant ragweed.

The "Perfect Weed"

GR Palmer amaranth has been called "the perfect weed." It has spread rapidly across the southern U.S. in the wake of RR cotton, soybeans, and more recently, corn.

By November 2007, WSSC had recorded GR Palmer amaranth on four to seven sites encompassing up to 1,000 acres in three states. Less than two years later, resistant biotypes had been confirmed by WSSC on up to 500 sites in seven states, covering an estimated two million acres.

The first confirmation of GR Palmer amaranth came in 2004 in just one county in Georgia. It spread quickly and reached nine additional counties in 2006, 10 more in 2007, and at least another nine in 2008.[12] Estimates of Georgia cotton and soybean acreage infested with GR Palmer amaranth rose from 500 acres in 2005 to as many as one million acres in 2009.[13]

In Tennessee, GR Palmer amaranth was first reported in 2006 on two to five sites covering up to 500 acres. By 2008, hundreds of fields in 10 Tennessee counties were infested.[14]

A similar pattern is unfolding in North and South Carolina, Arkansas, Alabama and Mississippi. For instance, up to one million acres are infested in North Carolina,[15] and another 130,000 acres are infested in South Carolina.[16] Auburn

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[11] For analysis of the WSSA data, see Center for Food Safety's Comments to USDA's Animal and Plant Health Inspection Service re: Proposed Rules for the Importation, Interstate Movement, and Release into the Environment of Certain Genetically Engineered Organisms, APHIS Docket No. 2008-0023, June 29, 2009, Addendum 1, at: http://truefoodnow.files.wordpress.com/2009/06/final-comments_june29_aphis-2008-0023_final.pdf.

[12] Culpepper and Kichler (2009), "University of Georgia Programs for Controlling Glyphosate-Resistant Palmer Amaranth in 2009 Cotton," University of Georgia Cooperative Extension, April.

[13] http://www.weedscience.org/Case/Case.asp?ResistID=5256.

[14] Robinson, E., (2009). "Pollen big factor in resistant pigweed spread," *Southeast Farm Press*, http://southeastfarmpress.com/cotton/herbicide-resistance-0428/ April 28, 2009.

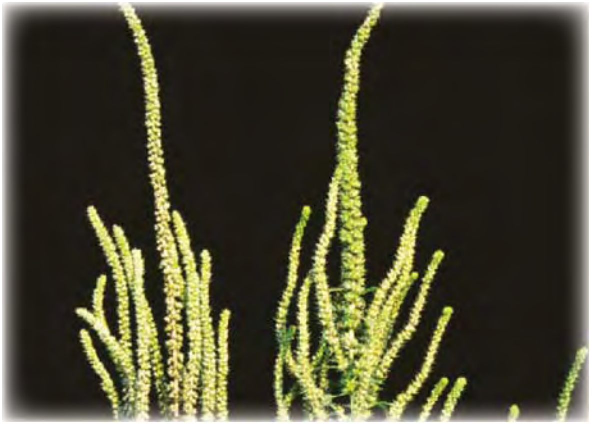
[15] http://www.weedscience.org/Case/Case.asp?ResistID=5360, a 2005 report that first appeared on WSSC-HRAC website in 2009.

[16] Robinson, E. (2008b). "Designing the perfect weed - Palmer amaranth," *Delta Farm Press*, http://deltafarmpress.com/cotton/palmer-amaranth-1226/ December 24.

University weed scientist Mike Patterson predicts that GR Palmer amaranth will spread across southern Alabama fields in the coming years.[17]

Both farmers and weed scientists fear the spread of GR Palmer amaranth for good reason. GR Palmer amaranth is aggressively invasive, as demonstrated by its explosive rate of spread. It has significant negative impacts on farm and harvest operations and is extremely difficult to control. The mature weed often grows to over six feet in height. Its sturdy stalk can reach six to eight inches wide at its base[18] and has damaged harvest equipment, including cotton pickers.[19]

GR Palmer amaranth infestations can trigger abandonment of cropland. Some 10,000 acres of cotton in Georgia in 2007 were abandoned because of the presence of GR Palmer amaranth,[20] examples of farm fields pushed over the "cliff" by resistant weeds.



Just two Palmer amaranth plants along a 20 feet section of a row of cotton can reduce yields by almost one-quarter, imposing on farmers a devastating economic loss. A single female plant can produce up 450,000 seeds.

Scientists in Arkansas and Tennessee believe that GR Palmer amaranth seed is spread via flooding, the movement of farm machinery, and the wind.[21] However, long-distance pollen flow is probably the most significant mode of propagation. In one experiment, a glyphosate-susceptible female plant was partially inoculated by a single resistant male plant that was 300 meters away. Some 20% of the resulting progeny were glyphosate resistant.[22]

Initially in Tennessee, some GR Palmer amaranth populations could survive 44 ounces of Roundup, more than twice the amount of Roundup a farmer would typically apply. By 2008 some populations of GR Palmer amaranth could withstand up to seven times the typical rate of glyphosate application. In some Palmer amaranth biotypes, the weed has attained a higher level of resistance to glyphosate than the RR crops planted in the field.[23]

Glyphosate resistance in this prolific weed is bound to increase weed management costs and the average pounds of herbicides applied per acre, regardless of whether farmers continue to plant RR crops. A weed scientist at the University of Tennessee estimated that on average GR Palmer amaranth would cost cotton growers in the South an extra $40 or more per acre in weed management costs in 2006,[24] a major increase given that expenditures on all

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[17] Hollis, P. L., (2009). "Resistant pigweed control programs updated," *Southeast Farm Press,* http://southeastfarmpress.com/cotton/weed-resistance-0519/ May 19.

[18] Roberson, R., (2008). "Herbicide-resistant weed problems spreading," *Southeast Farm Press,* May 14.

[19] Minor, E., (2006). "Herbicide-resistant weed worries farmers," *Associated Press,* 12/18/06, available at http://www.enn.com/top_stories/article/5679, Dec. 18. (last visited Sept. 9, 2007).

[20] Robinson, E., (2008b), op. cit.

[21] Bennett, D. (2008), op. cit. "Resistant pigweed 'blowing up' in Mid-South," *Delta Farm Press,* http://deltafarmpress.com/cotton/resistant-pigweed-0730/ July 30.

[22] Robinson, E., (2008a), op. cit.

[23] Robinson, E., (2008a), op. cit., emphasis added.

[24] Laws, F., (2006). "Glyphosate-resistant weeds more burden to growers' pocketbooks," *Delta Farm Press,* http://deltafarmpress.com/news/061127-glyphosate-weeds/ November 27.

cotton pesticides averaged around $60 per acre in 2005.[25] Making matters worse for farmers, there are few economical options for dealing with GR Palmer amaranth after it reaches six inches in height, in part because so many populations of Palmer amaranth are already resistant to other herbicides, including the ALS inhibitors. The only effective herbicides that remain on the market are PPO inhibitors. These herbicides inhibit the protoporphyrinogen oxidase (PPO) enzyme in the pigment synthesis pathway. Inhibition of this enzyme starts a reaction in plant cells that causes cell membranes to leak. The leaking cell membranes rapidly dry and disintegrate.

Cotton harvester reaching a patch of Palmer amaranth. Just two Palmer amaranth plants in 20 feet along a row can reduce yields by 25%. Photo: Joseph LaForest, University of Georgia, Bugwood.org

Preserving the efficacy of this last line of defense is now a priority for weed scientists in the region. One scientist asserts that an effective resistance management plan for the PPOs is all that stands between GR Palmer amaranth and "*…**the ability to do economic weed control in cotton and soybeans.**"'*[26]

Glyposate-Resistant Horseweed

Horseweed, or marestail, is a second "high impact" GR weed that has spread rapidly over the past two years. First documented in the year 2000 in Delaware, GR horseweed now infests up to 3.3 million acres across tens of thousands of sites in 16 states. In just the State of Illinois, up to 10,000 sites and as many as one million acres are infested.[27] Over two million acres were reported as infested in 2001 in Tennessee.[28] GR horseweed in Mississippi is also resistant to paraquat,[29] the first time multiple resistance to these two herbicides has been documented.

Weed scientists regard GR horseweed as a "worst-case scenario" in RR cropping systems because this weed is well adapted to no-tillage planting systems popular among GR crop growers. It also producers up to 200,000 seeds per plant, and its seeds can disperse extremely long distances in the wind.[30]

GR horseweed is high impact in part because it can reduce cotton yields by 40 to 70%.[31] An Arkansas weed scientist estimated that Arkansas growers would have to spend as much as $9 million to combat GR horseweed in 2004.[32] An uncontrolled outbreak of GR horseweed in Arkansas could reduce the income of cotton and soybean farmers by nearly $500 million, based on projected loss in yield of 50% in 900,000 acres of cotton and a 25% yield loss in the over three million acres of soybeans.[33]

The situation is even more precarious in Tennessee, where nearly all cotton acres are now infested with GR horseweed. In 2004, ten plants per square foot[34] were considered a heavy GR horseweed population. By 2007, the "heavy" infestation threshold has risen to 20 to 25 plants per square foot. In most of the Southeast, GR horseweed is now

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[25] USDA ERS (2007b). Cost and return data for cotton production: 1997-2005. USDA Economic Research Service, http://www.ers.usda.gov/data/CostsandReturns/data/recent/Cott/R-USCott.xls. last accessed January 12, 2007.

[26] Robinson, E. (2008b), op. cit.

[27] See http://www.weedscience.org/Case/Case.asp?ResistID=5276.

[28] http://www.weedscience.org/Case/Case.asp?ResistID=5122.

[29] http://www.weedscience.org/Case/Case.asp?ResistID=5384.

[30] Owen, M. D. K. (2008). "Weed species shifts in glyphosate-resistant crops," *Pest Manag Sci* 64: 377-387.

[31] Laws, F. (2006), op. cit.

[32] AP (2003). "Weed could cost farmers millions to fight," Associated Press, http://www.biotech-info.net/millions_to_fight.html, June 4.

[33] James, L. (2005). "Resistant weeds could be costly," *Delta Farm Press*, http://deltafarmpress.com/news/050721-resistant-weed/, July 21, 2005.

[34] Robinson, E. (2008c). "Weed control growing much more complex, new tools coming," *Delta Farm Press*, March 27.

forcing farmers to rely more heavily on mechanical tillage for weed control, in the process reducing substantially the cotton acreage planted using conservation tillage.[35] As farmers increase their use of tillage, average soil erosion rates increase. For this reason the emergence of GR weeds both increases pesticide use and erosion losses, negating two of the often-claimed benefits of HT technology.

This heavy infestation of glyphosate-resistant horseweed (marestail) will severely reduce per acre yields and impose higher weed management costs for several years.

Glyphosate-Resistant Giant Ragweed

Six states now have confirmed populations of GR giant ragweed: Ohio, Arkansas, Indiana, Minnesota, Kansas and Tennessee. In December 2006, Purdue University extension agents confirmed the first population of GR giant ragweed in Indiana.[36] Eighteen months later, GR giant ragweed had spread into 14 counties in Indiana and populations, with dual-resistance to glyphosate and ALS inhibitors reported in some populations.[37] Ohio State University researchers have identified giant ragweed with relatively high levels of resistance to both PPO and ALS inhibitor herbicides in three counties, and populations with lower levels of dual resistance in four other counties. They warn that although these weeds can be managed with glyphosate,"continuous use of this practice is likely to result in resistance to glyphosate as well."[38]

Giant ragweed is considered the most competitive broadleaf weed in Indiana soybean production. It can grow up to 15 feet tall. Three to four giant ragweed plants per square yard can reduce crop yields by as much as 70%.

Giant ragweed can reach 15 feet tall and just a few plants per square yard can reduce yields 70%

As new populations of resistant weeds emerge, and today's

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[35] Steckel, L., Culpepper S., and Smith K., (2006). "The Impact of Glyphosate-Resistant Horseweed and Pigweed on Cotton Weed Management and Costs," Power Point presentation at Cotton Incorporated's "Crop Management Seminar," Memphis, http://www.cottoninc.com/CropManagementSeminar2006/SeminarProceedings/images/Steckle%20Larry.pdf; Laws, F. (2006), op. cit.

[36] Johnson, B., and Loux, M. (2006). "Glyphosate-resistant giant ragweed confirmed in Indiana, Ohio," Purdue University press release, December 21.

[37] Johnson, B., and Nice, J., (2008). "Lots of weedy soybean fields," Purdue Extension Weed Science, July.

[38] Loux, M., and Stachler, J., (2008). "Giant ragweed with resistance to PPO and ALS inhibiting herbicides," Crop Observation and Recommendation Network Newsletter 2008-11, 4/29 to 5/6/08.

resistant weeds spread, the presence in any given field of weeds resistant to herbicides in multiple families of chemistry will become commonplace. This will compel farmers to rely more heavily on tillage and herbicides, including many older ones such as 2,4-D, that work through still effective modes of action.

HT Crops Accelerate the Pesticide Treadmill

Farmers have been creating, and then dealing with HR weeds since the use of herbicides became prevalent in the 1970s. As discussed in Chapter 2 , weeds resistant to triazine and later ALS-inhibitor herbicides (among others) emerged well before the introduction of GE HT crops in the mid 1990s (see also Figure 2.4). This fact has led some, notably the biotechnology and seed industries, to assert that there is nothing new or different with GR weeds. In fact, the causes and consequences of the emergence of GR weeds are different in many ways.

HT crop technology allows herbicides (in this case, glyphosate) to be applied in ways and at times not previously possible. Crops can be sprayed over an extended period of time, instead of during one optimal application window. This leads to multiple applications of the same herbicide in the same season. The rotation of one RR crop following another creates near-continuous selection pressure on weed populations over two or more years. Higher rates of application can be made, increasing the volume sprayed.

The sheer scope of introduction of GR crops has fostered such unprecedented reliance on a single chemical for weed control that one leading one expert has remarked that "Glyphosate is as important to world agriculture as penicillin is to human health."[39] This extreme reliance makes the threat of GR weeds far more menacing than herbicide-resistant weeds of the past. As discussed in Chapter 7, the responses to this threat proposed thus far will likely make matters worse.

Already in some regions, only one herbicide mode of action remains effective and available to manage resistant weeds. Ramping up use of herbicides in still-effective families of chemistry will buy farmers and industry some time, but it will also bring on more resistant weeds. Unless steps are taken to break the underlying ecological conditions favoring the selection and spread of resistant weeds, this vicious circle will grind through the list of registered herbicide products until there are no longer any economically viable herbicide-based options.

No one can predict with confidence when such a breaking point for herbicide-based weed management systems will occur for a given crop and region. Attempts to deal with resistant weeds through development of GE crops tolerant to a longer list of herbicides and more overall use of herbicides will almost certainly shorten the path to such breaking points.

Failure to act on the lessons learned in regions heavily reliant on HT crop technology that are now infested with two or more difficult to control weeds resistant to multiple herbicides will virtually guarantee that the tipping point will come sooner rather than later, and when it arrives, farmers will be forced to make systemic changes in farming systems that will be costly in multiple dimensions.

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[39] Stephen Powles, director of the Western Australian Herbicide Resistance Initiative, as quoted in Service, R.F. (2007). "A Growing Threat Down on the Farm," *Science* 316: 1114-17.

5. Impacts of *Bt* Crops on Insecticide Use

Bt corn and cotton have been modified to express a synthetic, truncated version of a natural bacterial toxin, as explained in Chapter 2. These crystalline compounds are produced by several subspecies of the bacterium *Bacillus thuringiensis*. GE corn and cotton have been developed expressing a variety of different *Bt* toxins, each with a unique spectrum of insect control activity.

Two types of *Bt* corn have been sold since 1997. The original *Bt* corn hybrids, expressing the Cry1Ab toxin, helped farmers control the European corn borer and the Southwestern corn borer (ECB/SWCB). In 2003, Monsanto introduced a new type of *Bt* corn that produces Cry3Bb1, a toxin active against the corn rootworm (CRW) and some other soil-borne insects. In 2005, Dow and Pioneer obtained approval to introduce *Bt* corn expressing the Cry34Ab1/Cry35Ab1 toxins, also active against CRW. These pests damage young corn plants by feeding on their roots and have historically been a much greater economic problem for farmers than the ECB/SWCB.

Cotton plants have also been genetically engineered to express different forms of *Bt*. Monsanto's original Bollgard cotton, expressing the Cry1Ac toxin, was introduced in 1996. The Bollgard trait, stacked with the RR trait, accounted for the majority of *Bt* cotton acres through 2006.

Bollgard II cotton, introduced by Monsanto in 2003, expresses two toxins – Cry1Ac and Cry2Ab2. Bollgard II cotton is gradually displacing its predecessor, and accounted for one-half of *Bt*-cotton acres in 2007 and about two-thirds in 2008. Both the original Bollgard and Bollgard II traits target the budworm-bollworm complex of insect pests, and have substantially reduced applications of insecticides, including several broad spectrum active ingredients that are moderately to highly toxic to many life forms (e.g., aldicarb, carbofuran, and methyl parathion). It is interesting to note that essentially all *Bt* cotton planted since 2005 has come in "stacked" varieties that include the Roundup Ready trait. Only Dow/Phytogen produces a competing insect-resistance trait in cotton, but acreage planted to this Widestrike cotton has been negligible through 2008.

The following estimates of the impact of GE corn and cotton on insecticide use do not take into account two significant factors:

- The amount of *Bt* toxins manufactured within plant cells during a growing season; and

- The volume of insecticidal seed treatments used to help plants thrive through the early stages of growth.

As discussed in Chapter 2, there is no way to accurately project the volume of *Bt* toxins produced by a GE plant. Moreover, there is unresolved debate over whether these toxins should be counted as an "insecticide applied" for purposes of estimating the impact of GE crops on insecticide use.

In order to estimate the total pounds of *Bt* toxins manufactured by a *Bt* plant, as well as by all plants on an acre of corn or cotton, scientists need to gain better understanding of *Bt* gene expression levels in different plant tissues, how long *Bt* toxins persist in plant cells, and how the toxins break down. Such information will also prove useful in conducting more refined dietary risk assessments and to assess impacts of *Bt* toxins on soil microbial communities.

Seed treatment technology has dramatically changed in recent years. The number of pesticide active ingredients utilized in seed treatment mixtures has gone up. Most seed treatment pesticides are now encapsulated around the seed in slow release formulations that markedly extend and improve their effectiveness. The increasing use of more potent pesticides in seed treatments tends to lower the total volume of active ingredients applied as seed treatments.

The larvae stage of the European corn borer, *Ostrinia nubilalis*, is a major target of YieldGard *Bt* corn. Photo: Frank Peairs, Colo. State Univ., Bugwood.org

CRW is the principle target insect for second-generation YieldGard for CRW *Bt* corn. Photo: Richard C. Edwards

Southwestern corn borer is a major target of the original *Bt* corn along the southern and western edges of the corn belt. Photo: Frank Peairs, Colo. State Univ., Bugwood.org

A. Stacked Traits and Multiple Insecticide Formulations Muddy the Water

Projecting the impact of *Bt* traits on insecticide use has grown more complicated as a result of the trend toward stacked traits. Since 2005, a growing portion of *Bt* corn has contained both the *Bt* gene for ECB control (Monsanto's YieldGard corn) and the *Bt* gene for CRW control (Monsanto's YieldGard for CRW). Varieties expressing both *Bt* traits are referred to as "YieldGard Plus."

It is difficult to project with certainty how the three forms of *Bt* corn – YieldGard, YieldGard for CRW, and YieldGard Plus – affect insecticide use. Many insecticides applied by corn farmers are sold in more than one formulation. One formulation, a liquid spray for example, might be labeled for control of the ECB/SWCB, while a granular formulation of the same insecticide(s) is labeled for control of the CRW and other soil-borne insects.

In its annual pesticide use reports, NASS provides data by active ingredient (not formulation) on the percent of acres treated, the rate, number of applications, and pounds applied. For active ingredients in formulations effective against both the ECB/SWCB and CRW, there is no accurate way of apportioning use (i.e., share of acres treated, amount) between them, and hence a degree of uncertainty is unavoidable in identifying the insecticide acre treatments displaced by the planting of a particular kind of *Bt* corn.

Another source of uncertainty can skew estimates of the number of insecticide applications displaced by *Bt* corn. Many acres of *Bt* corn are planted on farms where conventional varieties of corn were previously planted and not routinely sprayed with insecticides for either the ECB/SWCB or CRW.

As evident in Supplemental Table 9, generally 6% to 9% of national corn acres have been sprayed for ECB/SWCB control in any given year.[1] Yet by its third year of commercial use in 1998, *Bt* corn for ECB control was planted on 19.1% of national corn acres – more than twice the average acreage typically sprayed to control the ECB/SWCB.

In 2009, over one-half of national corn acres were planted to *Bt* corn for ECB/SWCB control. Clearly, many of these acres were not previously sprayed for ECB/SWCB control; hence, the planting of *Bt* corn on these acres did not reduce insecticide use. For this reason, annual estimates are made of the percent of *Bt* corn acres that would likely have been treated with an insecticide if conventional hybrids had been planted instead, and this estimate was used in calculating the pounds of insecticides actually displaced by *Bt* corn.

In the case of *Bt* corn for CRW management, historically 27% +/- 4% of national corn acres have been treated with soil insecticides for CRW control, a share close to the 35% market penetration in 2008 of Monsanto's *Bt* corn for CRW control. Clearly, however, the availability of CRW *Bt* corn has not eliminated the use of corn soil insecticides.

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[1] A 2000 NAS study, "Genetically Modified Pest-Protected Plants: Science and Regulation (2000), on *Bt* crops reported that 5.2% of corn acres in the Corn belt have been historically sprayed with insecticides for ECB. The percent of corn sprayed for the SWCB is higher in states surrounding the Corn belt, which is why this report estimates that 6% to 9% of national corn acres have been sprayed in most years.

B. Insecticide Use Displaced by Two Types of *Bt* Corn

Bt corn for ECB/SWCB control has had a modest, but positive impact in reducing insecticide applications to corn, while *Bt* corn for the CRW is having a more significant impact. There is a significant degree of uncertainty in the estimates of the impacts of *Bt* corn for CRW control on insecticide use. Only 5% of national corn acres were planted to CRW hybrids in the last year NASS collected corn insecticide use data (2005). The big jump upward in *Bt* corn acres for CRW control came in 2007 and 2008.

There is little publicly accessible information on corn insecticide use in recent years as a result of the decision by NASS in 2007 to suspend the annual pesticide use surveys in major field crops like corn.

Bt Corn for ECB Control

The introduction of *Bt* corn in 1997 increased research focus and funding for work on ECB/SWCB management and heightened grower awareness of the damage caused by these insects in some seasons. As a result, many farmers became more aggressive and pro-active in managing ECB/SWCB.

For example, in 2003 corn farmers planted 25 million acres to *Bt* corn and a projected 5.4 million acres were sprayed with insecticides for ECB/SWCB control, for a total acreage under active ECB management of 30.4 million acres. This total reflects about a four-fold increase over historical levels. Some university entomologists are urging farmers to rethink their decision to automatically plant *Bt* corn for ECB/SWCB in those parts of the Corn belt where population levels are usually low.[2]

While sound advice, more and more corn farmers will be unable to act on it since the majority of corn hybrids offered for sale now include the *Bt* gene for ECB/SWCB control.

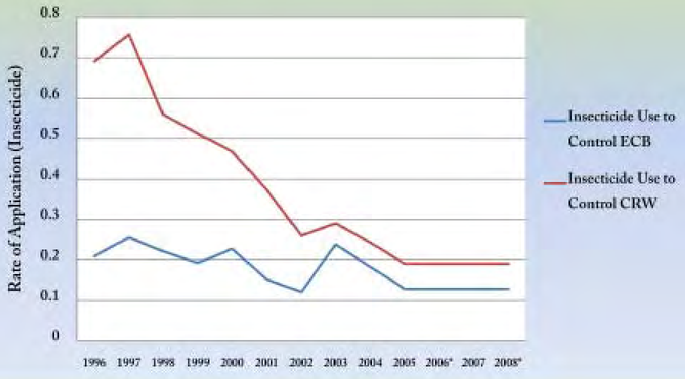
Supplemental Tables 9 and 11 set forth the basis for estimating the impact of *Bt* corn for ECB/SWCB control on corn insecticide use. Supplemental Table 9 projects the average rate of insecticides applied on conventional corn to control the ECB/SWCB, relying on NASS data on corn insecticide use. Since no NASS data have been collected since 2005, insecticide use rates for 2006-2008 were assumed to remain unchanged. No important new active ingredients have come on the market and attained significant corn use in this period, so it is very likely that average use rates have changed little since 2005.

University experts and insect-control guides were consulted to determine which corn insecticides target the ECB largely or exclusively, and which insecticides are partially applied for ECB control. The same was done for the CRW insecticides.

These percentages are incorporated in Supplemental Tables 9 (ECB/SWCB rates) and 10 (CRW rates). Average insecticide use rates for products targeting the ECB/SWCB were then calculated based on the weighted shares of total national corn acres treated for ECB/SWCB control.

The average rate of application of corn insecticides targeting the ECB fell gradually from 0.21 pounds in 1996 to 0.13 pounds in 2008, consistent with the long-term downward trend in the application rates of registered pesticides. Farmers relied less heavily on organophosphate insecticides applied at rates of 0.5 to 1.2 pound per acre, and more heavily on synthetic pyrethroid insecticides applied at rates between 0.01 and 0.1 pounds per acre.

Figure 5.1. Pounds of Insecticides Displaced by an Acre of Bt Corn for ECB/SWCB Control and an Acre of Bt Corn for CRW Control



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[2] For an intriguing assessment of trends in corn insect pest management, including the over-reliance on *Bt* corn, see Steffey, K., and Gray, M., (2009). "IPM and the Integrated Control Concept: Progress after 50 Years in the Commercial Corn and Soybean Landscape?," *The Bulletin*, University of Illinois Extension, No. 1, Article 5, March 19.

Figure 5.1 shows the generally downward trend in the rate of insecticide applications displaced by the planting of *Bt* corn for ECB/SWCB control, as well as *Bt* corn for CRW management.

Supplemental Table 11 calculates the percent of corn acres planted to ECB *Bt* corn, the number of acres planted each year, and the likely number of acres planted that would previously have been treated with an insecticide. As a result of this adjustment, *Bt*-ECB acres that would have been sprayed absent *Bt* technology changes from 90% in 1997 to 45% in 2007-2008 (see Chapter 2D for the rationale behind these adjustments).

The line in Supplemental Table 11 labeled "Adjusted Volume of Insecticide Displaced by a *Bt*-ECB Acre" is the estimated rate of insecticide applications for ECB/SWCB control from Supplemental Table 9 multiplied by the percent of *Bt* corn for ECB control that would have previously been treated with an ECB insecticide. This step addresses the previously described source of upward bias in estimates of insecticide applications displaced by *Bt* corn (i.e., the fact that not all acres planted to a *Bt* hybrid would have been sprayed with an insecticide if conventional corn had been planted).

Bt Corn for CRW Control

The impact of *Bt* corn for CRW control is projected in the same way as the impact of ECB *Bt* corn, as shown in Supplemental Tables 10 and 11. *Bt* corn for CRW control was introduced as a single-trait variety in 2003 and was planted on less than one percent of national corn acres in that year. By 2008, over one-third of national corn acres were planted to a variety expressing the CRW *Bt* gene.

The average pounds of insecticides applied per acre of corn to treat the CRW and related soil-borne insects are calculated in Supplemental Table 10. The volume of insecticides applied for CRW control fell from 0.29 pounds per acre in 2003 to 0.19 in 2005-2008, as shown in Figure 5.1. This reduction was driven by the shift away from relatively high dose insecticides to lower-dose active ingredients applied at rates between 0.01 and 0.1 pound per acre.

As with ECB *Bt* corn, the percent of corn acres under active management for the CRW – seed treatments, *Bt* genes, and conventional insecticides -- has far outpaced the historic percent of corn acres sprayed with an insecticide for CRW control. Accordingly, the percent of acres planted to CRW *Bt* corn that would have previously been treated with an insecticide is adjusted from an estimated 95% in the first year of adoption in 2003, to 60% in 2008, for reasons discussed further in Chapter 2.

Accordingly, the model projects in 2008 that 18 million acres of corn were not sprayed for CRW as a result of the planting of *Bt* corn for CRW control (0.6 x 30.1 million acres of *Bt* CRW corn).[3] In addition to these *Bt* acres, an estimated 8 million more acres were sprayed with a CRW insecticide, for a total of 38 million acres that were directly treated during the growing season. In addition, essentially all national corn acres were treated with a seed treatment targeting the CRW.

C. *Bt* Cotton Continues to Perform Well

Essentially 100% of the acres planted to *Bt* cotton were previously sprayed for control of the budworm/bollworm complex of insects – the prime target of *Bt* cotton. Moreover, *Bt* cotton is highly effective, so each acre planted is assumed to displace the average pounds of insecticides previously sprayed on an acre of conventional cotton for budworm/bollworm control.

Bollworm, *Helicoverpa zea*, is a moth in its adult stage. Photo: Johnny N. Dell, Bugwood.org

Accordingly, estimating the difference in insecticide use on acres planted to *Bt* and conventional cotton varieties is simpler than in the case of *Bt* corn. Plus, NASS surveyed cotton pesticide use in 2007, reducing the need for assumptions in extrapolating current use rates.

Estimates of the average pounds of insecticides displaced by each acre of *Bt* cotton are shown in Supplemental Table 12.

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[3] Monsanto's overview of biotechnology trait acreage dated June 24, 2009 reports that 30.1 million acres were planted to the CRW trait.

The percent of cotton acres planted to *Bt* varieties rose from 12% in 1996 to 52.5% in 2004 and reached 73% in 2008.

NASS pesticide use data includes the percent of crop acres treated with 11 insecticides known to target the budworm/bollworm complex, including organophosphates, synthetic pyrethroids, carbamates, liquid *Bt* sprays, and two reduced-risk insecticides, emamectin benzoate and indoxacarb. The extremely toxic carbamate insecticide aldicarb was the market leader throughout this period, accounting for one-half to two-thirds of the acres treated over the 13-year period.

Many of these insecticides were applied multiple times, and hence it is necessary to calculate the number of cotton acre-treatments with each insecticide, in order to calculate the weighted average rate of application per crop year (taking into account multiple applications). In 1996, the year *Bt* cotton was introduced, aldicarb accounted for 28% of the acre-treatments, followed by methyl parathion at 25%. The share of total acre-treatments accounted for by each of the 11 insecticides was used in calculating the weighted average rates in the last line in Supplemental Table 12.

The average budworm/bollworm insecticide application rate in 1996 was 0.56 pound per acre. The rate has dropped gradually to 0.47 pounds in 2008. The limited decline in cotton insecticide rates reflects the growing percentage of acre treatments accounted for by aldicarb, an insecticide applied at the rate around 0.6 pounds per acre. By 2008, the percent of cotton acres treated with insecticides for the budworm/bollworm complex had fallen from 48% to 25%, but aldicarb's share of the total number of acre-treatments had risen from 28% to 67%.

6. Aggregate Impacts of GE Crops on Pesticide Use: The First Thirteen Years

Corn, cotton, and soybeans account for nearly all GE crops grown in the U.S. since 1996. About 941 million acres have been planted to corn, soybeans and cotton with herbicide tolerance, while 357 million acres of corn and cotton have carried the *Bt* trait, for a total of 1.3 billion GE trait acres over the 13 years covered by this study (see Figures 6.1 and 6.2). As explained in Chapter 3, the actual area planted to GE crops over this period is substantially less than 1.3 billion acres due to the growing prevalence of stacked crops that contain both HT and *Bt* traits.

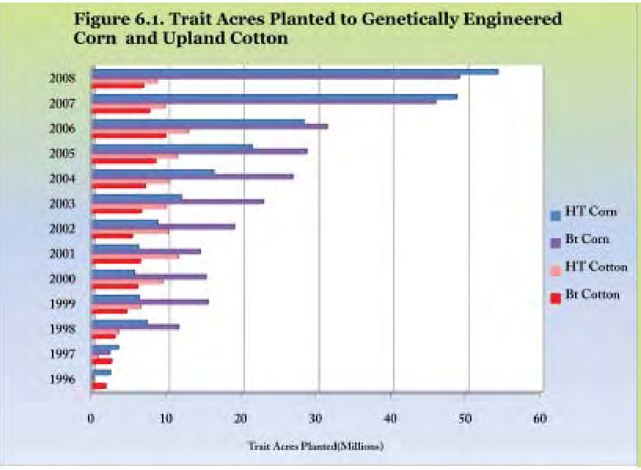

Figure 6.1. Trait Acres Planted to Genetically Engineered Corn and Upland Cotton

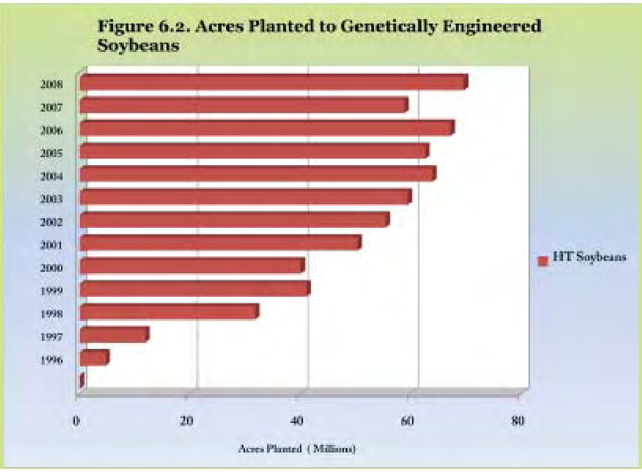

Figure 6.2. Acres Planted to Genetically Engineered Soybeans

A. Major Findings and Conclusions

Differences in the pounds of pesticides applied on acres planted to GE varieties, compared to acres planted to conventional seeds, are reported in Supplemental Table 7.

HT corn reduced herbicide use in its first year of introduction by almost 0.8 pounds per acre. Over time, increases in the average rate of application of glyphosate drove herbicide use upward on HT acres.

By 2005, herbicide use on conventional and HT corn acres was essentially identical and by 2006, the average pounds applied on an HT corn acre had risen to 0.08 pounds above the average pounds of herbicides applied to an acre of corn planted to a conventional variety.

The same pattern is evident with HT cotton. Each acre of HT cotton in 1996 reduced herbicide use by three-quarters of a pound, but by 2001, rising glyphosate use on HT acres had overtaken the average pounds applied on conventional acres.

Today, each acre of HT cotton increases the average pounds of herbicides applied by about two-thirds relative to conventional cotton. RR soybeans reduced average herbicide use by 0.3 pounds per acre planted in 1996. Just two years later, USDA data show that average herbicide use on HT soybean acres had already risen above the average rate on acres planted to conventional soybeans. By 2008, the difference had increased to 1.16 pounds per acre.

This dramatic change in herbicide application rates is unmistakable in USDA surveys of pesticide use on soybean farms. There is also general agreement on why the performance of RR soybeans has changed so dramatically over the years – intense selection pressure from excessive reliance on glyphosate has triggered weed shifts to species more tolerant of glyphosate, as well as evolution of glyphosate-resistant biotypes.

As is the case with corn and cotton, steady reductions over the 13 year period in average soybean herbicide application rates per acre also contributed to the growing margin of difference in overall herbicides applications on RR versus conventional crop acres. These reductions were brought about by the registration and growing market penetration of several low-dose herbicide products.

Figure 6.3 portrays these trends in the differences in pesticide use on an acre planted to a GE crop, compared to an acre planted to a conventional variety.

Estimates of the impacts of GE crops on pesticide use have been calculated by crop, trait, and year. The annual change in the volume of pesticide use triggered by the planting of an acre of GE crop (Supplemental Table 7) is multiplied by the acres planted to each GE trait, producing the values in Supplemental Table 8. A graphic depiction of the overall impact of GE crops on pesticide use from 1996 through 2008 appears in Figure 6.4.

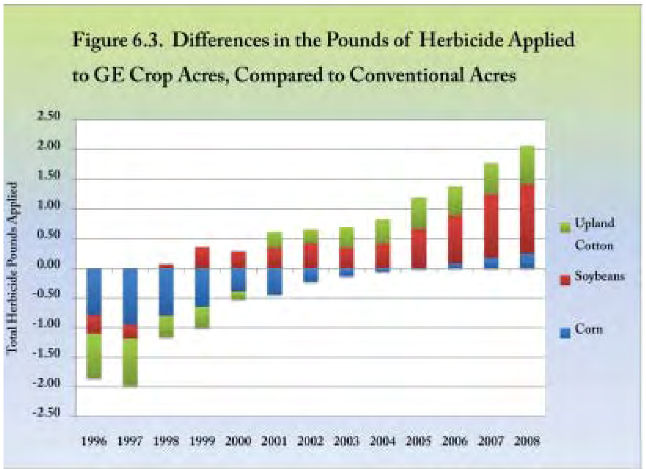
Figure 6.3. Differences in the Pounds of Herbicide Applied to GE Crop Acres, Compared to Conventional Acres

Key Conclusions

Over the first 13 years of commercial planting of major GE crops in the United States, this analysis shows that:

- GE crops increased overall pesticide use by 318.4 million pounds, or by 7.5% of combined use on the three crops;
- Herbicide tolerant crops increased herbicide use by 382.6 million pounds, while *Bt* crops reduced insecticide use by 64.2 million pounds;
- Herbicide tolerant soybeans accounted for 92% of the increased herbicide use across the three HT crops;
- GE crops reduced pesticide use in the first three years of commercial introduction by 1.1%, 2.3%, and 2.3% per year, but rising rates per crop year of glyphosate on RR varieties increased aggregate pesticide use across all GE traits and acres beginning in 1999;
- Rates of corn and soybean herbicide and corn insecticide applications on cropland planted to conventional varieties trended downward during the study period by 24% to over 90% as a result of the shift toward lower-dose pesticides;
- The 26% increase in the pounds of pesticides applied on GE crops in 2008, compared to acres planted to conventional varieties, was almost five-fold greater than the 5.8% increase just five years earlier, in 2003; and
- The upward trend in pesticide use on GE crops has been driven almost solely by the rapid emergence and spread of weeds tolerant of or resistant to glyphosate.

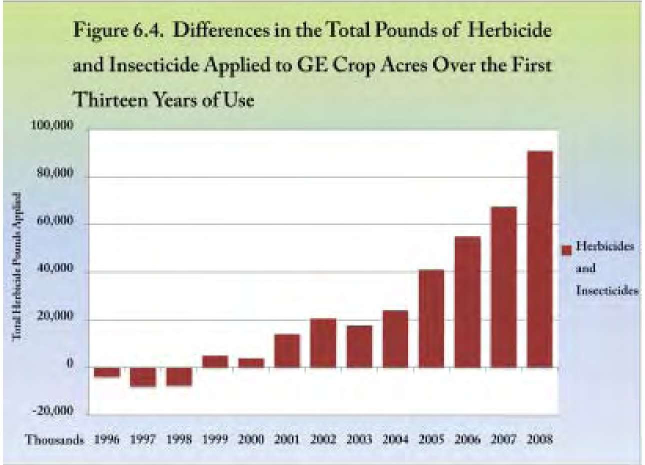
Figure 6.4. Differences in the Total Pounds of Herbicide and Insecticide Applied to GE Crop Acres Over the First Thirteen Years of Use

Moreover, further increases in overall pesticide use on GE crops is inevitable in 2010 and for the foreseeable future in the U.S. because of the further emergence and steady spread of weeds resistant to glyphosate.

B. Estimates in Other Studies

U.S. Department of Agriculture

The USDA has done very little research on the impacts of GE crops on pesticide use, and has been essentially silent on the topic for about a decade. A report by the ERS was issued in May 2002 entitled *Adoption of Bioengineered Crops*.[1] A short section addresses the impacts of GE crops on pesticide use

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[1] Fernandez-Cornejo, J., and McBride, W., (2002). Agricultural Economic Report No. 810.

between 1997 and 1998 for HT soybeans and cotton and *Bt* cotton, and between 1996-1997 for HT corn. Across the three major crops, the ERS analysts estimated a reduction of 2.5 million pounds of pesticides applied, very close to the 2.2 million pounds reduction estimated in this report for the corresponding years.

This 2002 ERS report concluded that herbicide use on HT soybeans went up in 1998 because 13.4 million pounds of glyphosate were substituted for 11.1 million pounds of other herbicides. The ERS projection of a 2.3 million pound increase in herbicide pounds applied on HT acres is also very close to the 2.2 million pound increase based on the methodology used in this report.

USDA's report *Agricultural Resources and Environmental Indicators, 2006 Edition*, addresses the adoption and impacts of GE crops.[2] The section on pesticide use restates the findings of the May 2002 report

It also states that overall pesticide use in corn, soybeans and cotton, on GE and conventional acres, has declined from 1995 to 2002 (based on NASS annual pesticide surveys). For some unexplained reason, however, the authors of this 2006 report neglect to include available NASS pesticide data for later years, including herbicide use data on corn and cotton for 2003, which show substantial increases in per acre use rates on corn (10% rise from 2002 to 2003) and cotton (20% rise from 2001 to 2003). In addition, the authors imply, but do not justify, a linkage between the reduction in overall pesticide use through 2002 and the adoption of GE crops. Nor does the ERS report acknowledge the sizable reductions in average herbicide and insecticide application rates on conventional crops during this period.

There is no discussion of the impact of GE crops on pesticide use in the current version of the "Agricultural Biotechnology" Briefing Room on the ERS website.[3] No other official reports have been issued by USDA addressing the overall impact of GE crops on pesticide use.

National Center for Food and Agriculture (NCFAP) Policy Studies

Several simulation studies by the National Center for Food and Agriculture Policy (NCFAP), an organization funded in part by the biotechnology industry, have addressed the impact of GE crops on pesticide use. The most recent report was released in November 2006 and projects impacts in crop year 2005.[4]

NCFAP's general method is to simulate pesticide use on GE and non-GE crops by simply extrapolating from particular pest management systems recommended by university extension agents for adoption on all GE and

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[2] Wiebe, K. and Gollehon, N., eds. (2006). USDA Economic Research Service Number 16, July 2006, see Chapter 3.3 at http://www.ers.usda.gov/Publications/AREI/EIB16/. For an essentially identical treatment based on 1990s data, see: Fernandez-Cornejo, J. and Caswell, M. (2006). "The First Decade of Genetically Engineered Crops in the United States," USDA ERS Economic Information Bulletin No. 11, April, pp. 11-13.

[3] http://www.ers.usda.gov/Briefing/Biotechnology/; accessed September 18, 2009.

[4] Sankula, S.,"Quantification of the Impacts on US Agriculture of Biotechnology-Derived Crops Planted in 2005," National Center for Food and Agricultural Policy, Washington, D.C.

non-GE crop acres. Such simplistic models are highly vulnerable to error, since actual pest management systems often deviate considerably from those recommended by university specialists. The results from such models need to be checked against real-world pesticide use data whenever possible.

Herbicide-Tolerant Corn

NCFAP estimates that genetically engineered HT corn was planted on 35% of corn acres in 2005, a considerably higher share compared to NASS's corresponding figure of 26%, a discrepancy that is not noted or explained by NCFAP. Based on this 35% figure, NCFAP estimates that GE HT corn reduced herbicide use by 21.8 million pounds in 2005, or about 0.8 pounds per acre.

This finding rests largely on two faulty assumptions that exaggerate the amount of herbicide applied to conventional/non-HT corn acres, which in turn inflates the "reduction" from a switch to HT corn. These faulty assumptions relate to the extent and rate of use of two high-dose herbicides, atrazine and s-metolachlor/metolachlor, that are used on both HT and conventional/non-HT[5] corn.

With regard to extent of use, NCFAP assumes that all non-HT corn farmers apply two premixed products: first, a mixture of the high-dose herbicides s-metolachlor and atrazine (preemergence), followed post-emergence by a product consisting of mesotrione, nicosulfuron and rimsulfuron.

NASS data demonstrate clearly that the atrazine-metolachlor premix could not have been used by a majority of, much less all, farmers planting non-HT corn. According to NCFAP, non-HT corn comprised 65% of national corn acres, while NASS reports that just 25% of all corn was treated with either s-metolachlor or metolachlor, so that at most 25% of corn acres were treated with this premix (atrazine was applied to 66% of corn acres). At most, 38% of non-HT corn acres could have been treated with this high-rate premix (25% maximum treated, divided by 65% planted).

NCFAP also overestimates the rate of herbicide applied to non-HT acres. NCFAP assumes that non-HT corn farmers apply the s-metolachlor/atrazine premix at 3.16 pounds of active ingredients per acre, and the low-dose post-emergence mix at 0.07 pounds per acre, for a total of 3.23 pounds per acre. However, NASS reports that the average amounts of atrazine and s-metolachlor applied to all corn in the 2005 season were 1.13 and 1.35 pounds per acre, respectively. Accordingly, the combined average rate of atrazine and s-metolachlor applied via the premix was at most 2.48 pounds of active ingredient per acre, much less than the 3.16 pounds assumed by NCFAP.

NCFAP projects that an average of 2.5 pounds of herbicides were applied on RR corn acres in 2005, resulting in a 0.73 pound per acre reduction (3.23 pounds on conventional acres, minus 2.5 pounds on RR acres). NCFAP would have projected a 0.02 pound increase on HT acres had it used the more realistic NASS application rates for atrazine and s-metolachlor on conventional corn. The methodology in this report projected a 0.01 pound reduction in per acre herbicide use on HT acres in 2005.

Herbicide-Tolerant Soybeans

In the case of soybeans, NCFAP both underestimates herbicide use on HT acres and overstates the amount applied to conventional acres. These faulty assumptions result in a simulated and illusory "reduction" of 20.5 million pounds nationally from the planting of HT soybeans in 2005. HT soybeans – all Roundup Ready – were planted on nearly 90% of national soybean acres in 2005.

NCFAP wrongly assumed that one application of glyphosate sufficed for over 80% of Roundup Ready soybean acres, resulting in a simulated 1.18 glyphosate applications to the average RR soybean acre for the year. In contrast, NASS reported an average of 1.5 applications of glyphosate (28% higher), a figure that reflects the need for two or more glyphosate applications to control resistant weeds in many states (see Chapter 4). Similarly, NCFAP's estimate of total herbicide applied to RR soybeans – 1.03 pounds per acres per year – does not even match the annual NASS figure for glyphosate alone, which is 1.1 pounds per acre, much less account for non-glyphosate herbicides applied to RR soybeans.

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[5] In the following discussion, the term "non-HT" encompasses both conventional corn and GE corn that does not contain an HT trait (i.e., single-trait *Bt* corn).

NCFAP assumes, for reasons not explained, that herbicides in addition to glyphosate were applied to RR soybeans in just one state (Iowa). In Iowa, NCFAP assumes that soybean farmers apply 0.19 pounds per acre of Canopy (a premix of chlorimuron and metribuzin), in addition to one application of glyphosate. In contrast, this report more realistically estimates that non-glyphosate herbicides were applied to RR soybean acres at an average rate of 0.12 pounds per acre in 2005.

NCFAP also vastly overstates the amount of herbicides applied to conventional soybean acres in 2005, assuming average total applications of 1.35 pounds per acre (all presumed to be non-glyphosate herbicides). This presumed rate for herbicides applied to conventional soybean acres is more than twice the rate of 0.59 pound per acre on conventional soybeans estimated in this study, based on NASS data. NCFAP's estimate of average herbicide use on conventional soybeans is clearly out of step with the trend toward lower-dose herbicides, some of which are applied at rates well below 0.1 pound per acre.

If NCFAP had used NASS data to calibrate its estimates of herbicide use on RR and conventional soybean, it would have arrived at a result much closer to the one in this report: an estimated increase in herbicide use of 41.5 million pounds in 2005 due to the planting of RR soybeans (see Supplemental Table 8).

PG Economics Ltd

A UK based consulting firm, PG Economics Ltd., has carried out several studies of GE crops funded by the pesticide and biotechnology industries. Their latest was released in May, 2009.[6] The PG Economics report uses methods and sources similar to NCFAP, and claims its estimates are based on "the average performance and impact recorded in different crops."

The PG Economics report estimates a 4.6% reduction worldwide in herbicide use attributable to GE crops from 1996 through 2007 (the first 12 years of commercial use). This report estimates that GE HT corn, soybeans, and cotton have increased herbicide use in the U.S . by 382 million pounds over 13 years, or by about 10% (NASS reports that 3.82 billion pounds of herbicides applied to these three crops from 1996-2008). It is worth noting that the increase in 2008 – the extra year covered by this analysis – was 100 million pounds, or about 26% of the total increase over the 13 years.

The methodology in the PG Economics report is worth a closer look. HT soybeans are by far the most important GE crop in the U.S. in terms of impacts on pesticide use, and so the focus herein is on the PG Economics analysis of herbicide use on conventional and HT soybeans, as set forth in Chapter 4 of their above-cited report.

The authors begin by noting that there are two primary sources of data on pesticide use in the U.S. – NASS surveys and private farm-level surveys (survey data from DMR Kynetec was used in the PG Economics report).

Their Table 33 reports herbicide use on HT and conventional soybeans for 1998 through 2007 in the U.S., based on Kynetec survey data. In every year, herbicide use was higher on HT soybeans than conventional soybeans. The margin was typically less than 0.2 pounds until 2002, when the margin increased to around 0.3 from 2003-2007, as shown in Table 6.1.

Estimates of herbicide use on HT soybean acres as reported in the PG Economics report and this analysis differ modestly, and are accounted for largely by the rate per crop year of glyphosate herbicides. Likewise, the PG Economics and this report's estimates of total herbicide use on conventional soybean acres, and the differences between HT and conventional acres, are relatively close for 1998 through 2004. The Kynetec dataset then projects increases in the total rate of herbicide application on conventional acres from 2004 through 2007, despite the continued trend toward greater reliance on relatively low-dose herbicides, as evident in the projections based on NASS data.

This deviation in estimates of herbicide use on conventional soybeans accounts for this report's progressively larger margin of difference in herbicide use rates on HT in contrast to conventional soybean acres.

Despite some differences, it is significant that the industry-sponsored Kynetec survey, as reported by PG Economics, supports the same basic conclusion as this report – HT soybeans have increased herbicide use by a substantial and growing amount.

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[6] Brookes, G., and Barefoot, P., "GM crops: global socio-economic and environmental impacts 1996-2007," PG Economics Ltd, UK, Dorchester, UK.

Table 6.1. Impacts of HT Soybeans on Herbicide Use as Projected by Kynetec Data and This Analysis Based on NASS Data [NA="Not Available"]

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Pounds Applied HT Acres											
Kynetec	1.33	1.29	1.32	1.34	1.3	1.39	1.41	1.4	1.33	1.48	NA
NASS-Based	1.2	1.2	1.18	1.07	1.31	1.32	1.22	1.25	1.5	1.58	1.65
Pounds Applied Conventional Acres											
Kynetec	1.28	1.15	1.11	1.17	1.09	1.07	1.08	1.1	1.02	1.16	NA
NASS-Based	1.13	0.84	0.9	0.73	0.88	0.97	0.8	0.59	0.7	0.52	0.49
Difference HT to Conventional Acres											
Kynetec	0.05	0.14	0.21	0.17	0.21	0.32	0.33	0.3	0.31	0.32	NA
NASS-Based	0.07	0.36	0.28	0.34	0.43	0.35	0.42	0.66	0.8	1.06	1.16

But curiously, right after reporting the Kynetec results in Table 33, the authors of the PG Economics report state:

> "The comparison data between the GM HT crop and the conventional alternative presented above is, however, not a reasonable representation of average herbicide usage on the average GM HT crop compared with the average conventional alternative for recent years." (page 66)

The PG Economics analysts disavow their own data-driven estimates, asserting that herbicide use is lower on conventional soybean acres in the Kynetec dataset because the majority of farmers planting conventional soybeans must be among those facing the lightest weed pressure. This creative argument, however, is incompatible with the pattern of adoption of HT soybeans across the states. Since 2006, the rate of adoption of HT soybeans varies modestly between states from 81% to 97%, with no clear pattern between states with relatively low weed pressure (Minnesota, South Dakota) and states with much higher levels of weed pressure (Mississippi, Arkansas).[7]

After rejecting the Kynetec survey findings that were based on real data, the PG Economics team then turns to another source for supposedly more reliable estimates – the National Center for Food and Agricultural Policy (see previous section for a critique of NCFAP's estimates). The PG Economics team revises its soybean herbicide use projections drawing on NCFAP's faulty simulations, and reaches the basic finding of a 6.8% reduction in herbicide use as a result of HT soybeans.

Similarly creative – and highly questionable – methodological strategies are employed by the PG Economics team in projecting the impacts of other GE crops on pesticide use. Like the NCFAP, the PG Economics team never explains the discrepancies between their estimates and those based on NASS data.

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[7] Supplemental Table 3 presents HT soybean adoption rate data by state, and shows that some relatively low weed pressure states have high adoption, while others have lower adoption. Several relatively low pressure states have higher adoption rates than states with high levels of weed pressure.

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Agricultural Biotechnology – Providing Economic and Environmental Benefits

Posted by susanatbio on May 21st, 2009 — BIO Events & Activities, Food & Agriculture [1 Comment]

By Michael J. Phillips

Further evidence was provided at BIO 2009 on the many benefits of agricultural biotechnology. Graham Brookes, Director of PG Economics (UK) released key findings from its Global Impact Study that showed that farmers around the world are growing more biotech crops with significant global economic and environmental benefits. Key highlights of the report include:

- Biotech crops contribute significantly to reducing the release of greenhouse gas emissions from agricultural practices – mainly from less fuel use and additional soil carbon storage from reduced tillage. In 2007, the reduction of carbon dioxide from the atmosphere by biotech crops was equivalent to removing nearly 6.3 million cars from the road for one year;

- Biotech crops reduced pesticide use (1996-2007) by 359 million kg (-8.8 percent), and as a result, decreased the environmental impact associated with herbicide and insecticide use on the area planted to biotech crops by 17.2 percent;
- Herbicide tolerant biotech crops have facilitated the adoption of no/reduced tillage production regions – especially South America;
- There have been substantial net economic benefits to farmers amounting to $10.1 billion in 2007, and $44.1 billion since 1996. Of the $44.1 billion, 46.5 percent ($20.5 billion) was due to increased yields and the rest to reductions in the cost of production.

The report countered a recent Union of Concerned Scientists (UCS) report that attempted to make the case that biotech crops have not significantly increased yields since their introduction 1996. However, the UCS report suffers from a very flawed, superficial and inconsistent analysis.

The UCS report is very selective in the data it chose to use and does not account for variation in yield, country and region. The UCS report does – in fact – state that Bt corn has increased yields in the United States, but states just the opposite in its executive summary. In addition, the report did not take into consideration the significant decrease in costs of production from biotech crops that are just as important to farmers as yield. And, the report did not include canola and cotton that have had significant yield increases over the past decade.

The findings of the PG Economics report were featured at the Biotechnology Industry Organization (BIO) 2009 conference and subsequently used by most biotechnology and pesticide industry trade associations in public relations efforts designed to promote awareness of the benefits of GE crop technology. Note that in this posting by Michael Phillips, BIO Vice President for the Food & Agriculture program, the PG Economics report is highlighted as a "counter" to the 2004 UCS report on the impacts of GE crops on pesticide use over the first nine years of commercial use.

7. The Road Ahead for Today's GE Crops

Genetically engineered corn, soybeans, and cotton now dominate the market. Across these three crops, the supply of conventional, non-GE seed is so thin now that GE seeds will continue to account for the majority of crop acres planted for at least several years to come.

The quantum leap in seed industry profits associated with the marketing of GE seeds, coupled with control of the seed supply by companies holding the patents on GE technology, virtually guarantee this outcome. But there are clouds on the horizon for both the biotech industry and corn, soybean, and cotton farmers. Resistant weeds will continue to emerge and spread, and the current pressure to relax resistance management plans applicable to *Bt* corn and cotton could undermine long-term efficacy.

Over the next decade, GE seeds will increasingly contain multiple traits, cost considerably more per acre, and pose unique and not well understood resistance management, food safety and environmental risks. These factors will assume ever greater importance in assessments of the costs, benefits, and risks of GE crop technologies.

A. The Tipping Point for RR Crops

In the 2009 crop year, the percentage of national soybean acres planted to Roundup Ready varieties decreased for the first time since their introduction in 1996. Though the decline in adoption was slight (92% to 91%), there are reasons to believe 2009 may mark the tipping point for RR soybean market penetration. These include the slipping efficacy of the RR system as glyphosate-resistant weeds spread, steeply rising production costs (RR seed, herbicides), early evidence that the 7% to 11% yield increase promised by Monsanto on farms planting Roundup Read 2 soybeans is not occurring in the field[1]; and the increasingly attractive economics of growing conventional soybeans.

The spread of glyphosate-resistant weeds is largely responsible for the sharply increased use of glyphosate on soybeans documented in this report. While incrementally higher glyphosate application rates, and more applications, on RR crop acres will further increase overall glyphosate use, resistant weeds will force a growing number of farmers to resort to additional herbicides as well. As an Iowa State University weed scientist argues in a prescient article entitled "Turn Out the Lights -- The Party's Over," the days have passed when a single, properly timed application of glyphosate controlled all weeds, all season long.[2]

In the future, most RR acres will be treated with two herbicide active ingredients including glyphosate, and many will be

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[1] A study carried out in five states involving 20 farm managers who planted RR2 soybeans in 2009, concluded that the new varieties "didn't meet their [yield] expectations." Source: Jack Kaskey, "Monsanto Facing 'Distrust' as It Seeks to Stop DuPont," Bloomburg.com, November 11, 2009. http://www.bloomberg.com/apps/news?pdi=newsarchive&sid-acv4aBI1Q4Ng

[2] Hager, A. (2009). "Turn Out the Lights – The Party's Over," *The Bulletin*, University of Illinois Extension, No. 3 Article 4, April 10.

sprayed with three or more, often in multiple-product premixes. As a result, growers planting RR crops will find themselves facing weed control regimes that are more complex, time-consuming, and expensive than those utilized by conventional corn, soybean, and cotton farmers.

Some farmers have already decided to explore life after RR soybeans. "Interest in Non-Genetically Modified Soybeans Growing" is the title of an April, 2009 story posted by the Ohio State University extension service. Growing interest stems from "cheaper seed and lucrative premiums [for non-GE soybeans]."[3] In anticipation of this growth in demand, the Ohio State extension service reports that seed companies are doubling or tripling their conventional soybean seed supply for 2010.

Similar reports are coming in from Missouri and Arkansas,[4] where demand for cheaper conventional soybeans that yield as well as or better than RR soybeans is outstripping supply. Agronomists in these states point to three factors driving this renewed interest in conventional soybean seed:

- The high and rising price of RR seed;
- Resistant and tougher-to-control weeds; and
- Regaining the option and freedom to save and replant seeds, a traditional practice prohibited with Monsanto's patented RR soybeans.

The cost of soybean seed has risen from around $10 per bushel in the early 1980s to around $50 for RR seed in 2008. Monsanto recently announced that the newly introduced RR 2 soybean seed will cost $74 an acre in 2010, a remarkable 42% increase from 2009.[5]

The rapid spread of horseweed, Palmer amaranth, and other weeds resistant to glyphosate will force soybean and cotton farmers to apply higher rates of glyphosate and make additional applications of it, as well as other herbicides. Already in 2006, it was estimated that controlling GR Palmer amaranth would increase cotton production costs by $40 or more per acre.

For many soybean farmers in the Southeast, increased costs in 2010 are likely to include:

- A $24 per acre increase in cost for RR 2 soybean seed;
- About $15 more per acre for additional Roundup (depending on whether and to what degree glyphosate prices are reduced); and
- Up to $40 per acre for additional herbicides targeting glyphosate-resistant weeds.

The potential $79 increase in costs associated with the RR 2 system in 2010 in the Southeast is roughly equal to 60% of forecasted soybean cash operating costs, and would represent a remarkable 28% of soybean income per acre over operating costs, based on USDA's forecast for 2010.

Resistant weeds are not confined to the particularly damaging Palmer amaranth in the Southeast, but have rapidly emerged throughout the Midwest as well. Glyphosate-resistant biotypes of four different weed species have been documented in Kansas, three each in Missouri and Ohio, and two each in Minnesota, Indiana and Illinois. Up to one million acres of glyphosate-resistant horseweed were recently documented in Illinois, with up to 100,000 acres in Missouri and Kansas. This emergence of resistant weeds in the Midwest was predicted years ago,[6] and is the result of widespread planting of RR soybeans, often in rotation with RR corn, especially in recent years.

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[3] Pollack, C. (2009). "Interest in Non-Genetically Modified Soybeans Growing," Ohio State University Extension, April 3, 2009, http://extension.osu.edu/~news/story.php?id=5099

[4] Jones, T. (2008). "Conventional soybeans offer high yields at lower cost," University of Missouri, Sept. 8, 2008. http://agebb.missouri.edu/news/ext/showall.asp?story_num=4547&iln=49; Medders, H. (2009). Soybean demand may rise in conventional state markets," University of Arkansas, Division of Agriculture, March 20, 2009. http://www.stuttgartdailyleader.com/homepage/x599206227/Soybean-demand-may-rise-in-conventional-state-markets

[5] Kaskey, J. (2009). "Monsanto to Charge as Much as 42% More for New Seeds," Bloomberg, August 13, 2009. http://www.bloomberg.com/apps/news?pid=20601103&sid=aLW8VZBkP3PA#

[6] Owen, M.D.K. (2005). "Update 2005 on Herbicide Resistant Weeds and Weed Population Shifts," 2005 Integrated Crop Management Conference, Iowa State University.

"Roundup is the greatest thing in agriculture in my lifetime."

"In hindsight, we screwed up. We can't rely on the same thing over and over."

Quotes from a North Carolina farmer and a retired scientist[7]

B. Industry's Response to Resistant Weeds

While biotechnology companies generally downplay the severity and adverse impacts of glyphosate-resistant weeds, they are nonetheless working aggressively to come up with responses to the problem. Three of these responses are discussed below: subsidies for use of herbicides with different modes of action, crops with enhanced resistance to glyphosate, and herbicide-resistant stacks that include resistance to toxic but inexpensive herbicides like 2,4-D.

Subsidies for Use of Non-glyphosate Herbicides

Since 1996 Monsanto has encouraged farmers to rely exclusively on glyphosate for control of weeds in Roundup Ready crops,[8] and discounted the possibility of significant problems triggered by glyphosate-resistant weeds.[9] Now that resistant weeds are threatening the viability of the RR crop system, however, Monsanto and other companies are responding with unprecedented initiatives that subsidize the purchase of competitors' products in a belated effort to deal with already-resistant weeds and/or slow the emergence of newly resistant weeds.

Farmers are hiring crews to hand weed cotton and soybean fields infested with glyphosate-resistant weeds. This costly tactic can reduce but not prevent serious reductions in crop yields. Photo by Brad Luttrell. http://www.bradluttrell.com

Monsanto's "Start Clean, Stay Clean Assurance Plan" is part of the Roundup Rewards program,[10] which offers farmers rebates and incentives for those farmers who agree to exclusively purchase specific, bundled Monsanto seed and herbicide products.[11] Under this program a farmer can receive a rebate up to $13 per acre for the purchase of a competitor's herbicide that works through a mode of action different from Roundup's.

The "Roundup Ready Cotton Performance Plus" program also offers rebates from Monsanto to growers to cover the cost of competitors' herbicides. This program pays up to $12 per acre and is designed to encourage the rotation of herbicide modes of action, a core resistance management practice.[12]

Syngenta, too, has recently announced a plan, the "2009 AgriEdge Corn and Soybean Program"[13] that offers rebates for the purchase of herbicides that work through a mode of action other than glyphosate's.

Although the rotation of herbicide modes of action is an important strategy for sustaining herbicide efficacy, the rotations must be done carefully. As the pesticide industry

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[7] Quotes from the article "Carolina farmers battle herbicide-resistant weeds," by Jeff Hampton, *The Virginia-Pilot*, July 19, 2009.

[8] Shaner, D.L. (2000). "The impact of glyphosate-tolerant crops on the use of other herbicides and on resistance management," *Pest Management Science* 56: 320-26.

[9] Bradshaw LD, Padgette SR, Kimball SL and Wells BH (1997). "Perspectives on glyphosate resistance," *Weed Technol* 11:189–198.

[10] The 32 page brochure that explains the Roundup Rewards program and presents details on the rebates for purchase of herbicides sold by other companies is accessible at http://www.monsanto.com/monsanto/ag_products/pdf/rr_rewards_brochure.pdf.

[11] Offering rebates contingent on exclusive purchase of a single company's products, or requiring farmers to purchase one input in order to have access to another is a practice called "bundling" which is, in general, frowned upon by the Federal Trade Commission and Justice Department. Some farm leaders have called for a government investigation of the anti-competitive impacts of Monsanto's current marketing programs and policies.

[12] "RR cotton growers can receive rebates for multiple herbicides," *Carolina-Virginia Farmer*, February 2009.

[13] For more details, see http://www.garstseed.com/GarstClient?GarstNews/news.aspx?NewsItem=10103.

moves to more multiple-herbicide premix products, farmers will have a more difficult time following recommended herbicide-resistant management plans. In addition, several GR weed biotypes are also already resistant to herbicides in one, two, or more herbicide families of chemistry, as documented in Chapter 4.

Enhanced Glyphosate Resistance

A second strategy to respond to the rapid spread of glyphosate-resistant weeds is engineering crops with enhanced resistance to glyphosate. Such crops will tolerate the use of higher rates of application, in the hope that more glyphosate will control increasingly resistant weeds. While of limited effectiveness in the short term, this strategy will accelerate the emergence of weeds with higher levels of glyphosate-resistance, and is, for farmers, like pouring gasoline on a fire in the hope of putting it out.

Monsanto's Roundup Ready Flex cotton, the successor to its original RR cotton, was introduced in 2006 and was the first crop variety to hit the market with enhanced glyphosate resistance.[14] The label for Roundup Ready Flex cotton recommends almost 1.5 times the glyphosate application rate, compared to original RR cotton (32 ounces/acre for RR Flex vs. 22 ounces/acre for original RR cotton).[15] In addition, RR Flex cotton permits glyphosate application on sexually mature cotton plants (unlike original RR cotton).

Bayer CropScience recently obtained commercial approval for its glyphosate-resistant Glytol cotton, which is associated with an increased tolerance level for glyphosate residues on cotton gin byproducts (from 175 to 210 ppm), higher application rates, and corresponding label changes.[16]

DuPont-Pioneer's Optimum GAT soybeans and corn contain a new mechanism rendering plants resistant to glyphosate.[17] GAT stands for glyphosate acetyltransferase, an enzyme that inactivates glyphosate by adding an acetyl group to it. One report by DuPont scientists suggests that GAT corn may survive six times the normal dose of glyphosate "with no adverse symptoms."[18] This would presumably permit higher doses of glyphosate, if necessary changes in glyphosate herbicide labels and tolerance levels were requested and approved by the EPA.

In a patent filing, DuPont-Pioneer proposes to "stack" GAT with one or both of Monsanto's mechanisms of glyphosate-resistance (CP4 EPSPS and GOX [glyphosate oxidoreductase]) in order to enhance tolerance to glyphosate and enable applications of higher rates to control increasingly resistant weeds.[19]

A second patent issued to DuPont-Pioneer contains two examples of glyphosate application to soybeans incorporating dual glyphosate resistance comprising both DuPont-Pioneer's GAT mechanism and Monsanto's CP4 EPSPS mechanism. Glyphosate applications ranged between 3 and 4 pounds of active ingredient per acre per crop year in weed management scenarios outlined in the patent application.[20] These rates per crop year are double to triple the average pounds of glyphosate applied to GE soybeans in 2006 (1.36 pounds per crop year, from NASS annual pesticide survey).

Stine Seed recently petitioned USDA for commercial approval of a new variety of glyphosate-resistant corn,[21]

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[14] Bennett, D. (2005). "A look at Roundup Ready Flex cotton," *Delta Farm Press*, 2/24/05, http://deltafarmpress.com/news/050224-roundup-flex/.

[15] See Monsanto 2008 Technology Use Guide, pdf pages 31 & 34.

[16] EPA (2009). "Glyphosate; Pesticide Tolerances," FR Vol. 24, No. 120, June 24, 2009, pp. 29963-29996.

[17] Optimum GAT soybeans have been deregulated by the USDA; Optimum GAT corn is under review by the USDA. For fuller discussion of this dual-HR corn, see also: "Comments to USDA APHIS on Environmental Assessment for the Determination of Nonregulated Status for Pioneer Hi-Bred International, Inc. Herbicide Tolerant 98140 Corn," Center for Food Safety, February 6, 2009, http://www.centerforfoodsafety.org/pubs/CFS%20comments%20on%20Pioneer%20HT%2098140%20corn%20EA_final_2_6_09-FINAL.pdf.

[18] Castle et al (2004). "Discovery and directed evolution of a glyphosate tolerance gene," *Science* 304: 1151-54. For discussion, see CFS comments cited in last footnote.

[19] "Novel Glyphosate-N-Acetyltransferase (GAT) Genes," U.S. Patent 2005/0246798, issued Nov. 3, 2005, assigned to: Verdia, Inc. and Pioneer Hi-Bred International.

[20] "Novel Glyphosate-N-Acetyltransferase (GAT) Genes," U.S. Patent Application Publication, Pub. No. US 2009/0011938 A1, January 8, 2009, paragraphs 0152 & 0154.

[21] See petition number 09-063-01p at http://www.aphis.usda.gov/brs/not_reg.html.

Field trial of herbicide-resistant transgenic sugarcane (T) compared to control (C).

though it is unclear whether it has enhanced glyphosate tolerance. A biotech startup company in North Carolina, Athenix, is developing a bacterial gene to confer enhanced glyphosate tolerance in multiple crops.[22]

The higher glyphosate application rates made possible by and expected with these new, enhanced glyphosate-resistant crops will almost certainly accelerate the evolution and spread of resistant weed populations. The only viable alternative for conventional farmers to delay the unraveling of RR technology, whether enhanced or not, is to diversify their weed management tactics to include more tillage, altered crop rotations, the planting of cover crops, and more reliance on alternative herbicide modes of action.

Crops Resistant to Multiple Herbicides

The third approach being employed by industry is to develop crops that are resistant to more than one herbicide. Since there are relatively few new herbicides in the development pipeline, this strategy requires companies to engineer resistance to older and often higher-risk herbicides like 2,4-D, paraquat, and dicamba. A review of the scientific literature, the farm press, and petitions for deregulation of herbicide-tolerant crop varieties pending at the USDA shows that the industry is investing heavily in the development of crops with resistance to multiple herbicides.

DuPont-Pioneer's Optimum GAT soybeans and corn combine resistance to glyphosate with resistance to herbicides that inhibit the acetolactate synthase (ALS) enzyme (ALS inhibitors). Optimum GAT crop technology does not seem a promising approach in that it combines resistance to the two classes of herbicides (glyphosate and ALS inhibitors) to which weeds have already developed the most extensive resistance (see Figure 2.4). BASF has also developed ALS inhibitor-resistant soybeans,[23] which will likely also be "stacked" with resistance to glyphosate in the context of a Monsanto-BASF joint-licensing agreement (see below).

From an environmental and human health perspective, the most troubling new resistance traits will allow the use of relatively inexpensive, but toxic herbicides that have not been used widely in corn, soybean, and cotton production for many years because of the initial efficacy of glyphosate in the RR system. In collaboration with the University of Nebraska, Monsanto has developed soybeans that are tolerant to the chlorophenoxy herbicide dicamba.[24] These dicamba-tolerant soybeans are to be stacked with resistance to glyphosate in collaboration with BASF, the largest producer of dicamba.[25] Dicamba-resistant corn and cotton are also under development, with potential triple-stacking of herbicide tolerance to dicamba, glyphosate, and glufosinate.[26]

Dow AgroSciences recently petitioned USDA for commercial approval of a GE-corn variety resistant to a second chlorophenoxy herbicide – 2,4-D, a component of the Vietnam War defoliant Agent Orange. This 2,4-D-resistant corn will be stacked with resistance to aryloxyphenoxypropionate grass herbicides of the ACCase

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[22] Service, R.F. (2008). "A growing threat down on the farm," *Science* 316: 1114-1117.

[23] See USDA petition #09-015-01p. http://www.aphis.usda.gov/brs/not_reg.html

[24] Behrens, M.R. et al (2008). "Dicamba resistance: enlarging and preserving biotechnology-based weed management strategies," *Science* 316: 1185-1188; Service, R.F. (2008). "A growing threat down on the farm," *Science* 316: 1114-1117.

[25] Monsanto (2009). "BASF and Monsanto formalize agreement to develop dicamba-based formulation technologies," Press Release, Jan. 20, 2009, http://monsanto.mediaroom.com/index.php?s=43&item=683

[26] Robinson, E. (2008). "Weed control growing much more complex, new tools coming," *Delta Farm Press*, March 27, 2008. http://deltafarmpress.com/cotton/weed-control-0327/index.html.

Farmers are now dealing with a new "weed" - volunteer RR corn plants in RR soybean fields. The converse is also a growing problem - volunteer RR soybeans in RR corn fields.

inhibitor class.[27] Dow projects introduction of this dual herbicide-resistant corn in 2012, and a corresponding soybean variety in 2013 or 2014.[28]

Finally, Monsanto and Dow are collaborating to produce "SmartStax" corn, which combines resistance to glyphosate and glufosinate, together with six *Bt* insecticidal toxins.[29]

Moreover, the multiple HT crops described above are just the tip of the iceberg. The major players in the industry have discovered or developed at least 12 genes conferring resistance to most major classes of herbicides.[30] One scenario for the future of biotech crops is provided by a 2009 patent granted to DuPont-Pioneer, describing a single plant that is tolerant to at least two, three, four, five, six, or seven or more different herbicide families of chemistry, encompassing dozens to hundreds of individual herbicide products.[31]

The rationale stated in patent applications and other seed industry documents supporting the development of multiple herbicide-resistant crops is that they will provide farmers new options to deal not just with resistant weeds, but also volunteer plants in a subsequent crop season that also happen to be herbicide tolerant. For instance, glyphosate-resistant weeds and RR corn in a soybean field planted to a variety with dual tolerance to glyphosate and ALS inhibitors could be treated with an over-the-top application of an ALS inhibitor. Likewise, Dow's dual-tolerant corn could be sprayed directly with 2,4-D to control weeds or soybeans resistant to glyphosate, and perhaps other herbicides.

Managing resistant weeds triggered by GE crops by developing new varieties tolerant of multiple herbicides is

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[27] See petition number 09-233-01p at http://www.aphis.usda.gov/brs/not_reg.html.

[28] Dow (2007). "Dow AgroSciences reveals progress on new herbicide tolerance trait," August 28, 2007. http://www.dowagro.com/newsroom/corporatenews/2007/20070828a.htm.

[29] http://www.monsanto.com/pdf/investors/2007/09-14-07.pdf.

[30] Green et al (2007). "New multiple-herbicide crop resistance and formulation technology to augment the utility of glyphosate," *Pest Management Science* 64(4): 332-9, Table 1.

[31] Use of the word "type" in this context refers to a herbicide mode of action that might encompass a dozen or more registered active ingredients, and hundreds (even thousands) of products. "Novel Glyphosate-N-Acetyltransferase (GAT) Genes," U.S. Patent Application Publication, Pub. No. US 2009/0011938 A1, January 8, 2009, paragraph 33.

appealing to biotech seed companies, because each herbicide-tolerant trait qualifies the patent holder for a technology fee premium. Progress down this road, however, will draw farmers onto an increasingly costly herbicide treadmill that will erode net farm-level returns and pose significant new public health and environmental risks.

Plus, it likely won't work for long, if at all. Weed biotypes that are resistant to two or three different herbicide modes of action, and literally dozens of herbicide products, are already common. Weeds resistant to glyphosate, ALS inhibitors, or both comprise by far the majority of herbicide-resistant weeds, as measured by both acreage infested and number of resistant biotypes.[32]

Multiple-herbicide-resistant crops will also facilitate more frequent applications of 2,4-D, paraquat, and dicamba, as well as higher rates of application. The two phenoxy herbicides, 2,4-D and dicamba, have been linked to reproductive problems and birth defects in the Midwest, and pose significantly higher risks to a range of organisms than most other contemporary herbicides.[33] Paraquat is a known risk factor for Alzheimer's disease, Parkinson's disease, and other neurological diseases of aging.[34]

Already, and before the introduction of any 2,4-D resistant crops, the spread of glyphosate resistant weeds has markedly increased 2,4-D use. NASS data show 2,4-D applications on soybeans rising from 1.73 million pounds in 2005 to 3.67 million pounds in 2006, a 112% increase. In Louisiana in 2006, soybean farmers sprayed 36% of their acres with paraquat, 19% with 2,4-D, and applied 2.3 applications of glyphosate to 87% of planted acres.

In summary, glyphosate-resistant crops were rapidly adopted by farmers, who were encouraged to rely exclusively on glyphosate for weed control. Farmers were assured by experts that resistant weeds would never be extensive or difficult to control. Voluntary resistance management guidelines weakly advanced by Syngenta, Monsanto, and others have largely failed, while federal regulators have done essentially nothing to stem the rapid emergence of resistant weeds.

Now that glyphosate-resistant weeds infest millions of acres of cropland and are threatening the viability of the RR system, the industry is proposing "solutions" that are, in truth, technical fixes that are almost certain to make matters worse by creating a greater number of weeds resistant to multiple herbicides. It is also inevitable that there will be further, significant increases in herbicide use, including relatively more toxic herbicides like 2,4-D, dicamba, and paraquat.

Increased use of chlorophenoxy herbicides will also lead to much more serious and frequent problems with off-target movement of herbicides and damage to crops, shrubs, and other valuable vegetation. Not only are these herbicides prone to drift during application, they also re-volatilize after application under certain weather conditions. The heat of the sun can transform these herbicides back into vapor phase, allowing them to float on the wind and come into contact with non-target plants, such as the wheat or alfalfa in a neighbor's field, or roses in a garden. At low doses, susceptible plants usually do not die, but often suffer harm to their reproductive functions. Pollen and nectar sources for bees and habitat for beneficial insects can collapse due to movement of dicamba into hedgerows and uncultivated land.

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[32] For details, see the Weed Science Society of America's "International Survey of Resistant Weeds," http://www.weedscience.org.

[33] For an excellent review of the extensive literature on phenoxy herbicides and reproductive problems, see Theo Colborn and Lynn Carroll, "Pesticides, Sexual Development, Reproduction and Fertility: Current Perspective and Future Direction," *Human and Ecological Risk Assessments*, Vol. 13, pages 1078-1110, 2007. On dicamba and birth defects, see Weselak, M. et al., "Pre- and post-conception pesticide exposure and risk of birth defects in an Ontario farm population," *Reproductive Biology*, Vol. 24, Issue 4, August, 2008.

[34] Landrigan, P. et al., "Early Environmental Origins of Neurological Disease in Later Life," *Environmental Health Perspectives*, Vol. 113, Num. 9, September 2005.

Some high-value crops like grapes and tomatoes can be damaged by chlorophenoxy herbicide drift at levels that are essentially undetectable. Factoring this often hidden and always difficult to diagnose damage into the GE crop cost-benefit equation is going to be a major challenge.

Avoiding damage in crop fields from off-target movement and carryover of herbicides is one reason the biotechnology industry is moving toward coupling resistance to glyphosate with resistance to chlorophenoxy and other herbicide modes of action. In fact, some have already advanced the troubling proposition that farmers should purchase chlorophenoxy-resistance traits precisely in order to defend their crops against drift and revolatilization, problems that will be greatly exacerbated if the industry aggressively markets corn, soybean, and cotton varieties engineered for resistance to these herbicides.[35]

C. Resistance Management Still Key in Sustaining *Bt* Crop Efficacy

The future of *Bt* crops is brighter than the future of RR crops. Unlike glyphosate, *Bt* was recognized from the beginning as a valuable, relatively benign insecticide whose continued efficacy required government action to protect against the evolution of resistant insects. As a result, the EPA established programs to preserve the efficacy of *Bt* toxins through the use of refuges for susceptible insect populations and close monitoring of pest populations.

The program has been successful, especially in the case of *Bt* cotton. The attention focused by university entomologists on resistance management, the mandatory resistance management plans imposed by the EPA, and the introduction of Bollgard II cotton that expresses two *Bt* toxins have proven effective, thus far, in delaying the emergence of resistance in cotton pests in most regions.

However, the discovery of several *Bt*-resistant populations of bollworms in Mississippi and Arkansas between 2003 and 2006 by Dr. Bruce Tabashnik and colleagues stands as a reminder that *Bt* resistance must be closely monitored and aggressively managed.

History, too, suggests that continued diligence in cotton *Bt* resistance management is warranted. Since the 1950s, it has taken 10-15 years for key cotton insects to develop resistance to each new type of insecticide applied to control them. This cycle began with the organochlorines from the early 1960s to mid-1970s, and then repeated itself with the carbamates in the 1970s and 1980s and the synthetic pyrethroids in the 1980s and 1990s. The *Bt* cotton varieties have been in use for about 10 years. Researchers have recently shown that cross-resistance can develop in some cotton insect pests to the two *Bt* toxins in Bollgard II varieties.[36] As a result, prudence dictates waiting a few more years before determining whether contemporary resistance management plans are excessive.

Bt corn also remains highly effective for control of ECBs and SWCBs, but is being used in ways that impose significant selection pressure on insect populations. Unfortunately, the industry has convinced the EPA to relax resistance management requirements applicable to recently approved, stacked *Bt* corn varieties expressing two or more modes of action for ECB/SWCB control.

The industry has also asked for reduced resistance management requirements for corn hybrids expressing *Bt* for control of the CRW, an insect notorious for its ability to develop resistance.[37] Scientists convened by the EPA to assess future CRW resistance management plans questioned the science supporting such requests by industry to relax

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[35] Charles, G, et al (2007). "Tolerance of cotton expressing a 2,4-D detoxification gene to 2,4-D applied in the field," *Australian Journal of Agricultural Research* 58(8): 780–787.

[36] Tabashnik, B. et al., 2009. "Asymmerical cross-resistance between *Bt* toxins Cry 1Ac and Cry2Ab in pink bollworm," *Proceedings of the National Academy of Sciences*, www.pnas.org/cgi/doi/10.1073/pnas.0901351106.

[37] The CRW is resistant to insecticide active ingredients in nearly all major insecticide families of chemistry. In addition, the corn rootworm is the first and only insect known to have developed resistance to crop rotations. The western CRW is listed as resistant to 11 insecticides in four families of chemistry in the Arthropod Pesticide Resistance Database at Michigan State University. Details on western CRW resistance are at http://www.pesticideresistance.org/search/12/0/558/0/

resistance management provisions,[38] but the requests were nevertheless approved.

D. Why the Dramatic Increase in the Number of Toxins Needed to Grow Corn?

Another way of looking at pesticide dependence is to track the number rather than the amount of insecticides used on a crop. The combination of nicotinyl and other insecticide seed treatments and the increasing number of toxins in stacked *Bt* corn varieties represents a stunning increase in the number of different pesticidal toxins now being used to bring the nation's corn crop to harvest.

Eight-stack corn hybrids will be planted in 2010 expressing three different *Bt* toxins for control of the ECB/SWCB, and three more to control CRWs – a total of six *Bt* toxins. The seeds will be coated with two insecticides, including one nicotinyl insecticide that will move systemically throughout the tissues of the corn plant. A portion of the acres planted to these varieties will still be treated with one or more conventional corn insecticides.

Accordingly, nine or more chemicals will be used to manage corn insects on many fields in 2010. But on other conventional and organic farms, millions of acres of corn will receive no insecticide, and several million more, just a seed treatment. Traditionally, about two-thirds of corn acres have not required an insecticide spray application.

E. Stacking Traits Poses New and Poorly Understood Risks

There has been virtually no independent field research on the ecological and food safety implications when widely planted *Bt* corn varieties are simultaneously expressing two, three, or six *Bt* toxins. Current USDA and EPA approvals are based on the assumption that multiple genes producing different *Bt* toxins in corn plants will operate exactly as they do in varieties engineered to produce just a single *Bt* toxin.

Current EPA policy also apparently assumes there are no interactions in GE plants between the novel DNA introduced in the plant, the novel proteins produced in the plant as a result, and the systemic insecticides and fungicides now routinely used as seed treatments.

These are critical assumptions grounded upon very little science, that also require suspension of common sense. If interactions do, in fact, occur under some circumstances, or if the stability of gene expression patterns is reduced as the number of traits engineered into a plant increases, unpleasant surprises will lie ahead. For this reason, the government and industry should pursue deeper understanding of the impacts of multiple-stacked GE traits, and hopefully before hundreds of millions of acres are planted to them.

There is urgent need for more rigorous and independent scientific examination of the unique risks posed by stacked crop varieties. Multiple-trait varieties are already on the market and will gain a much larger share of the market in 2010. Within a few years, single-trait GE varieties will account for only a fraction of GE-planted acres.

Assessment of the risks of multi-trait crops faces a new and deeply troubling obstacle. Because genetically engineered crops are considered inventions under the patent law, patent holders control their use and sale. Patent rights plus market control give the biotechnology industry extraordinary control over the corn, soybean, and cotton seed supply. Through technology agreements that every buyer or user of GE seeds must sign and comply with, the seed industry also controls who can conduct research on GE seeds, what topics receive research attention, and how,

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[38] A summary of the EPA Scientific Advisory Panel's comments in February, 2009 on this topic has been prepared by Dr. Mike Gray, "Scientific Advisory Panel Report on Pioneer's Optimum AcreMax Seed Mix Refuge (Refuge-in-a-bag) Request Available On-Line," *The Bulletin*, University of Illinois, No. 9, Article 5, May 22, 2009.

and sometimes even whether, the findings of independent scientists can be reported publicly.[39] Under such a system there simply is no way that scientists can objectively assess the risks of new biotechnology crops, including the new stacked varieties.

Compared to 15 years ago when the first GE crop was planted, farmers and the public have, for the most part, lost control over the seed supply. Until public plant breeding programs and seed companies re-emerge that are dedicated to producing conventional seeds, farmers will have to accept and plant what the seed industry chooses to offer, and the public will have to live with considerable uncertainty over the novel food safety and environmental risks posed by these new crops.

For the foreseeable future, this study confirms that one direct and predictable outcome of the planting of GE corn, soybean, and cotton seed will be steady, annual increases in the pounds of herbicides applied per acre across close to one-half the nation's cultivated cropland base. Farm production costs and environmental and health risks will rise in step with the total pounds of pesticides applied on GE crops.

Vastly expanded use of 2,4-D and other older, relatively more toxic herbicides on fields infested with glyphosate-resistant weeds will increase human and environmental risks, and greatly increase off-target movement of herbicides, in some instances leading to more damage to plants on nearby farms and in neighboring areas.

As glyphosate-resistant weeds spread, farmers are forced to return to deep tillage in an effort to bury resistant weed seeds. The tillage renaissance unfolding in the Southeast, in step with the spread of resistant weeds, increases soil erosion, energy use, non-point source water pollution, agriculture's contribution to global warming, and grower production costs. These consequences must now be incorporated in the GE-crop risk-benefit equation.

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[39] Pollack, A. (2009). "Crop Scientists Say Biotechnology Seed Companies Are Thwarting Research," *New York Times*, Feb. 20, 2009. http://www.nytimes.com/2009/02/20/business/20crop.html?_r=1&emc=eta; Waltz, E. (2009). "Under Wraps," News Feature, *Nature Biotechnology* 27(10): 880-82.