Seeds of Concern

Are genetically modified crops an environmental dream come true or a disaster in the making? Scientists are looking for answers

By Kathryn Brown

Two years ago in Edinburgh, Scotland, eco-vandals stormed a field, crushing canola plants. Last year in Maine, midnight raiders hacked down more than 3,000 experimental poplar trees. And in San Diego, protesters smashed sorghum and sprayed paint over greenhouse walls.

This far-flung outrage took aim at genetically modified crops. But the protests backfired: all the destroyed plants were conventionally bred. In each case, activists mistook ordinary plants for GM varieties.

It's easy to understand why. In a way, GM crops—now on some 109 million acres of farmland worldwide—are invisible. You can't see, taste or touch a gene inserted into a plant or sense its effects on the environment. You can't tell, just by looking, whether pollen containing a foreign gene can poison butterflies or fertilize plants miles away. That invisibility is precisely what worries people. How, exactly, will GM crops affect the environment—and when will we notice?

Advocates of GM, or transgenic, crops say the plants will benefit the environment by requiring fewer toxic pesticides than conventional crops. But critics fear the potential risks and wonder how big the benefits really are. "We have so many questions about these plants," remarks Guenther Stotzky, a soil microbiologist at New York University. "There's a lot we don't know and need to find out."

As GM crops multiply in the landscape, unprecedented numbers of researchers have started fanning into the fields to get the missing information. Some of their recent findings are reassuring; others suggest a need for vigilance.

Fewer Poisons in the Soil?

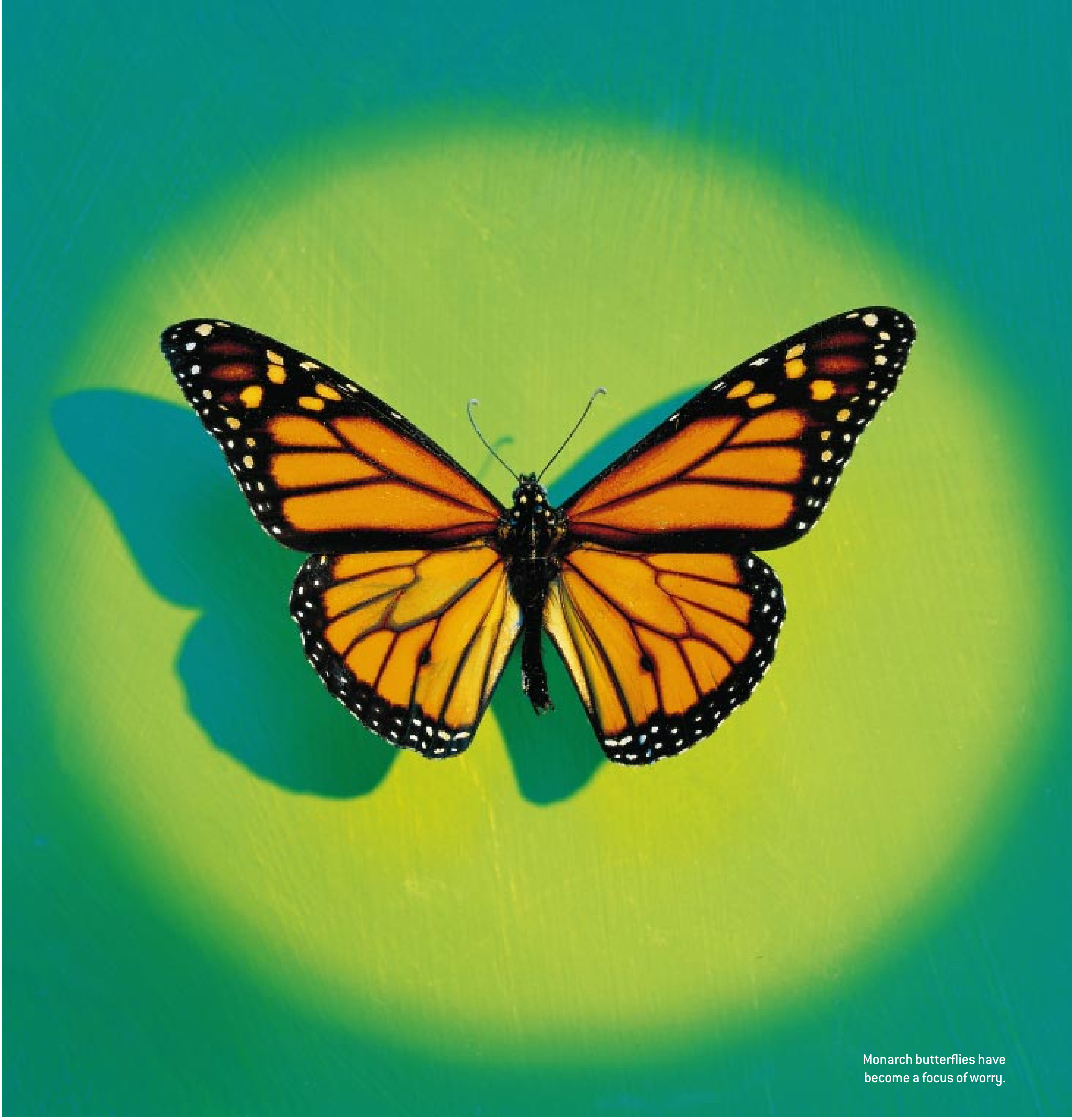
EVERY YEAR U.S. GROWERS shower crops with an estimated 971 million pounds of pesticides, mostly to kill insects, weeds and fungi. But pesticide residues linger on crops and the surrounding soil, leaching into groundwater, running into streams and getting gobbled up by wildlife. The constant chemical trickle is an old worry for environmentalists.

In the mid-1990s agribusinesses began advertising GM seeds that promised to reduce a farmer's use of toxic pesticides. Today most GM crops—mainly soybean, corn, cotton and canola—contain genes enabling them to either resist insect pests or tolerate weed-killing herbicides [*see box on page 56*]. The insect-resistant varieties make their own insecticide, a property meant to reduce the need for chemical sprays. The herbicide-tolerant types survive when exposed to broad-spectrum weed killers, potentially allowing farmers to forgo more poisonous chemicals that target specific weed species. Farmers like to limit the use of more hazardous pesticides when they can, but GM crops also hold appeal because they simplify operations (reducing the frequency and complexity of pesticide applications) and, in some cases, increase yields.

But confirming environmental benefit is tricky. Virtually no peer-reviewed papers have addressed such advantages, which would be expected to vary from plant to plant and place to place. Some information is available, however. According to the U.S. Department of Agriculture, farmers who plant herbicide-tolerant crops do not necessarily use fewer sprays, but they do apply a more benign mix of chemicals. For instance, those who grow herbicide-tolerant soybeans typically avoid the most noxious weed killer, turning instead to glyphosate herbicides, which are less toxic and degrade more quickly.

Insect-resistant crops also bring mixed benefits. To date, insect resistance has been provided by a gene from the soil bacterium *Bacillus thuringiensis* (Bt). This gene directs cells to manufacture a crystalline protein that is toxic to certain insects—especially caterpillars and beetles that gnaw on crops—but does not harm other organisms. The toxin gene in different strains of *B. thuringiensis* can affect different mixes of insects, so seed makers can select the version that seems best suited to a particular crop.

Of all the crops carrying Bt genes, cotton has brought the biggest drop in pesticide use. According to the Environmental Protection Agency, in 1999 growers in states using high amounts of Bt cotton sprayed 21 percent less insecticide than usual on the crop. That's a "dramatic and impressive" reduction, says Stephen Johnson, an administrator in the EPA's Office of Pesticide Programs. Typically, Johnson says, a farmer might spray



Monarch butterflies have become a focus of worry.

insecticides on a cotton field seven to 14 times during a single growing season. "If you choose a Bt cotton product, you may have little or no use for these pretty harsh chemicals," he notes. Growers of Bt corn and potatoes report less of a pesticide reduction, partly because those plants normally require fewer pesticides and face fluctuating numbers of pests.

Defining the environmental risks of GM crops seems even harder than calculating their benefits. At the moment, public attention is most trained on Bt crops, thanks to several negative studies. Regulators, too, are surveying the risks intensely. This spring or summer the EPA is expected to issue major new guidelines for Bt crops, ordering seed producers to show more thoroughly that the crops can be planted safely and monitored in farm fields.

In the face of mounting consumer concern, scientists are stepping up research into the consequences of Bt and other GM crops. Among their questions: How do Bt crops affect "non-target" organisms—the innocent bugs, birds, worms and other creatures that happen to pass by the modified plants? Will GM crops pollinate nearby plants, casting their genes into the wild to create superweeds that grow unchecked? What are the odds that the genetically engineered traits will lose their ability to protect against insects and invasive weeds, leaving GM plants suddenly vulnerable?

At What Cost to Wildlife?

IN 1998 A SWISS STUDY provoked widespread worry that Bt plants can inadvertently harm unlucky creatures. In this laboratory experiment, green lacewing caterpillars proved more likely to die after eating European corn-borer caterpillars that had fed on Bt corn instead of regular corn. The flames of fear erupted again a year later, when Cornell University entomologist John Losey and his colleagues reported that they had fed milkweed leaves dusted with Bt corn pollen to monarch butterfly larvae in the lab and that those larvae, too, had died.

"That was the straw that broke the camel's back," says David Pimentel, also an entomologist at Cornell. Suddenly, all eyes turned to the organisms munching GM plant leaves, nipping modified pollen or wriggling around in the soil below the plants—organisms that play vital roles in sustaining plant populations. Another alarming study relating to monarch butterflies appeared last August.

But the lab bench is not a farm field, and many scientists question the usefulness of these early experiments. The lab insects, they note, consumed far higher doses of Bt toxin than they would outside, in the real world. So researchers have headed into nature themselves, measuring the toxin in pollen from plots of GM corn, estimating how much of it drifts onto plants such as milkweed and, finally, determining the exposure of butterfly and moth larvae to the protein. Much of that work, done during the 2000 growing season, is slated to be reported to the EPA shortly.

According to the agency, however, preliminary studies evaluating the two most common Bt corn plants (from Novartis and Monsanto) already indicate that monarch larvae encounter Bt corn pollen on milkweed plants—but at levels too low to be toxic. What is toxic? The EPA estimates that the insects face no observable harm when consuming milkweed leaves laden with up to 150 corn pollen grains per square centimeter of leaf surface. Recent studies of milkweed plants in and around the cornfields of Maryland, Nebraska and Ontario report far lower levels of Bt pollen, ranging from just six to 78 grains of Bt corn pollen per square centimeter of milkweed leaf surface. "The weight of the evidence suggests Bt corn pollen in the field does not pose a hazard to monarch larvae," concludes EPA scientist Zigfridas Vaituzis, who heads the agency's team studying the ecological effects of Bt crops.

> The weight of evidence suggests that pollen from insect-resistant corn plants in the field does not pose a hazard to the larvae of monarch butterflies. But the jury is still out.

But the jury is still out. "There's not much evidence to weigh," notes Jane Rissler of the Union of Concerned Scientists. "This issue of nontarget effects is just a black hole, and EPA has very little good data at this point to conclude whether the monarch butterfly problem is real, particularly in the long term."

In an EPA meeting on GM crops last fall, Vaituzis acknowledged the lack of long-term data on Bt crops and insect populations. Such studies "require more time than has been available since the registration of Bt crops," Vaituzis remarked. The EPA,

THREE WORRIES

1 INNOCENT CREATURES WILL BE HURT	2 SUPERWEEDS WILL ARISE	3 GM CROPS WILL SUDDENLY FAIL
1 INNOCENT CREATURES WILL BE HURT by insecticides built into many GM crops.	**2 SUPERWEEDS WILL ARISE** as genes that give crops the ability to kill insect pests or to withstand herbicides find their way into weeds.	**3 GM CROPS WILL SUDDENLY FAIL** because insect pests will evolve tolerance to built-in insecticides and because weeds will evolve immunity to herbicides sprayed over fields of herbicide-tolerant GM plants.
What the research says: Laboratory studies indicate that nontarget insects, such as monarch butterflies, could be harmed, but field studies suggest that the risk is small.	*What the research says:* Studies have found no superweeds, but anecdotal reports have surfaced. Because pollen from GM plants can often fertilize weedy relatives of those plants, GM crops should not be grown near such relatives.	*What the research says:* No failures have been documented, but they are likely to occur. Critics and proponents of GM crops disagree over the adequacy of current preventive measures.

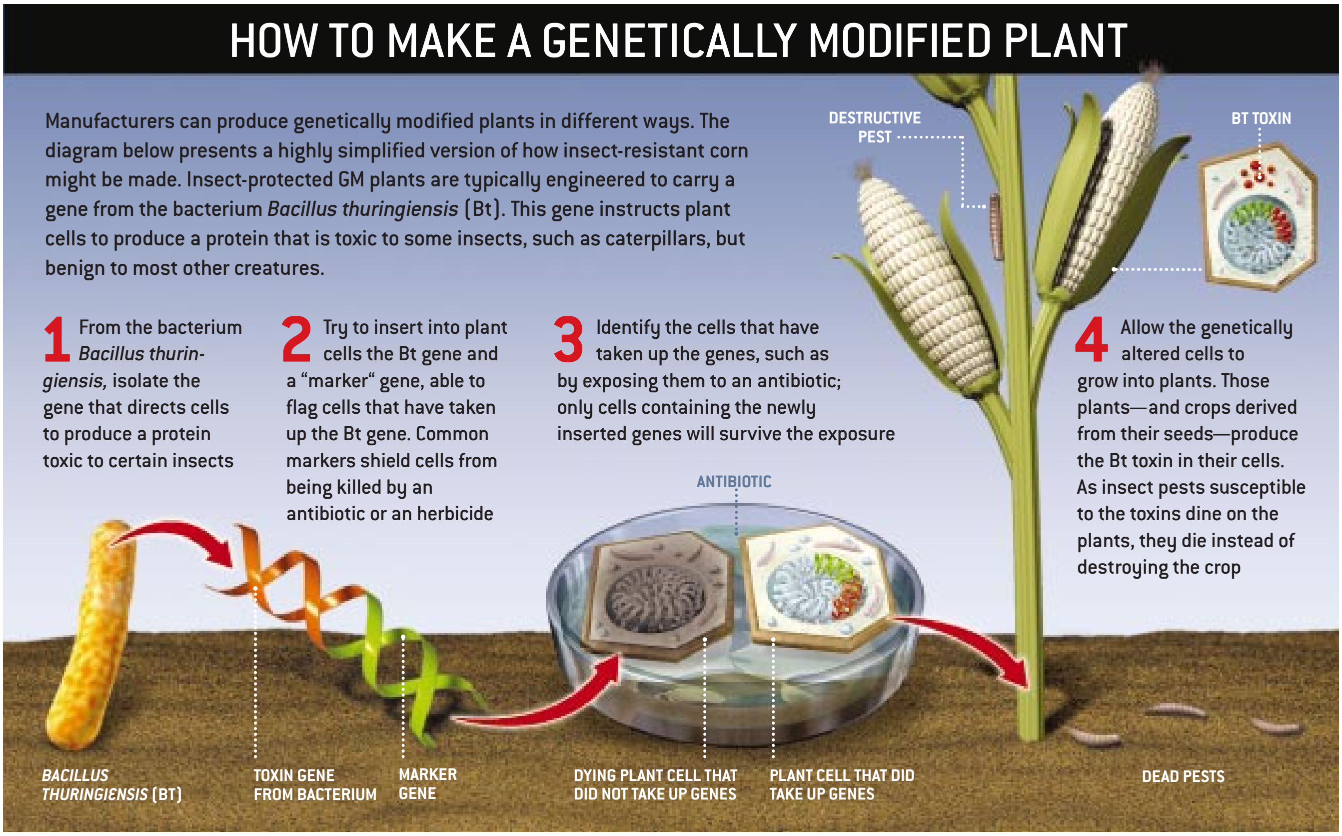


ILLUSTRATION BY JOE ZEFF

he added, continues to collect Bt crop data—but so far without evidence of "unreasonable adverse effects" on insects in the field.

Seeding Superweeds?

WORRIES ABOUT THE FLOW of genes from the original plant to others also surround GM crops. Unwitting insects or the right wind might carry GM crop pollen to weedy plant relatives, fertilizing them. And if that happens, the newly endowed plants could break ecological rank, becoming "superweeds" that are unusually resistant to eradication by natural predators or pesticides. Scientists have stopped asking if such gene flow is possible. "In many cases," says Cornell ecologist Allison Power, "we know gene flow will occur. The question now is, What will the consequences be?"

So far no scientific studies have found evidence of GM crops causing superweeds, and a 10-year study reported in *Nature* in February found no weedlike behavior by GM potatoes, beets, corn or canola planted in England. But worrisome anecdotes have appeared. Canadian farmers, in particular, have described GM canola escaping from farm fields and invading wheat crops like a weed. This canola also resisted pesticide sprays.

Power's studies of gene flow from virus-resistant GM plants give further reason for precaution. For now, virus-resistant crops stake a small share of the GM landscape, but they are likely to become more prevalent, particularly in the developing world. Power investigates gene flow in cultivated grain crops—wheat, barley and oats—engineered to contain genes that make the plants resistant to the barley yellow dwarf virus (which damages some 100 grass species). These GM grain crops could be on the market within the next decade.

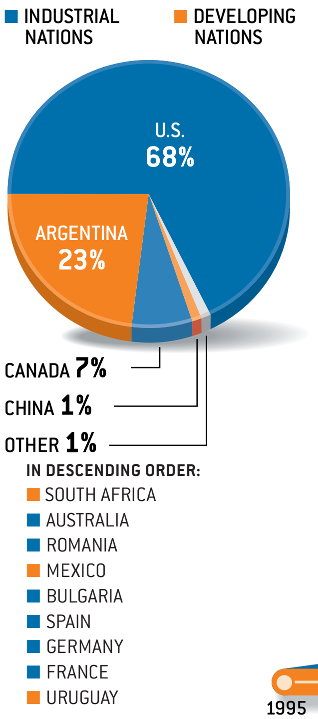
Power's work, carried out in the laboratory, indicates that wild oats—a weedy relative of cultivated oats—can "catch" the genes conferring resistance to barley yellow dwarf virus. If that happened in the field, she says, wild oats might run amok in the western U.S., outcompeting native grasses with kudzu-like intensity. Every GM crop, Power cautions, brings its own environmental personality and its own risks.

In the U.S., at least, landscape logistics make it rather unlikely that herbicide-tolerant or Bt crops will spread their biotech genes to weeds. That's because the GM crops sown in this country have no close relatives in the regions where they grow; most plants can pollinate others only if the recipients and the donors have certain features in common, such as the same chromosome number, life cycle or preferred habitat. A known exception to the "no relatives" rule in the U.S. is wild cotton growing in Hawaii and southern Florida, which, by virtue of its unusual similarity to GM cotton, can accept the GM pollen. To separate the wild and biotech plants from each other, the EPA has ordered companies not to sell GM cotton south of Florida's Interstate 60 or in Hawaii.

But it may prove harder to avoid creating superweeds outside North America, where weedy relatives of cultivated crops are common. Wild cotton, for instance, creeps past the Florida Keys, across the Gulf of Mexico and into Mexico. In South America, a weedy corn relative, teosinte, dresses the edges of domesticated cornfields. Either plant would readily

THE LATEST CROP OF NUMBERS

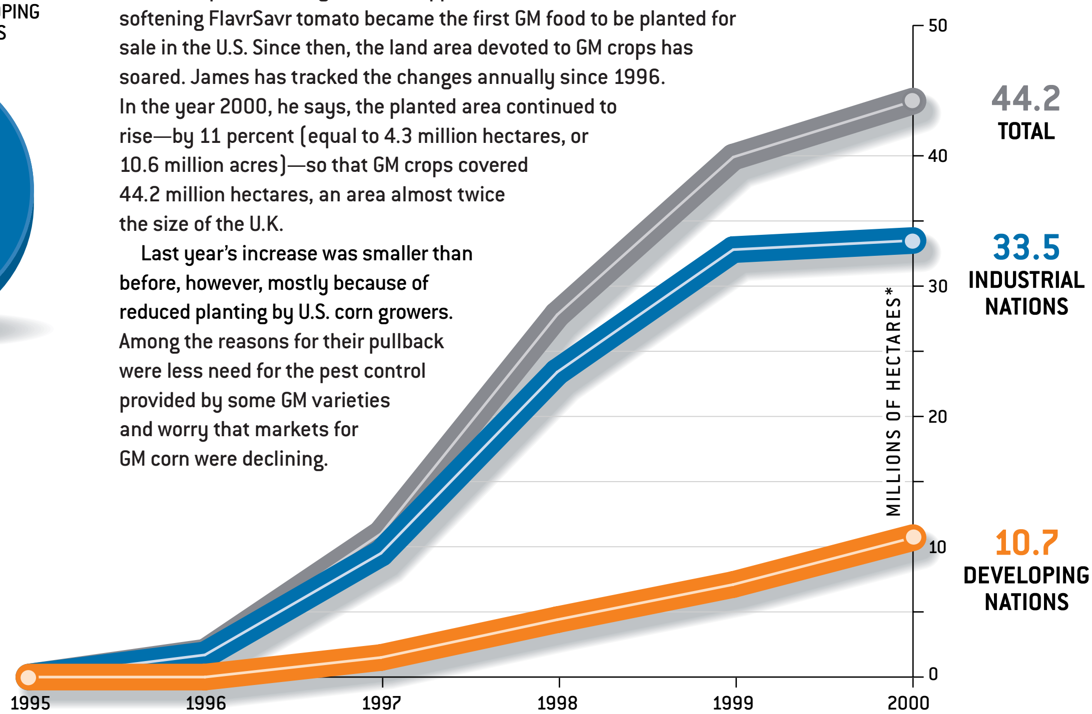
COUNTRIES PRODUCING GM CROPS IN 2000



Commercial planting of genetically modified crops began in China with tobacco in 1992, according to Clive James of the International Service for the Acquisition of Agri-biotech Applications. In 1994 the slow-softening FlavrSavr tomato became the first GM food to be planted for sale in the U.S. Since then, the land area devoted to GM crops has soared. James has tracked the changes annually since 1996. In the year 2000, he says, the planted area continued to rise—by 11 percent (equal to 4.3 million hectares, or 10.6 million acres)—so that GM crops covered 44.2 million hectares, an area almost twice the size of the U.K.

Last year's increase was smaller than before, however, mostly because of reduced planting by U.S. corn growers. Among the reasons for their pullback were less need for the pest control provided by some GM varieties and worry that markets for GM corn were declining.

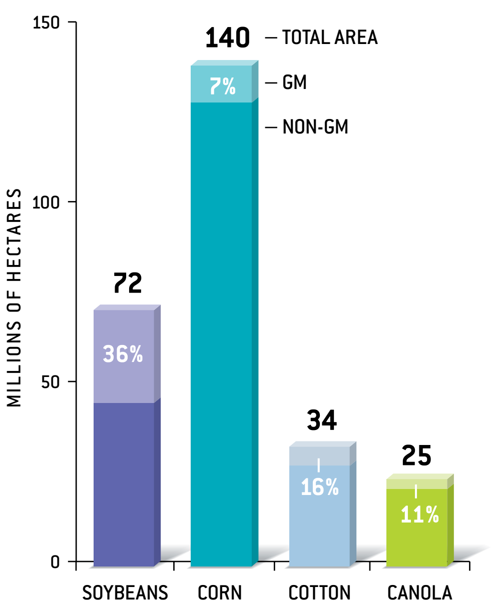
GLOBAL AREA OF GM CROPS



*Data were rounded to the nearest 100,000 hectares. 1 hectare = 2.471 acres

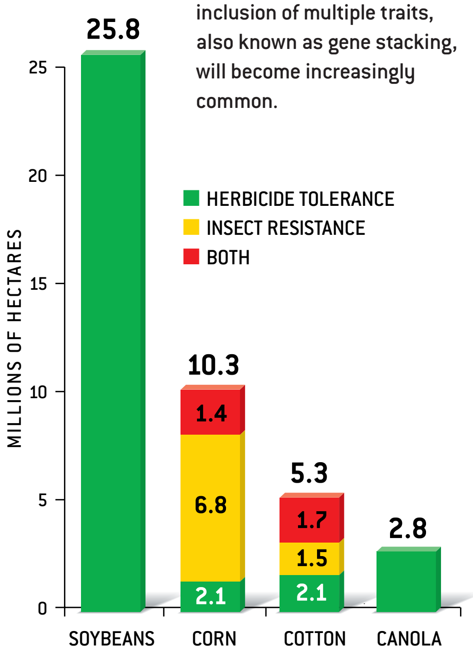
THE MOST COMMON GM CROPS . . .

Soybeans, corn, cotton and canola were the dominant GM crops in 2000, covering 16 percent of the 271 million hectares devoted to those four commodities.

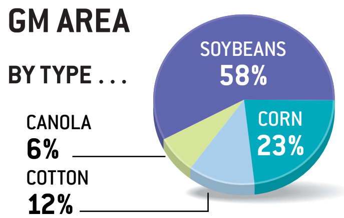


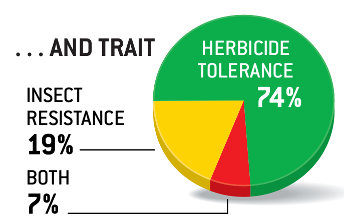
. . . AND HOW THEY'RE MODIFIED

Virtually all GM soybeans and canola planted in 2000 were herbicide-tolerant; corn and cotton were herbicide-tolerant or insect-resistant, or both. James predicts that inclusion of multiple traits, also known as gene stacking, will become increasingly common.



PERCENT OF TOTAL GM AREA





Figures may not add up to 100% because of rounding.

Farmers cultivated other GM crops as well, but these essentially dropped off the data screen when James rounded his figures to the nearest 100,000 hectares. Among them were potatoes, squash, papayas, melons, tomatoes and plants engineered for such traits as virus resistance, delayed spoilage and improved nutrition.

SOURCE: Clive James, ISAAA Briefs No. 21, *Global Status of Commercialized Transgenic Crops: 2000*; www.isaaa.org accept the pollen from a GM relative. Indeed, scientists say, GM crops in many countries could end up growing near their ancestral plants—and sharing more than the sunshine overhead. "Almost every crop has weedy relatives somewhere in the world," says Stephen Duke, a USDA plant physiologist in Oxford, Miss. "How do you keep GM crops out of places where they're not supposed to be?"

Taking Refuge

FINALLY, ONE RISK follows GM crops wherever they're planted: evolution. Over time, insect pests and weeds can become resistant to killing by routine chemical sprays. The same is bound to happen in the biotech age: eventually, impervious insects will munch away on GM insect-resistant plants, and the weeds surrounding herbicide-tolerant crops will shrug off the herbicide of choice. "Agriculture is an evolutionary arms race between plant protections and pests," comments botanist Jonathan Wendel of Iowa State University. "And GM crops are just one more way that we're trying to outsmart pests—temporarily."

After five years of commercial Bt crop use, no reports of insect resistance to the crops have emerged, according to Monsanto. The company contends that roughly 90 percent of Bt corn and cotton growers comply with refuge requirements.

But some environmentalists question that rosy scenario and also argue that non-Bt refuges are either too small or too poorly designed to keep insect resistance at bay for long. "At the EPA meeting last fall, scientists seemed to agree that bigger, better refuges were the way to go but that cotton farmers would never agree to big refuges," says Rebecca Goldburg, a senior scientist at Environmental Defense, a nonprofit organization based in New York City. More broadly, Goldburg questions how much GM crops really do for the environment. "In however many years," she says, "we'll lose Bt as an effective control against insects, and then we'll be on to another chemical control. Many of us view this current generation of biotech crops as a kind of diversion, rather than a substantive gain for agriculture." She favors sustainable agriculture alternatives, including careful crop rotation and organic farming methods, over pesticides sprayed on or engineered into plants.

U.S. landscape logistics make it unlikely that herbicide-tolerant or Bt crops will spread their biotech genes. It may be harder to avoid creating superweeds elsewhere.

To keep weeds vulnerable to herbicides, Monsanto and other companies urge growers to use the sprays responsibly, only when necessary. To slow insect resistance to the Bt toxin, the EPA requires Bt crop growers to set aside some part of their farmland for crops that have not been genetically modified. These "refuges" may be a corner of a field outside a Bt crop, for instance, or rows of standard plants that break up a Bt plot. Inside the refuges, insects that have acquired some Bt resistance breed with those that have not, diluting the resistance trait.

Virus-resistant GM crops have escaped widespread public concern, but they, too, pose some of the same risks as other GM crops. Some scientists worry that viruses will pick up resistance traits from virus-fighting GM crops and evolve into hard-to-beat strains that infect a newly expanded repertoire of plants. Some critics also question the ecological safety of emerging crops designed to resist drought, tolerate salt or deliver an extra nutritional punch. For example, Margaret Mellon of the Union of Concerned Scientists notes that salt-tolerant rice could potentially behave like a disruptive weed if it found its way into vulnerable wetlands.

"I don't think it's fair to say that every single GM crop is going to be a problem," Rissler remarks. "But we need to devote the research to risks now, rather than deal with repercussions later."

Still, some farmers are confident that GM technology can revolutionize agriculture for the better. For 30 years, Ryland Utlaut of Grand Pass, Mo., has been sowing and reaping 3,500 acres along the Missouri River. Last year, for the first time, he planted only herbicide-tolerant corn and soybeans across his entire, soil-friendly, no-till farm. As a result, he claims, he sprayed the crops half as often as he did before and got bigger yields. "If even the strongest environmentalist could see my farming practices now, I think they'd understand the benefits," Utlaut says. "I'm a fervent believer in this technology." Now he has to wait and see whether science confirms that belief. SA

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MORE TO EXPLORE

Transgenic Plants and World Agriculture. Royal Society of London, U.S. National Academy of Sciences, Brazilian Academy of Sciences, Chinese Academy of Sciences, Indian National Science Academy, Mexican Academy of Sciences, Third World Academy of Sciences. National Academy Press, July 2000.

The Ecological Risks and Benefits of Genetically Engineered Plants. L. L. Wolfenbarger and P. R. Phifer in *Science,* Vol. 290, pages 2088–2093; December 15, 2000.

Genetically Modified Pest-Protected Plants: Science and Regulation. National Research Council. National Academy Press, 2000.

Transgenic Crops in Natural Habitats. M. J. Crawley and R. S. Chails et al. in *Nature,* Vol. 409, pages 682–683; February 8, 2001.

Royal Society of Canada Expert Panel Report on the Future of Food Biotechnology. February 5, 2001. Available at **www.rsc.ca**

Information generally favorable to agricultural biotechnology, and extensive links, can be found at the Agbioworld Web site at **www.agbioworld.org/**

Information generally skeptical of agricultural biotechnology, and extensive links, can be found at the Union of Concerned Scientists Web site at **www.ucsusa.org/food/0biotechnology.html**

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