Sowing Disaster?

by Mark Schapiro

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The Nation

It’s an hour-and-a-half drive over switchbacks from the southern Mexican city of Oaxaca to the village of Capulalpan, a settlement of some 1,500 people nestled in the Sierra Norte Mountains. The thick forest and remoteness of this mountainous region has long enabled the local Zapotec Indians to maintain their cultural integrity and, to a great extent, write their own rules. When Mexican clocks were turned back for daylight saving time in the spring, the Zapotecs refused to make the adjustment, insisting that they live in "God’s time," not in what they derisively call "Fox time," referring to President Vicente Fox in far-off Mexico City. Carlos Castaneda wrote about this region as a center for natural transcendence in his book *Journey to Ixtlan*. But over the past year, this tiny puebla among the cedars and the wild mustard of the Sierra Norte has been unwillingly thrust into the center of a worldwide controversy over something quite different than the quality of its peyote: genetically engineered corn.

Last winter a team of plant scientists from the University of California, Berkeley, published a paper in the journal *Nature* asserting that the genes from genetically altered corn had been discovered in the local varieties of corn grown here in Capulalpan. ["Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico," David Quist & Ignacio H. Chapela, Department of Environmental Science, Policy and Management, University of California, Berkeley, California 94720-3110, USA; *Nature*, Volume 4141, November 29, 2001, pp. 541-543.] The news traveled quickly. The biotechnology industry has long claimed that genetic engineering is predictable: that the genes end up where they are put, and that their presence in the environment can be controlled. But the discovery of genetically engineered (GE) corn in Capulalpan appeared to defy those claims. In 1998 the Mexican government outlawed the planting -- although not the eating -- of GE corn, in order to protect the genetic diversity of the crop that is the country’s most important food supply.

Preserving the rich genetic diversity of Capulalpan’s corn is a matter of more than sentimental significance. When disaster strikes corn anywhere in the world -- disease, too much rain, not enough rain, a new pest -- plant scientists traditionally come to this region, which stretches from the Sierra Norte Mountains down to the southernmost state of Chiapas and into Guatemala, for the germ plasm to rejuvenate beleaguered domestic varieties. Genetic diversity is what provides a hedge against unanticipated environmental changes. In the state of Oaxaca alone, corn grows in sixty different varieties, in shades of blue, black, purple and white, as well as the yellow that we have come to associate with our most widely grown crop.

"This is the world's insurance policy," says Mauricio Bellon, director of the economics programs at the International Maize and Wheat Improvement Center (CIMMYT) , the world's foremost public research facility for corn. "The diversity of these land races, these genes, is the basis of our food supply. We'll have great science, we'll have great breeding, but at the end of the day, the base [of this crop] is here. We need this diversity to cope with the unpredictable.... The climate changes, new plant diseases and pests continue to evolve. Diseases we thought we had controlled come back. We don't know what's going to happen in the future, and so we need to keep our options open. And this," says Bellon, in the middle of a Oaxacan cornfield, "is what keeps our options open."

The villagers in Capulalpan had no idea what genetic engineering was until they found the errant genes in their fields. Genetic engineering involves introducing genes from a separate organism into corn -- or any of a number of other food crops -- in order to express a desired trait. Olga Maldonado, the first villager in Capulalpan to discover transgenic elements in her corn, found the very concept bewildering. "Maybe it comes from some other plant," she said, "or animal -- it has another ingredient that's different from corn."

Americans, too, might be blindsided by such a revelation, even though most of us eat genetically engineered products practically every day. Walk through your local supermarket, and you'll find it in breakfast cereals, canned drinks, processed foods of every sort. Unless it's duly labeled, chances are anything with processed soy or corn has been genetically modified. The most popular sweetener today is not sugar, but corn syrup -- and most corn syrup is made from genetically modified corn. GE corn and soybeans are fed to animals, so it's in our beef, our pork, our chicken and our milk. Over the past five years, the products of genetic engineering have slipped almost unnoticed into the American food system. Though there is no hard evidence that these products are harmful to human health, foreign and domestic scientists and activists are questioning their long-term impact on the environment, whether their much-heralded benefits are actually coming true and whether the introduction of what is, in essence, a new living organism into the ecosystem can be so easily controlled. And now here these organisms were in Mexico -- which had banned the planting of genetically engineered crops four years ago. If the genetic traces could make their way all the way to tiny Capulalpan, where else are they going to go?

I am walking through Olga Maldonado's field in Capulalpan. A Zapotec Indian with a broad, weathered face, Olga now approaches her field, where her ancestors have farmed for centuries, with a new diffidence and uncertainty. "I only know that I am afraid," she says.

Her field is on a hillside over the town, with a sweeping view of the Sierra valleys below. The field itself is a patch of perhaps 200 plants; you can walk from one end to the other in about a minute. But it's enough to produce food for her, her husband and their young children for most of the year.

The problems surfaced when Olga first discerned that some of the corn in her field did not have the hardiness to which she was accustomed. Several others in the village were having similar problems: nothing devastating, just that their yields were off, and in an area where corn is central to the region's economic and cultural life, that registers as a significant event.

How could transgenic crops have made it into the fields in this remote location in Mexico? In Capulalpan, Olga herself remembers buying some corn from the local store, where imported kernels are sold by the crate (and are, legally, only supposed to be ground up for food). She didn't know about the government ban on planting, and she figured she'd try some of it out in her fields. "I planted that corn out of curiosity," she says. "I bought it at the government store and planted it to see if it was better than ours. And because there was more corn in each plant."

But later, when the corn had problems maturing, she had her plants tested at a small laboratory located on the cusp of a hillside overlooking the Sierra valley, in the town of La Trinidad. There, the UC Berkeley microbiologist Ignacio Chapela had helped to establish a genetic testing facility as part of a successful effort to demonstrate to Japanese buyers that the large, brimmed fungi that grow wild at the foot of the trees in the surrounding forest and look like shiitake mushrooms actually are shiitake mushrooms. Every month traders make the trek to Capulalpan to purchase mushrooms, which are flown express to Japan, providing much-needed cash to the community. This time, however, the lab discovered something it didn't want: Within the genome of Olga's corn kernels -- varieties that have grown here for centuries -- was, suddenly, evidence of genetic manipulation. The lab ultimately found that fifteen of the twenty-two corn samples it tested from the surrounding mountain communities also had traces of transgenes.

Genetic engineering has transformed American agriculture: In just six years, 34 percent of our corn, 75 percent of our soy, 70 percent of our cotton and 15 percent of our canola is genetically engineered. Genetically engineered potatoes, tomatoes and wheat are also headed toward mass production. The critical forces behind the development of the technology itself are just five companies -- Dow, DuPont, Syngenta, Aventis and Monsanto -- which control three out of every four patents issued over the past ten years for genetically modified crops. And fully 90 percent of the genetically modified seed technology planted around the world is either owned by or licensed by one company, Monsanto, according to the ETC Group (erosion, technology and concentration), a sustainable-agriculture NGO that has followed changes in the seed industry over the past two decades. According to an assessment by *Chemical and Engineering News*, just two companies -- DuPont (owner of Pioneer and other smaller seed companies) and Monsanto -- control nearly three-quarters of the US corn-seed market. These companies are now anxious to export the rapid advances the technology has made across America.

But the very idea of manipulating the genetic structure of a living organism has caused unease around the world. While I and a production crew from the PBS newsmagazine show *NOW With Bill Moyers* (which aired a version of this story on October 4) were visiting Olga Maldonado in Mexico last summer, half a world away, two southern African countries, Zambia and Zimbabwe, were refusing to accept American donations of genetically engineered corn to help them contend with a food crisis that was sending tens of thousands of people into starvation. The European Union was facing down a possible US challenge at the World Trade Organization over European restrictions on imports of genetically engineered food. In countries as far afield as France, India and New Zealand, the new technology was sparking anti-American demonstrations. The release of genetically modified

organisms (GMOs) into the environment would later emerge as one of the most contentious issues to be discussed at the Earth Summit in Johannesburg, South Africa. Altogether, more than thirty countries have imposed either a total ban or heavy restrictions on GMO imports from the United States.

The news from Mexico stoked fears around the world that genetic engineering is out of control. While Ignacio Chapela and his graduate student David Quist's discovery ignited a firestorm of controversy by scientists who criticized their work, in August a study commissioned by Mexico's National Institute of Ecology confirmed their findings: Transgenic corn genes were in Oaxacan corn. "What is most important about these findings," Exequiel Ezcurra, president of the institute, told the newspaper *La Jornada*, "is that transgenic creations move quickly into the environment and that it's time to reconsider ways of insuring our bio-security."

Nobody knows for sure what precise variety of transgenes wound up in Capulalpan corn. Dr. Norman Ellstrand, professor of genetics at the University of California, Riverside, and one of the country's foremost experts on corn genetics, says that the corn in Capulalpan could contain any number of characteristics that have been engineered into American corn. Since corn is openly pollinated, he explains, pollen from one plant can blow or be transported in some other way to fertilize another plant. "And if just 1 percent of [American] experimental pollen escaped into Mexico, that means those land races could potentially be making medicines or industrial chemicals or things that are not so good for people to eat. Right now, we just don't know what's in there."

Chances are good, however, according to Ellstrand, that the genes are from Bt corn, a popular US corn variety genetically engineered to produce its own toxins against a pest known as the European corn borer. The borer presents a sporadically serious threat to US and European cornfields but is rare in Mexico. Ellstrand says there would likely be no immediate damaging effects from the presence of Bt corn in Mexico, but what frightens him is how much we don't know: This year, he is researching how long transgenes will persist in native varieties -- whether, in fact, they can ever be bred out of the population. This is a question that until now has not even been studied.

At least for the foreseeable future, then, here in the heart of the world's reservoir for genetic diversity of corn will be transgenes developed for the vast rolling flatlands of American corn country -- where, in just six years, Bt corn has moved from laboratory petri dishes into one of every five acres of cornfield.

Frank McLain shifts the gears on his 1982 pickup as we drive through his family's cornfields in central Iowa. This land has been in his family for five generations, since it was homesteaded in 1862. "What they passed on to me is the feeling that this land is not just a hunk of dirt that you use and sell," he says, "that a piece of ground is something that should be kept for the next generation; that you're just a steward and you're not just to use it as a tool or as a doormat."

Frank is the first in his family to plant transgenic crops. On the left side of the road, we're passing a field of Bt corn; on the right, Roundup Ready soybeans. Monsanto's Bt corn contains a gene inserted from a bacteria that prompts the plant to produce its own insecticide; when the corn borer eats it, the plant's toxins go to work in its digestive tract, literally blowing up its stomach. It means that Frank has cut in half the amount of pesticides he used to have to apply to his corn. And Monsanto's Roundup Ready soybean seeds have been genetically altered -- using a gene from a bacterium -- in a way that enables them to resist the application of Monsanto's own herbicide, Roundup. "When I was a kid you'd see grass or other weeds poking up in these fields, and we'd have to go through and chop them out with hoes or shovels or whatever to clean them up manually or mechanically as best we could," Frank explains. "Now it's pretty easy to come in here with a [Roundup] sprayer and accomplish the same thing."

Frank's experience with genetic engineering illustrates both the allure and the potential dangers of the new technology. For many American farmers, genetically engineered crops offer a level of predictability in a business that can rise or fall with a few degrees Fahrenheit each season.

Twenty years ago I visited Frank and his father, Fred, while reporting a story on the American seed industry. At the time, the industry was undergoing rapid consolidation as regionally based seed companies were being bought out by large multinational pesticide and pharmaceutical companies. Hundreds of locally bred seed varieties were being phased out in favor of hybrids that could be grown in broad swaths of land across America.

I talked with the McLains then about what effect this consolidation would have on genetic diversity. They had lived through the infamous corn blight of 1970, a year in which 15 percent of the US corn crop was devastated by a blight that attacked a single hybridized corn variety that had been planted in one out of four acres from Florida to the Midwest. Meat prices shot up that year, as most of the lost corn was being grown as cattle feed. The reason for the blight was subsequently identified by the National Academy of Sciences as genetic uniformity: Corn seed across the country was, the academy reported, "as alike as identical twins." Fred told me how he watched as his plants became black and shriveled under the corrosive effects of the blight. When scientists quickly raced another slew of corn varieties onto the market for the following season, they relied on genetic material contained in traditional corn varieties, whose roots could be traced back to those land races around Oaxaca.

I hadn't seen the McLains since the summer of 1982, except once the following year, during a cross-country trip when Fred and his wife, Donnie, graciously laid out a lunch for me when I pulled into their farm, located just off Highway 30. At the time, Monsanto had just announced the creation of the first transgenic plant, launching the technology that would later evolve into full-scale genetic engineering. Few understood what that would mean.

Today, Fred has retired, and Frank, 50, is running the farm. I have a vivid memory of when I last saw Frank, sitting with him in a cramped tractor cab listening to the Rolling Stones' *Exile on Main Street* at full volume as we churned fertilizer into the soil. Now, on a sweltering July day, we're rumbling along the dirt road past those same fields, past acre upon acre of corn plants of identical height, a perfect crop. Frank points out the window of his

pickup to a field of seed corn almost five feet high. In addition to his fields of Bt feed corn, he is growing experimental seed for Monsanto, the nation's largest producer of genetically engineered crops. "They're wanting to see how it will do maybe one last time before putting it out in large acreage," he says. Growing the experimental seed pays a premium and insulates him from the rollicking prices of commodity feed corn, enabling him to make a comfortable living from farming -- an increasing rarity for American family farmers.

Frank, like many American family farmers, is struggling to keep the farm afloat in an era when hundreds of farms a month are thrown into bankruptcy by the twin forces of low commodity prices and the rising cost of inputs, like seed and agricultural chemicals. He needs to obtain an ever-rising production from his 1,400 acres just to stay alive as a farmer. Through careful tailoring, the new crops shrink, by at least a bit, the immense workload involved in running a family farm, and add, at least a bit, to the reliability of being able to make a livelihood off the land.

But like most farmers, he is now deeply dependent on the multinational agribusiness enterprises that dominate the US food production system. To grow transgenic seeds, Frank has to agree to Monsanto's conditions. Every year Frank signs a contract with Monsanto for its patented Bt corn and Roundup Ready soy, agreeing not to replant it the following season -- which means Monsanto gets to resell it to him the following year. Frank sees himself as entrenched on the conveyor belt of American industrial agriculture. "My job," he says, "is the production end of this assembly line. We're just a small little cog in the wheel.... What we're concerned with is production agriculture. To most of us that means our five or ten miles that we were born and raised and will probably die in."

But whether he likes to think about it or not, Frank's fate is entwined with that of Olga Maldonado and other farmers like her. Indeed, it's even possible, among infinite possibilities, that Frank is growing the same type of corn that surfaced in Capulalpan. Ultimately, it is questions of control and predictability that lie at the heart of the controversy over genetically modified crops. In the farmer's fields, it is a question of control over corn's free-floating means of insemination -- those tassels you see feathering the air in corn country are like a plant's version of a peacock's tail, there to produce and release "male" pollen to be carried to the "female" silks. And inside the corn plant itself is the issue of whether genetic manipulations might have unforeseen effects. These are questions that bedevil even the scientists who are engineering the changes.

Some twenty miles from Frank McLain's farm, in Ames, the Iowa State University campus spreads out amid leafy oak trees and pleasant, low-slung buildings. The university hosts one of the nation's leading plant-science research institutions for agricultural biotechnology.

Dr. Mike Lee, a plant biologist, is in the agronomy department's plant-transformation center doing genetic engineering. Lee is at work on a research project to increase the nutritional value of corn by inserting the most nutritious part of a hog -- the gene for hog's milk -- into a corn embryo. A lab technician has inserted a petri dish of corn embryos onto the lower shelf of what Lee calls "the gene gun" -- a critical tool of today's genetic engineers, actually a rectangular box made from thick plastic. On the top shelf the technician places a petri dish containing genetic information from a female hog's milk onto a thin layer of gold pellets -- which serve as the "bullets." She flicks a switch, and as a meter measuring air pressure per

square inch marches quickly upward, there's a notable "pop": The bullet is fired. Lee explains:

"You just accelerate those particles inside that chamber at a very high speed. High enough so that it can crash through the cell walls, get into the nucleus and then somehow, by a process that is not completely understood, the DNA that's coating those gold particles gets integrated into the corn chromosomes. They'll start to form roots and shoots and a new plant emerges, hopefully a plant that carries those genes now in their chromosomes." This is genetic engineering in action, mixing the genetic material from two organisms that would never ordinarily mix in nature. It's been done with flounder genes in strawberries, mice genes in potatoes, cow genes in sugarcane and soy, chicken genes in corn. And now, as Lee explains, he hopes to increase the nutritional value of corn with genes from hog's milk.

For Mike Lee, like many other scientists, this technology has huge potential to increase yields, make food more nutritious, and develop new varieties of crops that are better adapted to climatic and pest conditions that threaten food production. "That's why I got into this business," Lee says, "to create new versions of existing plant species that are just a little bit more beneficial to the needs and wants of society."

Lee has a scientist's natural curiosity and excitement about the new technology, but he is also willing to acknowledge that considerable uncertainties accompany it. "We're not just changing carburetors on cars or parts on a machine," he says. "When you introduce a new DNA sequence into a chromosome it has a new function for the plant. Well, that function doesn't operate in a vacuum. It operates in the context of a complex organism growing in a complex dynamic environment."

It is those uncertainties that provoke ire among critics, aghast at the hubris of genetic manipulation. More to the point, perhaps, is the fact that people like Mike Lee are not the ones driving the development of this technology. Public universities are significantly outgunned in resources by private research labs, which are looking, increasingly, for blockbuster products to be used where they have the biggest markets; even the gene gun used by Dr. Lee is available through an annual leasing arrangement from DuPont, which owns the patent on the technology. Lee's public-spirited ambitions for the technology, and his willingness to entertain doubts while forging ahead with his research in the controlled environment of a publicly funded laboratory, are an anomaly in an arena dominated by a handful of corporations.

The reality is that agricultural biotechnology has little to do with idealism, and far more with the financial imperatives of the biotechnology industry. "If you ask why these are the technologies that are on the market," says Dr. Chuck Benbrook, former executive director of the Board on Agriculture of the National Academy of Sciences, "the reason is that the companies that had invested so heavily in the technology and in buying up the seed industry had to have product on the market."

Monsanto alone poured at least a billion dollars into biotech research, according to NPR technology correspondent Daniel Charles in his book *Lords of the Harvest*, "before it had a single genetically engineered plant to sell." Other companies -- DuPont, Dow, Aventis and Syngenta -- spent billions more on research and on a seed-company buying spree that lasted

well into the 1990s. The stakes for these companies are huge.

Few studies assessing the long-term impact of genetically engineered products on the environment or human health were conducted before they were rushed into mass production. As Benbrook explains, "Promoters of the technology and certainly the federal government in the early 1990s embraced biotechnology so enthusiastically that there was just no patience, no interest in, no serious investigation of those potential problems. It was sort of a don't look, don't see policy. As a result, there really was no serious science done in the United States for most of the 1990s on the potential risks of biotechnology."

Those risks, as documented by scientists writing in the *American Journal of Botany* and the *International Journal of Food Science and Technology*, and at the Weed Science Society of America, the British Environment Ministry and the Pasteur Institute in Paris, include the emergence of potential allergens that could trigger reactions in humans; the rising resistance rates of pests to the Bt toxin; the persistence of Bt toxins in sediment, threatening nontarget insect populations; lingering residues from Roundup Ready herbicides left behind in the soil, which could injure subsequent seasons of crops; and the crossing of new genes into wild relatives. Unintended environmental consequences are surfacing around the world. In Canada, Bt toxins produced by Bt corn were discovered in the sediment of the St. Lawrence River -- which could potentially affect the river soil and marine life. In Switzerland a scientist demonstrated that in Bt corn the "lignin" content -- the material that keeps the stalk erect -- is tougher than in non-GE varieties, a physiological change with as-yet-unknown consequences. According to an assessment by the US Department of Agriculture's own Economic Research Service last spring, yields from GE crops are no higher than yields from conventional crops, and are already starting to decline -- largely because of the extra energy it takes the plant to produce its own insecticide.

Even the industry's spokesman in Washington, Dr. Mike Phillips, executive director of the food and agriculture department of the industry trade group BIO, concedes that industry studies have only followed the trajectory of impact of genetically engineered organisms "for eight or nine generations." That's not a lot of time in evolutionary terms. But once a transgenic crop is introduced, the evolutionary dynamics of living organisms insure that ripple effects will continue for hundreds of years -- in fact, they're virtually unstoppable once loose in the environment.

Ten years ago the government's position toward the new technology was expressed by then-Vice President Dan Quayle, who declared that no new "unnecessary regulation" was needed to oversee the genetic engineering of food crops. Genetically engineered crops were, as was later enunciated by USDA policy, not "significantly different" from previously existing means of breeding new types of plants. That principle has provided the foundation of the government's position ever since.

The result has been inattention to potential risks and sporadic regulation by the government. The USDA apportioned just $1.6 million out of a $250 million budget for all biotech-related programs to inquire into risk assessment. (By statute, just 1 percent of the total USDA research budget on agricultural biotechnology is allocated to risk assessments. Ohio Congressman Dennis Kucinich fought the biotech industry last spring and succeeded in raising that figure to 2 percent, which will double the budget for USDA risk assessments

next year.)

The USDA issues use permits for experimental trials of new genetic varieties of crops, but once they enter commercial production, the agency has no mandate to oversee them. For ten years, the FDA has engaged in what it calls "voluntary safety consultations" with biotech companies, reviewing safety data supplied by the companies; not once over the past ten years has it refused to permit development of new GE crop varieties to move forward.

The Environmental Protection Agency has responsibility for any new variety producing its own insecticide -- which the Bt gene does for corn, cotton and potatoes. But it relies on the companies to submit studies as to the potential for environmental harm; nor is it required by law to do follow-up inspections or independent monitoring. In August of last year, top officials from each of the EPA's ten regional offices sent an internal memorandum to their superiors in Washington expressing concern about the agency's lack of regulatory authority. A year later the agency still has no rules supporting long-term monitoring of these crops in the field. According to the EPA website, twenty "Experimental or Conditional Use" permits were granted for trial runs of new varieties of Bt corn between November 1998 and June 2002. Not one had been inspected until this past August, when officials from the EPA's Region IX office decided to pay a visit to two experimental plots of Bt corn being grown by Dow Chemical's Mycogen seed division and DuPont's seed subsidiary Pioneer in Hawaii. Both were found to be in violation, and on August 5 were cited for defying requirements intended to protect surrounding fields from the drift of genetically altered pollen from its experimental plots.

Michael Hanson, who follows genetic engineering for the Consumers Union, says that while there are abundant regulations governing the technology on paper, in reality "the lack of legal authority to pursue independent investigations, to do follow-up on producer assertions or to conduct independent assessments of safety claims means that in practice, the biotech industry has been given a free ride."

Lax regulation, however, is only part of the story. The industry received its most important historical spur from Congress, which passed the Plant Variety Protection Act in 1980, giving patentlike, proprietary protection to the developers of new plant varieties. These protections made the seed industry an attractive investment for chemical and pharmaceutical companies. And genetic engineering made patent protection far simpler to enforce; by inserting genetic "markers" alongside the new genes, the proprietary genes inside the plant become clearly identifiable. If Frank McLain, for example, were to defy his agreement with Monsanto and replant the seed he purchases from them every year, the company would be able to tell that its gene was inside his plants. Thus, genetic engineering also serves as a sort of branding mechanism -- the brand is imprinted in the very biology of the plant -- strengthening the proprietary hold of corporate patent-holders over their creations, and giving them an ever-tighter grip on the farmer.

A hundred miles east of the McLain farm, Laura Krause is standing amid her fields of corn, which sway with a refreshing summer breeze. Krause is one of Iowa's 500 organic farmers. Wearing a straw hat, with a sun-reddened face and lively eyes, Krause appears the very icon

of the American farmer from the last century. Her farm is tiny; she farms a hundred acres of corn, broccoli, potatoes, kale and carrots, all of them certified organic.

Krause's cornfield varies wildly, with plants from four feet to others over six feet tall, a notable contrast from most of the corn in Iowa, which seems to spread for miles in tight walls of plants of identical height. Her field crackles with insects, and birds swooping in and out to eat them. Krause bought the farm here ten years ago, and has kept growing her home-grown seed, a variety developed by the owner of this land a century ago, by replanting it every year. She sells the seed to other organic farmers.

But not this year. In February, she sent her seed to a local lab for routine tests: Because she's certified organic, her customers want to know if there are transgenes in her corn. And sure enough, she discovered that genetically modified genes were in there. The test didn't tell her which variety they were, but she says they were most likely from Yield Guard, Monsanto's variety of Bt corn, which is widely grown in her area of Iowa. She lost her certification, and the price she received for her corn dropped by half -- from $3.50 a bushel to $1.75 a bushel.

Now, like Olga Maldonado in Oaxaca, Laura Krause has transgenes in her corn whether she wants them or not. "There's no way for me to go into that field and look for the plants that contain the transgenes and deselect them," Krause says. "There's no way for me to sort them out, because they all look exactly alike. I can't get my business back, because I don't have any way to remove this gene from this [corn] population."

How did it get there? Corn pollen containing the transgene could have come from the local combine operator, who is supposed to clean out his machinery before visiting organic farms, or -- most likely, she thinks -- it came from pollen that blew in from a neighbor's field. All it takes is a handful of loose pollen to land on one of her silks, and transgenes enter the genetic mix.

But Krause does not want to sue her neighbor. Besides, corn pollen is known to travel as far as six miles by the wind, so it could have come from anywhere within striking distance in this corn-filled corner of the state. And there is as yet no legal precedent establishing liability for the financial damage caused by genetically engineered crops. Ron Rosmann, president of the board of the Organic Farming Research Foundation, whose own cornfields in southern Iowa were contaminated with Bt genes, says that cases like Krause's are only going to increase "as they release more and more genetically engineered seeds.... What we're unfortunately coming to is that zero contamination for corn is impossible." Organic farmers in Nebraska, Minnesota and elsewhere in Iowa, Rosmann says, have also experienced contamination similar to that on Laura Krause's farm.

Companies retain the legal right to enforce their patent-holder prerogatives over unlicensed use of their seed. And if their pollen happens to escape and fertilize crops in another field such as Krause's, there is no legal means for farmers to enforce the purity of their own varieties. Laura Krause, and thousands of farmers like her, are finding themselves in a legal black hole.

In response, a group of farmers in Iowa has crafted a state bill that would establish an indemnity fund to be paid out in instances of GE contamination with the hope that the bill

will be introduced in this coming legislative session. In Congress, Kucinich has introduced a bill that would establish firm lines of liability for the companies that produce the "contaminating" seed, but at this stage it has little chance of passing. And next month, state residents in Oregon will be voting on an initiative that would require labeling of all foods containing GE ingredients.

As for Mexico, the biotech industry itself no longer even disputes Chapela's assertions that transgenic corn made its way over that "ironclad wall" into Oaxaca. Rather, according to Dr. Phillips of BIO, the fact that GE crops are in Mexico's soil now, despite the government planting ban, should be an invitation to let more in. "If you're the government of Mexico," he says, "hopefully you've learned a lesson here and that is that it's very difficult to keep a new technology from entering your borders, particularly in a biological system.... It really is incumbent upon the Mexican government to step up the process and get their regulatory system in place so that [they] can begin accepting these products and give farmers the opportunity to choose."

American farmers, both those growing organic and non-GMO conventional corn, have paid a heavy price for the porousness of that "biological system." The American Corn Growers Association, representing corn producers in twenty-eight states, estimates that US corn farmers have lost more than $814 million in foreign sales over the past five years as a result of restrictions on genetically modified food imports imposed by Europe, Japan and other world buyers. That enormous figure doesn't even account for the depressed prices farmers now receive for their corn as a result of an oversupply (of unexported corn) on the domestic market -- with a deleterious effect on farmers' livelihood that the recent farm bill attempts to address with up to $20 billion in subsidies. For every American taxpayer, that amounts to a personal subsidy to the agricultural biotech industry.

Defying evolution by customizing traits that would never appear in nature holds out the dream of new markets -- and premium prices -- in the evergreen enterprise of food production. But the dream, even according to the USDA's own assessments, is turning sour. While promoting agricultural biotechnology with one hand, the department's Economic Research Service is reporting, with the other, that not only are yields not coming anywhere near expectations, but that genetically engineered corn and soybeans have not meant an overall improvement in the financial status of farmers.

Still, the horizons of agricultural biotechnology continue to expand. I am driving in a van with Dr. Kan Wang, an agronomist at Iowa State University in Ames. We turn off a country lane onto a dirt road and into the woods. A student of Dr. Wang's unlocks a gate, and we continue driving on the dirt road through the woods until we reach an extraordinary sight: a tiny cornfield, set amid a large soybean field, in the middle of the woods. This is where the next generation of genetic engineering is unfolding: Dr. Wang is conducting research into the development of vaccines in corn.

In the field a hundred or so corn plants are surrounded by an electric fence. Each tassel is capped by a brown paper bag, what Wang jokingly refers to as a "corn condom." I am here to witness corn sex, or, really, safe sex for corn. The reason? Wang is experimenting with a vaccine in this corn that will prevent diarrhea in baby pigs: When pigs eat the corn, she wants them to be immunized against a disease that is costing hog farmers millions of dollars

in losses each year. And they don't want the corn pollen flowing anywhere they don't want it to go; nor do they want any outside pollen fertilizing these special plants. Thus the corn condoms. Right now, Wang is testing the corn to insure that it's not also developing potential allergens for the pigs. And if it works for pigs, says Wang, "it could work for humans too."

This is the future of agricultural biotechnology. One might have some measure of confidence with the prospect of corn vaccines in the hands of Dr. Wang, the only scientist in the country working exclusively with public funding to explore the possibilities -- and risks -- of breeding medicines into corn. She has taken extreme precautions with this field: It is miles away from any neighboring corn, and is surrounded by soybeans and woods, with which corn has no chance of cross-pollinating.

But Dr. Ellstrand, the plant geneticist, fears what might happen when the pharmaceutical industry, which is now testing corn as a vehicle for antibiotics and vaccines, starts putting such medicines into mass production. "Corn produces a lot of pollen," he says. "And once there's a little bit of contamination, there's the potential for releasing pharmaceutical corn genes into food crops."

Thus far, the record has not been reassuring. Farmers like Laura Krause and Olga Maldonado have already, through the various routes that a living organism may travel, been the recipients of unwanted transgenes propelled beyond the barriers of control.

Standing in his Berkeley, California, greenhouse, Ignacio Chapela, the scientist who ignited the controversy in Mexico, comments: "The genie is out of the bottle. What we are confronted with now is just thousands of very different genies that are still in their bottles, and the question is this: Do we want to keep those bottles closed or are we opening them?"