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The Emperor's New Crops

by Brian Halweil

WORLDWATCH INSTITUTE

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To its proponents, agricultural biotechnology is the way to reconcile ecological health with the food demand of the world's 6 billion people—and the billions yet to come. But it's hard to find that vision in the industry's first products.

by Brian Halweil

It's June 1998 and Robert Shapiro, CEO of Monsanto Corporation, is delivering a keynote speech at "BIO 98," the annual meeting of the Biotechnology Industry Organization. "Somehow," he says, "we're going to have to figure out how to meet a demand for a doubling of the world's food supply, when it's impossible to conceive of a doubling of the world's acreage under cultivation. And it is impossible, indeed, even to conceive of increases in productivity—using current technologies—that don't produce major issues for the sustainability of agriculture."

Those "major issues" preoccupy a growing number of economists, environmentalists, and other analysts concerned with agriculture. Given the widespread erosion of topsoil, the continued loss of genetic variety in the major crop species, the uncertain effects of long-term agrochemical use, and the chronic hunger that now haunts nearly 1 billion people, it would seem that a major paradigm shift in agriculture is long overdue. Yet Shapiro was anything but gloomy. Noting "the sense of excitement, energy, and confidence" that engulfed the room, he argued that "biotechnology represents a potentially sustainable solution to the issue of feeding people."

To its proponents, biotech is the key to that new agricultural paradigm. They envision crops genetically engineered to tolerate dry, low-nutrient, or salty soils—allowing some of the world's most degraded farmland to flourish once again. Crops that produce their own pesticides would reduce the need for toxic chemicals, and engineering for better nutrition would help the overfed as well as the hungry. In industry gatherings, biotech appears as some rare hybrid between corporate mega-opportunity and international social program.

The roots of this new paradigm were put down nearly 50 years ago, when James Watson and Francis Crick defined the structure of DNA, the giant molecule that makes up a cell's chromosomes. Once the structure of the genetic code was understood, researchers began looking for ways to isolate little snippets of DNA—particular genes—and manipulate them in various ways. In 1973, scientists managed to paste a gene from one microbe into another microbe of a different species; the result was the first artificial transfer of genetic information across the species boundary. In the early 1980s, several research teams—including one at Monsanto, then a multinational pesticide company—succeeded in splicing a bacterium gene into a petunia. The first "transgenic" plant was born.

Such plants represented a quantum leap in crop breeding: the fact that a plant could not interbreed with a bacterium was no longer an obstacle to using the microbe's genes in crop design. Theoretically, at least, the world's entire store of genetic wealth became available to plant breeders, and the biotech labs were quick to test the new possibilities. Among the early creations was a tomato armed with a flounder gene to enhance frost resistance and with a rebuilt tomato gene to retard spoilage. A variety of the oilseed crop known as rape or canola was outfitted with a gene from the California Bay tree to alter the composition of its oil. A potato was endowed with bacterial resistance from a chicken gene.

Transgenic crops are no longer just a laboratory phenomenon. Since 1986, 25,000 transgenic field trials have been conducted worldwide—a full 10,000 of these just in the last two years. More than 60 different crops—ranging from corn to strawberries, from apples to potatoes—have been engineered. From 2 million hectares in 1996, the global area planted in transgenics jumped to 27.8 million hectares in 1998. That's nearly a fifteenfold increase in just two years.

In 1992, China planted out a tobacco variety engineered to resist viruses and became the first nation to grow transgenic crops for commercial use. Farmers in the United States sowed their first commercial crop in 1994; their counterparts in Argentina, Australia, Canada, and Mexico followed suit in 1996. By 1998, nine nations were growing transgenics for market and that number is expected to reach 20 to 25 by 2000.

Ag biotech is now a global phenomenon, but it remains powerfully concentrated in several ways:

In terms of where transgenics are planted. Three-quarters of transgenic cropland is in the United States. More than a third of the U.S. soybean crop last year was transgenic, as was nearly one-quarter of the corn and one-fifth of the cotton. The only other countries with a substantial transgenic harvest are Argentina and Canada: over half of the 1998 Argentine soybean crop was transgenic, as was over half of the Canadian canola crop. (See table, page 23.) These three nations account for 99 percent of global transgenic crop area. (Most countries have been slow to adopt transgenics because of public concern over possible risks to ecological and human health.)

In terms of which crops are in production. While many crops have been engineered, only a very few are cultivated in appreciable quantities. Soybeans account for 52 percent of global transgenic area, corn for another 30 percent. Cotton—almost entirely on U.S. soil—and canola in Canada cover most of the rest.

In terms of which traits are in commercial use. Most of the transgenic harvest has been engineered for "input traits" intended to replace or accommodate the standard chemical "inputs" of large-scale agriculture, especially insecticides and herbicides. Worldwide, nearly 30 percent of transgenic cropland is planted in varieties designed to produce an insect-killing toxin, and almost all of the rest is in crops engineered to resist herbicides. (A crop's inability to tolerate exposure to a particular herbicide will obviously limit the use of that chemical.)

These two types of crops—the insecticidal and the herbicide-resistant varieties—are biotech's first large-scale commercial ventures. They provide the first real opportunity to test the industry's claims to be engineering a new agricultural paradigm.

The Bugs

The only insecticidal transgenics currently in commercial use are "Bt crops." Grown on nearly 8 million hectares worldwide in 1998, these plants have been equipped with a gene from the soil organism *Bacillus thuringiensis* (Bt), which produces a substance that is deadly to certain insects.

The idea behind Bt crops is to free conventional agriculture from the highly toxic synthetic pesticides that have defined pest control since World War II. Shapiro, for instance, speaks of Monsanto's Bt cotton as a way of substituting "information encoded in a gene in a cotton plant for airplanes flying over cotton fields and spraying toxic chemicals on them." (As with other high technologies, the substitution of information for stuff is a fundamental doctrine of biotech.) At least in the short term, Bt varieties have allowed farmers to cut their spraying of insecticide-intensive crops, like cotton and potato. In 1998, for instance, the typical Bt cotton grower in Mississippi sprayed only once for tobacco budworm and cotton bollworm—the insects targeted by Bt—while non-Bt growers averaged five sprayings.

Farmers are buying into this approach in a big way. Bt crops have had some of the highest adoption rates that the seed industry has ever seen for new

Global Transgenic Area, 1996–98

Country	1996	1997	1998	Share of global area, 1998
	(million hectares)			(percent)
United States	1.5	8.1	20.5	74
Argentina	0.1	1.4	4.3	15
Canada	0.1	1.3	2.8	10
Australia	<0.1	0.1	0.1	1
Mexico	<0.1	<0.1	0.1	1
Spain	–	–	<0.1	<1
France	–	–	<0.1	<1
South Africa	–	–	<0.1	<1
TOTAL	1.7	11.0	27.8	100

Note: China is not included because of uncertainty over the extent of area planted, but a rough estimate for 1998 is 1 million hectares.

SOURCE: Clive James, *Global Review of Commercialized Transgenic Crops: 1998* (Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications, 1998).

varieties. In the United States, just a few years after commercialization, nearly 25 percent of the corn crop and 20 percent of the cotton crop is Bt. In some counties in the southeastern states, the adoption rate of Bt cotton has reached 70 percent. The big draw for farmers is a lowering of production costs from reduced insecticide spraying, although the savings is partly offset by the more expensive seed. Some farmers also report that Bt crops are doing a better job of pest control than conventional spraying, although the crops must still be sprayed for pests that are unaffected by Bt. (Bt is toxic primarily to members of the Lepidoptera, the butterfly and moth family, and the Coleoptera, the beetle family.)

Unfortunately, there is a systemic problem in the background that will almost certainly erode these gains: pesticide resistance. Modern pest management tends to be very narrowly focused; the idea, essentially, is that when faced with a problematic pest, you should look for a chemical to kill it. The result has been a continual toughening of the pests, which has rendered successive generations of chemicals useless. After more than 50 years of this evolutionary rivalry, there is abundant evidence that pests of all sorts—insects, weeds, or pathogens—will develop resistance to just about any chemical that humans throw at them. (See graph, next page.)

The Bt transgenics basically just replace an insecticide that is sprayed on the crop with one that is packaged inside it. The technique may be more sophisticated but the strategy remains the same: aim the chemical at the pest. Some entomologists are predicting that, without comprehensive strategies to prevent it, pest resistance to Bt could appear in the field within three to five years of widespread use, rendering the crops ineffective. Widespread resistance to Bt would affect more than the transgenic crops, since Bt is also commonly used in conventional spraying. Farmers could find one of their most environmentally benign pesticides beginning to slip away.

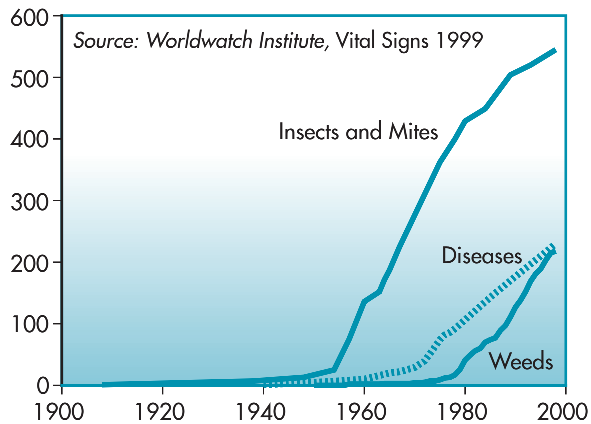
In one respect, Bt crops are a throwback to the early days of synthetic pesticides, when farmers were encouraged to spray even if their crops didn't appear to need it. The Bt crops show a similar lack of discrimination: they are programmed to churn out toxin during the entire growing season, regardless of the level of infestation. This sort of prophylactic control greatly increases the likelihood of resistance because it tends to maximize exposure to the toxin—it's the plant equivalent of treating antibiotics like vitamins.

Agricultural entomologists now generally agree that Bt crops will have to be managed in a way that discourages resistance if the effectiveness of Bt is to be maintained. In the United States, the Environmental Protection Agency, which regulates the use of pesticides, now requires producers of Bt crops to develop "resistance management plans." This is a new step for the EPA, which has never required analogous plans from manufacturers of conventional pesticides.

The usual form of resistance management involves the creation of "refugia"—areas planted in a crop variety that isn't armed with the Bt gene. If the refugia are large enough, then a substantial proportion of the target pest population will never encounter the Bt toxin, and will not be under any selection pressure to develop resistance to it. Interbreeding between the refugia insects and the insects in the Bt fields should stall the development of resistance in the population as a whole, assuming the resistance gene is recessive. (See illustration, page 27.)

The biotech companies themselves have been recommending that their customers plant refugia, although the recommendations generally fall short of what most resistance experts consider necessary. This is not surprising, of course, since there is an inherent inconsistency between the refugia idea and the inevitable interest on the part of the manufacturer in selling as much product as possible. An even greater obstacle may be the reactions of farmers themselves, since the refugia concept is counter-intuitive: farmers, who spend much of their lives trying to control pests, are being told that the best way to maintain a high yield is to leave substantial portions of their land vulnerable to pests. The impulse to plant smaller refugia—or to count someone else's land as part of one's own refugia—may prove irresistible. And the possibility of enforcing the planting of larger refugia seems remote, especially once Bt crops are deployed to hundreds of millions of small-scale farmers throughout the developing world. (Such a prospect is still remote in most developing countries, but small-scale use of Bt cotton is increasingly common in China.)

But the companies haven't put all their money on the refugia approach. According to Gary Barton, director of ag biotech communications at Monsanto, "products now in the pipeline which rely on different insecticidal toxins or multiple toxins could replace Bt crops in the event of widespread resistance." Every major company in the field is working on potential successors to Bt crops. And as is apparent from Barton's comment, the goal of such research is to engineer not just for toxins that could replace Bt, but for other toxins that kill pests unaffected by Bt. (Multiple-toxin crops are a primary industry objective; a case in point is the rush to develop a form of Bt corn that also resists corn rootworm.)



Reported Numbers of Pesticide-Resistant Species, 1908–98

The result, according to Fred Gould, an entomologist at the University of North Carolina, would be "a crop with a series of silver bullet pest solutions." And each of these solutions, in Gould's view, would be highly vulnerable to pest resistance. This scenario does not differ essentially from the current one: in place of a pesticide treadmill, we would substitute a sort of gene treadmill. The arms race between farmers and pests would continue, but would include an additional biochemical dimension. Transgenic plants, designed to secrete increasingly potent combinations of pesticides, would vie with a host of increasingly resistant pests.

The Weeds

The global transgenic harvest is currently dominated, not by Bt crops, but by herbicide-resistant crops (HRCs), which occupy 20 million hectares worldwide. HRCs are sold as part of a "technology package" comprised of HRC seed and the herbicide the crop is designed to resist. The two principal product lines are currently Monsanto's "Roundup Ready" crops—so-named because they tolerate Monsanto's best-selling herbicide, "Roundup" (glyphosate)—and AgrEvo's "Liberty Link" crops, which tolerate that company's "Liberty" herbicide (glufosinate).

It may sound contradictory, but one ostensible objective of HRCs is to reduce herbicide use. By designing crops that tolerate fairly high levels of exposure to a broad-spectrum herbicide (a chemical that is toxic to a wide range of plants), the companies are giving farmers the option of using a heavy, once-in-the-growing-season dousing with that herbicide, instead of the standard practice, which calls for a series of applications of several different compounds. It's not yet clear whether this new herbicide regime actually reduces the amount of material used, but its simplicity is attracting many farmers into the package.

Another potential benefit of HRCs is that they may allow for more "conservation tillage," farming techniques that reduce the need for plowing or even—under "no till" cultivation—eliminate it entirely. A primary reason for plowing is to break up the weeds, but because it exposes bare earth, plowing causes top soil erosion. Top soil is the capital upon which agriculture is built, so conserving soil is one of agriculture's primary responsibilities. In the U.S. soybean crop, the area under no-till has been increasing substantially and that increase correlates to some degree with the increasing use of Monsanto's Roundup Ready soybeans. But here too, the data are still vague: it's too early to say how much of the trend is due to the transgenic crop.

The bigger problem is that HRCs, like Bt crops, are really just an extension of the current pesticide paradigm. HRCs may permit a reduction in herbicide use over the short term, but obviously their widespread adoption would encourage herbicide dependency. In many parts of the developing world, where herbicides are not now common, the herbicide habit could mean substantial additional environmental stresses: herbicides are toxic to many soil organisms, they can pollute groundwater, and they may have long-term effects on both people and wildlife.

And of course, resistance will occur. Bob Hartzler, a weed scientist at Iowa State University, warns that if HRCs encourage reliance on just a few broad-spectrum herbicides, then resistance is likely to develop faster—and agriculture is likely to be more vulnerable to it. Hartzler cites an ad for Roundup Ready cotton, which displays a jug of Roundup and boasts, "The only weed control you need."

In the U.S. Midwest, heavy use of Roundup on Roundup Ready soybeans is already encouraging weed species, like waterhemp, that are naturally resistant to that herbicide. (As Roundup suppresses the susceptible weeds, the resistant ones have more room to grow.) Thus far, the evolution of resistance in weed species that are susceptible to Roundup has been relatively rare, despite decades of use. The first reported case involved wild ryegrass in Australia, in 1995. But with increasing use, more such cases are all but inevitable—especially since Monsanto is on the verge of releasing Roundup Ready corn. Corn and soybeans are the classic crop rotation in the U.S. Midwest—corn is planted in one year, soy in the next. Roundup Ready varieties of both crops could subject vast areas of the U.S. "breadbasket" to an unremitting rain of that herbicide. As with the Bt crops, the early promise of HRCs is liable to be undercut by the very mentality that inspired them: the single-minded chemical pursuit of the pest.

Transgenes on the Loose

In 1997, just one year after its first commercial planting in Canada, a farmer reported—and DNA testing confirmed—that Roundup Ready canola had cross-pollinated with a related weed species growing in the field's margins, and produced an herbicide-tolerant descendant. The gene for herbicide resistance had "escaped."

If a transgenic crop is capable of sexual reproduction (and they generally are), the leaking of "transgenes" is to some degree inevitable, if any close relatives are growing in the vicinity. This type of genetic pollution is not likely to be common in the industrialized countries, where most major crops have relatively few close relatives. But in the developing world—especially in regions where a major crop originated—the picture is very different. Such places are the "hot spots" of agricultural diversity: the cultivation of the ancient, traditional varieties—whether it's corn in Mexico or soybeans in China—often involves a subtle genetic interplay between cultivated forms of a species, wild forms, and related species that aren't cultivated at all. The possibilities for genetic pollution in such contexts are substantial.

Ordinary breeding creates some degree of genetic pollution too. But according to Allison Snow, an Ohio State University plant ecologist who studies transgene flow, biotech could amplify the process considerably because of the far more diverse array of genes it can press into service. Any traits that confer a substantial competitive advantage in the wild could be expected to spread widely. The Bt gene would presumably be an excellent candidate for this process, since its toxin affects so many insect species.

There's no way to predict what would happen if the Bt gene were to escape into a wild flora, but there's good reason to be concerned. John Losey, an entomologist at Cornell University, has been experimenting with Monarch butterflies, by raising their caterpillars on milkweed dusted with Bt-corn pollen. Losey found that nearly half of the insects raised on this fare died and the rest were stunted. (Caterpillars raised on milkweed dusted with ordinarily corn pollen did fine.) According to Losey, "these levels of mortality are comparable to those you find with especially toxic insecticides." If the gene were to work a change that dramatic in a wild plant's toxicity, then it could trigger a cascade of second- and third-order ecological effects. (See illustration, page 28.)

The potential for this kind of trouble is likely to grow, since a major interest in biotech product development is "trait-stacking"—combining several engineered genes in a single variety, as with the attempts to develop corn with multiple toxins. Monsanto's "stacked cotton"—Roundup Ready and Bt-producing—is already on the market in the United States. Eventually, a single crop could diffuse a wide array of potent genes into the wild.

In the agricultural hot spots, there is an important practical reason to be concerned about any resulting genetic pollution. Plant breeders depend on the genetic wealth of the hot spots to maintain the vigor of the major crops—and there's no realistic possibility of biotech rendering this natural wealth "obsolete." But it certainly is possible that foreign genes could upset the relationships between the local varieties and their wild relatives. How would that affect the entire genetic complex? There's probably no way to know until after the fact.

Toward a New Feudalism

The advent of transgenic crops raises serious social questions as well—beginning with ownership. All transgenic seed is patented, as are most nontransgenic commercial varieties. But beginning in the 1980s, the tendency in industrialized countries and in international law has been to permit increasingly broad agricultural patents—and not just on varieties but even on specific genes. Under the earlier, more limited patents, farmers could buy seed and use it in their own breeding; they could grow it out and save some of the resulting seed for the next year; they could even trade it for other seed. About the only thing they couldn't do was sell it outright. But under the broader patents, all of those activities are illegal; the purchaser is essentially just paying for one-time use of the germplasm.

The right to own genes is a relatively new phenomenon in world history and its effects on agriculture—and life in general—are still very uncertain. The biotech companies argue that ownership is essential for driving their industry: without exclusive rights to a product that costs hundreds of millions of dollars to develop, how will it be possible to attract investors? And some industry advocates see patents as a way of "investing" in biodiversity in general. Val Giddings of the Biotechnology Industry Organization makes this case: "intellectual property rights allow us to harness genetic resources for commercial use, making biodiversity concretely more valuable. One can make economic arguments for the conservation of biodiversity, whereas previously one could only make aesthetic or inherent value arguments."

Patents are clearly an important ingredient in the industry's expansion. Global sales of transgenic crop products grew from $75 million in 1995 to $1.5 billion in 1998—a 20-fold increase. Sales are expected to hit $25 billion by 2010. And as the market has expanded, so has the scramble for patents. Recently, for example, the German agrochemical firm AgrEvo, the maker of "Liberty" herbicide, bought a Dutch biotech company called Plant Genetic Systems (PGS), which owned numerous wheat and corn patents. The patents were so highly valued that AgrEvo was willing to pay $730 million for the acquisition—$700 million more than PGS's annual sales. A recent *Wall Street Journal* article reports that in U.S. patent litigation, only computer software continues to attract more cases than plants.

This patent frenzy is contributing to an intense wave of consolidation within the industry. AgrEvo, for example, is itself a subsidiary of another German chemical company, Hoechst. Hoechst recently merged with one of its French counterparts, Rhône-Poulenc, to form Aventis, which is now the world's largest agrochemical firm and a major player in the biotech industry. On the other side of the Atlantic, Monsanto has spent nearly $8 billion since 1996 to purchase various seed companies. DuPont, a major competitor, has bought the world's largest seed company, Pioneer Hi-Bred. DuPont and Monsanto were minor players in the seed industry just a decade ago, but are now respectively the largest and second-largest seed companies in the world.

Since 1996, the industry has seen $15 billion worth of mergers and acquisitions involving 25 corporations. Of the 56 transgenic products approved for commercial planting in 1998, 33 belonged to just four corporations: Monsanto, Aventis, Novartis, and DuPont. The first three of these companies control the transgenic seed market in the United States, which amounts to three-fourths of the global market. (Monsanto accounted for 88 percent of the U.S. transgenic area in 1998, while Aventis and Novartis split the remainder.)

Even when viewed purely in market terms, these trends may be working a kind of paradox within the young industry: the drive to secure research potential may be leading to less research. According to John Barton, an expert in biotech law at Stanford University Law School, "the incentives for the industry leaders to conduct research are now limited, for these leaders are now in an oligopolistic (and potentially monopolistic) situation." Less competition and innovation and more squabbling over patents—is this the future of ag biotech? One biotech company, Agracetus (recently acquired by Monsanto), has filed a patent that would cover *all* transgenic cotton and soybeans. In the face of such claims, it's not hard to imagine that the focus of industry research may be shifting from the lab to the law library.

But there is far more at stake here than the fortunes of the industry itself: patents and similar legal mechanisms may be giving companies additional control over farmers. As a way of securing their patent rights, biotech companies are requiring farmers to sign "seed contracts" when they purchase transgenic seed—a wholly new phenomenon in agriculture. The contracts may stipulate what brand of pesticides the farmer must use on the crop—a kind of legal cement for those crop-herbicide "technology packages." And the contracts generally forbid the types of activities that had been permitted under the earlier patent regimes.

The most troubling aspect of these contracts is the possible effect on seed saving—the ancient practice of reserving a certain amount of harvested seed for the next planting. In the developing world, some 1.4 billion farmers still rely almost exclusively on seed saving for their planting needs. As a widespread, low-tech form of breeding, seed saving is also critical to the husbandry of crop diversity, since farmers generally save seed from plants that have done best under local conditions. The contracts have little immediate relevance to seed saving in the developing world, since the practice there is employed largely by farmers who could not afford transgenic seed in the first place. But even in industrialized countries, seed saving is still common in certain areas and for certain crops, and Monsanto has already taken legal action against over 300 farmers for replanting proprietary seeds.

The struggle to enforce those broad patents is unlikely to stop with seed contracts—or to remain a First World concern. A recent invention—officially entitled the "gene protection technology" but popularly dubbed the "terminator technology"—may make the seed contracts a biological reality. The terminator prevents harvested seeds from germinating. Its principal inventor, a U.S. Department of Agriculture molecular biologist named Melvin Oliver, notes that "the technology primarily targets Second and Third World markets"—in effect guaranteeing patent rights even in nations where patent enforcement is weak or non-existent. The terminator may also encourage the patenting of some major crops, such as rice, wheat, and sorghum, that have generally been ignored by private-sector breeders. Although there has been a great deal of public sector development of these crops, it has been difficult for private companies to make money on them, because it is relatively easy for farmers to breed stable, productive varieties on their own. The terminator could allow companies to get a better "grip" on such crops.

NGOs focused on agriculture have tended to view the prospect of the terminator with alarm. "The terminator will increase crop uniformity by restricting seed-saving and breeding by farmers," says Neth Daño of the Philippines-based SEARICE, a rural development organization. In that sense, the terminator is just the latest variation on a well-established theme: at least since the 1970s, the developing world's highly diverse farm-saved varieties have been losing ground to a much smaller array of uniform commercial varieties. The substitution of commercial for farm-saved seed has been a primary reason for the loss of genetic diversity in the agricultural hot spots. Hope Shand, research director for the Rural Advancement Foundation International (RAFI), a farmer advocacy group based in Winnipeg, Canada, regards the extension of patents in general as a means of reducing farmers to "bioserfs," who provide little more than land and labor to agribusiness.

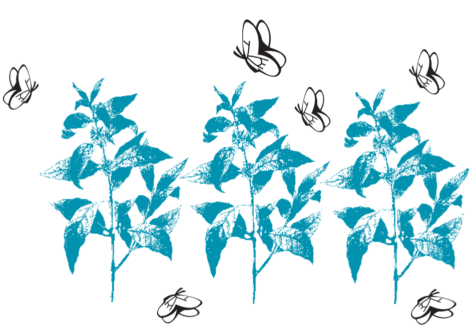
Although the terminator is still some five years from commercialization, it has already become a public relations disaster for the entire industry. Monsanto, which had recently acquired exclusive rights to the technology, has announced that it may reconsider its use. But research by RAFI has shown that virtually all the major companies—Monsanto, Novartis, Astra/Zeneca, DuPont, BASF, and Aventis—are working on seed sterility technology. Such technologies, according to Shand are "the Holy Grail of the agricultural biotechnology industry."

The terminator may be the harbinger of technologies that attempt to seal other aspects of farming within the seed. The suicidal terminator genes are activated by dousing the seed with the antibiotic tetracycline. (This external trigger is necessary because it would not otherwise be possible to grow the seeds out for sale.) The development of such trigger mechanisms may ultimately be of far greater consequence than the terminator itself. Novartis was recently awarded a patent for a gene technology that would tie a whole set of plant development processes, including germination, flowering, and fruit ripening, to externally applied chemicals—perhaps even to Novartis' own agrochemicals.

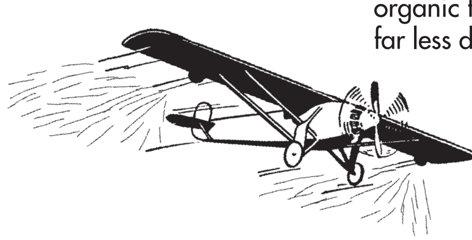
But beyond these control issues, there remains the basic question of biotech's potential for feeding the world's billions. Here too, the current trends are not very encouraging. At present, the industry has funneled its immense pool of investment into a limited range of products for which there are large, secured markets within the capital-intensive production systems of the First World. There is very little connection between that kind of research and the lives of the world's hungry. HRCs, for example, are not helpful to poor farmers who rely on manual labor to pull weeds because they couldn't possibly afford herbicides. (The immediate opportunities for biotech in the developing world are not the subsistence farmers, of course,

Bt Crops: What's Supposed to Happen

1 A toxin-producing gene from *Bacillus thuringiensis* (Bt), a common soil bacterium, is spliced into the DNA of a crop variety.



2 Any pests that attempt to eat the Bt crop are poisoned.



Bt is already widely used as a conventional pesticide, especially by small-scale and organic farmers. It's generally considered far less dangerous than synthetic pesticides.

3 Substantial "refugia"—areas planted in a variety without the Bt gene—insure that much of the pest population won't be exposed to the Bt variety, making it much harder for the pest to evolve resistance to the toxin.

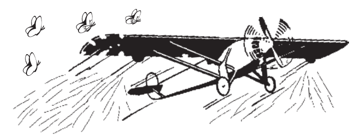
but the larger operations, which are often producing for export rather than for local consumption.)

Just to get a sense of proportion on this subject, consider this comparison. The entire annual budget of the Consultative Group for International Agricultural Research (CGIAR), a consortium of international research centers that form the world's largest public-sector crop breeding effort, amounts to $400 million. The amount that Monsanto spent to develop Roundup Ready soybeans alone is estimated at $500 million. In such numbers, one can see a kind of financial disconnect. Per Pinstrup-Andersen, director of the International Food Policy Research Institute, the CGIAR's policy arm, puts it flatly: "the private sector will not develop crops to solve poor people's problems, because there is not enough money in it." The very nature of their affliction—poverty—makes hungry people poor customers for expensive technologies.

In addition to the financial obstacle, there is a biological obstacle that may limit the role of biotech as agricultural savior. The crop traits that would be most useful to subsistence farmers tend to be very complex. Miguel Altieri, an entomologist at the University of California at Berkeley, identifies the kind of products that would make sense in a subsistence context: "crop varieties responsive to low levels of soil fertility, crops tolerant of saline or drought

Some Things that Could Happen

Farmers may not plant enough of their land in refugia and resistance could develop. The effectiveness of Bt, even as a conventional pesticide, would be compromised.

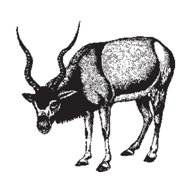


1. A more complex scenario could unfold in the tropics, where many crops have wild relatives with which they interbreed. That may allow the Bt gene to "escape" into related species. The wild Bt plants could become much less edible to the insects that normally feed on them and that do not normally feed on the crops. (Such insects, symbolized here by the gray butterfly, would not presumably have acquired resistance to Bt.)

2. The toxicity of the crop relatives could give them a competitive edge over other plants that grow in the same areas, since the insects would continue to feed on the other plants.

3. The Bt plants could suppress their competitors and the herbivorous insect population could decline.

4. Insect-eating birds could be in trouble. . .



. . . and so could grazers in need of the suppressed plant species.

conditions and other stresses of marginal lands, improved varieties that are not dependent on agrochemical inputs for increased yields, varieties that are compatible with small, diverse, capital-poor farm settings." In HRCs and Bt crops, the engineering involves the insertion of a single gene. Most of the traits Altieri is talking about are probably governed by many genes, and for the present at least, that kind of complexity is far beyond the technology's reach.

Beyond the Techno-Fix

In the 1970s, Hans Herren set out to deal with the cassava mealybug, which was decimating harvests of this staple crop throughout Africa. Herren was then an entomologist with the International Centre of Insect Physiology and Ecology, based in Nairobi, and is now the Center's director. He knew that cassava was feeding some of the poorest of Africa's poor, because cassava can be planted on dry, low-nutrient soils where little else will grow. This South American root crop had become an essential part of Africa's food security—a kind of social safety net. But the net had begun to fray rapidly after the arrival of the mealybug, a native predator of cassava in South America. Because the mealybug had arrived in Africa without any of its own natural predators, it was a much more serious pest there than on its native continent. So Herren orchestrated the introduction of a wasp that parasitizes the mealybug in its native range. (The wasp was chosen because of its high degree of prey specificity, minimizing the risk that it would attack anything else.) Seven years after the introduction, the mealybug had been virtually eliminated in most African nations, and remains so today. The latest accounting analysis has put the cost-to-benefit ratio of this "biological control" effort at 1:200—a very modest statement of the benefits, given cassava's role as a crop of last resort.

On a 300-acre farm in Boone, Iowa—the heart of the U.S. corn belt—Dick Thompson rotates corn, soybeans, oats, wheat interplanted with clover, and a hay combination that includes an assortment of grasses and legumes. The pests that plague neighboring farmers—including the corn borer targeted by Bt corn—are generally a minor part of the picture on Thompson's farm. High crop diversity tends to reduce insect populations because insect pests are usually "specialists" on one particular crop. In a very diverse setting, no single pest is likely to be able to get the upper hand. Diversity also tends to shut out weeds, because complex cropping uses resources more efficiently than monocultures, so there's less left over for the weeds to consume. Thompson also keeps the weeds down by grazing a herd of cattle—a rarity on midwestern corn farms. Even without herbicides, Thompson's farm has been on conservation tillage for the last three decades. The cattle, a hog operation, and the nitrogen-fixing legumes provide the soil nutrients that most U.S. farmers buy in a bag. The soil organic matter content—the sentinel indicator of soil health—registers at 6 percent on Thompson's land, which is more than twice that of his neighbors. (Untouched Midwestern prairie registers at 7 percent.) Thompson's soybean and corn yields are well above the county average and even as the U.S. government continues to bail out indebted farmers, Thompson is making money. He profits both from his healthy soil and crops, and from the fact that his "input" costs—for chemical fertilizer, pesticides, and so forth—are almost nil.

In the activities of people like Herren and Thompson it is possible to see a very different kind of agricultural paradigm, which could move farming beyond the techno-fix approach that currently prevails. Known as agroecology, this paradigm recognizes the farm as an ecosystem—an agroecosystem—and employs ecological principles to improve productivity and build stability. The emphasis is on adapting farm design and practice to the ecological processes actually occurring in the fields and in the landscape that surrounds them. Agroecology aims to substitute detailed (and usually local) ecological knowledge for off-the-shelf and off-the-farm "magic bullet" solutions. The point is to treat the disease, rather than just the symptoms. Instead of engineering a corn variety that is toxic to corn rootworm, for example, an agroecologist would ask why there's a rootworm problem in the first place.

Where would biotech fit within such a paradigm? In the industry's current form, at least, it doesn't appear to fit very well at all. Biotech's first agricultural products are "derivative technologies," to use a term favored by Frederick Buttel, a rural sociologist at the University of Wisconsin. Buttel sees those products as "grafted onto an established trajectory, rather than defining or crystallizing a new one."

There is no question that biotech contains some real potential for agriculture, for instance as a supplement to conventional breeding or as a means of studying crop pathogens. But if the industry continues to follow its current trajectory, then biotech's likely contribution will be marginal at best and at worst, given the additional dimensions of ecological and social unpredictability—who knows? In any case, the biggest hope for agriculture is not something biochemists are going to find in a test tube. The biggest opportunities will be found in what farmers already know, or in what they can readily discover on their farms.

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