The Environmental Risks of Transgenic Crops: An Agroecological Assessment

Is the failed pesticide paradigm being genetically engineered?

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Genetic engineering is an application of biotechnology involving the manipulation of DNA and the transfer of gene components between species in order to encourage replication of desired traits (OTA 1992). Although there are many applications of genetic engineering in agriculture, the current focus of biotechnology is on developing herbicide tolerant crops and on pest and disease resistant crops. Transnational corporations such as Monsanto, DuPont, Norvartis, etc., which are the main proponents of biotechnology, view transgenic crops as a way to reduce dependence on inputs such as pesticides and fertilizers. What is ironic is the fact that the biorevolution is being brought forward by the same interests that promoted the first wave of agrochemically-based agriculture. But this time, by equipping each crop with new "insecticidal genes," they are promising the world safer pesticides, reduction in chemically intensive farming and a more sustainable agriculture.

As long as transgenic crops follow closely the pesticide paradigm, such biotechnological products will do nothing but reinforce the pesticide treadmill in agroecosystems, thus legitimizing the concerns that many scientists have expressed regarding the possible environmental risks of genetically engineered organisms. The most serious ecological risks posed by the commercial-scale use of transgenic crops are (Rissler and Mellon 1996; Krimsky and Wrubel 1996):

- The spread of transgenic crops threatens crop genetic diversity by simplifying cropping systems and promoting genetic erosion;
- The potential transfer of genes from herbicide resistant crops (HRCs) to wild or semidomesticated relatives thus creating super weeds;
- HRC volunteers become weeds in subsequent crops;
- Vector-mediated horizontal gene transfer and recombination to create new pathogenic bacteria;
- Vector recombination to generate new virulent strains of virus, especially in transgenic plants engineered for viral resistance with viral genes;
- Insect pests will quickly develop resistance to crops with *Bacillus thuringiensis* (Bt) toxin;
- Massive use of Bt toxin in crops can unleash potential negative interactions affecting ecological processes and non-target organisms.

The above impacts of agricultural biotechnology are herein evaluated in the context of agroecological goals aimed at making agriculture more socially just, economically viable and ecologically sound (Altieri 1996). Such evaluation is timely, given that worldwide there have been over 1,500 approvals for field testing transgenic crops (the private sector has accounted for 87% of all field tests since 1987), despite the fact that in most countries stringent procedures are not in place to deal with environmental problems that may develop when engineered plants are released into the environment (Hruska and Lara Pavón 1997). A main concern is that international pressures to gain markets and profits is resulting in companies releasing transgenic crops too fast, without proper consideration for the long-term impacts on people or the ecosystem (Mander and Goldsmith 1996).

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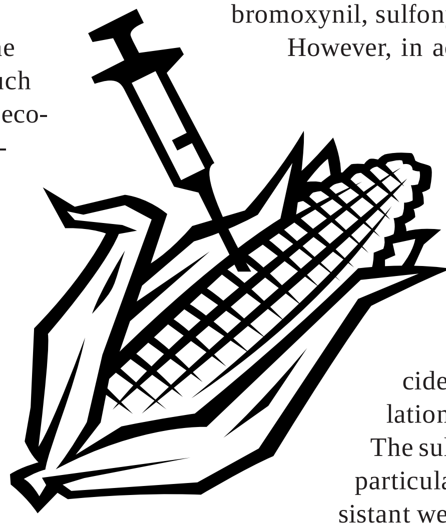
Actors and Research Directions

Most innovations in agricultural biotechnology are profit driven rather than need driven, therefore the thrust of the genetic engineering industry is not really to solve agricultural problems, but to create profitability. This statement is supported by the fact that at least 27 corporations have initiated herbicide tolerant plant research, including the world's eight largest pesticide companies Bayer, Ciba-Geigy, ICI, Rhone-Poulenc, Dow/Elanco, Monsanto, Hoescht and DuPont, and virtually all seed companies, many of which have been acquired by chemical companies (Gresshoft 1996).

In the industrialized countries from 1986-1992, 57% of all field trials to test transgenic crops involved herbicide tolerance and 46% of applicants to the U.S. Department of Agriculture (USDA) for field testing were chemical companies.

Crops currently targeted for genetically engineered tolerance to one or more herbicides includes: alfalfa, canola, cotton, corn, oats, petunia, potato, rice, sorghum, soybean, sugarbeet, sugar cane, sunflower, tobacco, tomato, wheat and others. It is clear that by creating crops resistant to its herbicides a company can expand markets for its patented chemicals. The market for HRCs has been estimated at more than $500 million by the year 2000 (Gresshoft 1996).

Although some testing is being conducted by universities and advanced research organizations, the research agenda of such institutions is being increasingly influenced by the private sector in ways never seen in the past. Forty-six percent of biotechnology firms support biotechnology research at universities, while 33 of the 50 states have university-industry centers for the transfer of biotechnology. The challenge for such organizations will not only be to ensure that ecologically sound aspects of biotechnology are researched and developed (nitrogen-fixing, drought tolerance, etc.), but to carefully monitor and control the provision of applied non-proprietary knowledge to the private sector, so as to ensure that such knowledge will continue in the public domain for the benefit of all society.



Biotechnology and Agrobiodiversity

Although biotechnology has the capacity to create a greater variety of commercial plants, the trends set forth by transnational corporations create broad international markets for a single product, thus creating the conditions for genetic uniformity in rural landscapes. In addition, patent protection and intellectual property rights contained in GATT, inhibiting farmers from re-using, sharing and storing seeds, raises the prospect that few varieties will dominate the seed market.

Although a certain degree of crop uniformity may have certain economic advantages, it has two ecological drawbacks. First, history has shown that a huge area planted to a single cultivar is very vulnerable to a new, matching strain of pathogen or pest. And, second, the widespread use of a single cultivar leads to a loss of genetic diversity (Robinson 1996).

Evidence from the Green Revolution leaves no doubt that the spread of modern varieties has been an important cause of genetic erosion, as massive government campaigns encouraged farmers to adopt these varieties and abandon many local varieties (Tripp 1996). The uniformity caused by increasing areas sown to a smaller number of varieties is a source of increased risk for farmers, as the varieties may be more vulnerable to disease and pest attack and most of them perform poorly in marginal environments (Robinson1996).

All the above effects are now ubiquitous to modern varieties and it is expected that, given their monogenic nature and fast acreage expansion, transgenic crops will only exacerbate such effects.

Environmental Problems of Herbicide Resistant Crops

According to proponents of HRCs, this technology represents an innovation that enables farmers to simplify their weed management requirements, by reducing herbicide use to post-emergence situations using a single, broad-spectrum herbicide that breaks down relatively rapidly in the soil. Herbicide candidates with such characteristics include glyphosate, bromoxynil, sulfonylurea, imidazolinones among others. However, in actuality the use of herbicide-resistant crops is likely to increase herbicide use as well as production costs. It is also likely to cause serious environmental problems.

Herbicide Resistance

It is well documented that when a single herbicide is used repeatedly on a crop, the chances of herbicide resistance developing in weed populations greatly increases (Holt et al. 1993). The sulfonylureas and the imidazolinones are particularly prone to the rapid evolution of resistant weeds and up to now fourteen weed species have become resistant to sulfonylurea herbicides. Cocklebur, an aggressive weed of soybean and corn in the southeastern U.S., has exhibited resistance to imidazolinone herbicides (Goldburg 1992).

The problem is that given industry pressures to increase herbicide sales, acreage treated with these broad-spectrum herbicides will expand, exacerbating the resistance problem. For example, it has been projected that the acreage treated with glyphosate will increase to nearly 150 million acres. Although glyphosate is considered less prone to weed resistance, the increased use of the herbicide will result in weed resistance, even if more slowly, as it has been already documented with populations of annual ryegrass, quackgrass, birdsfoot trefoil, and Cirsium arvense (Gill 1995).

Ecological impacts of Herbicides

Companies affirm that bromoxynil and glyphosate, when properly applied, degrade rapidly into soil, do not accumulate in groundwater, have no effects on non-target organisms and leave no residues in food. There is, however, evidence that bromoxynil causes birth defects in laboratory animals, is toxic to fish and may cause cancer in humans. Because bromoxynil is absorbed dermally, and because it causes birth defects in rodents, it is likely to pose hazards to farmers and farm workers. Similarly, glyphosate has been reported to be toxic to some non-target species in the soil —both to beneficial predators such as spiders, mites, carabid and coccinellid beetles and to detritivores such as earthworms, as well as to aquatic organisms, including fish (Pimentel et al. 1989). As this herbicide is known to accumulate in fruits and tubers suffering little metabolic degradation in plants, questions about food safety also arise.

Creation of "Super Weeds"

Although there is some concern that transgenic crops themselves might become weeds, a major ecological risk is that large scale releases of transgenic crops may promote transfer of transgenes from crops to other plants, which may then become weeds (Darmency 1994). The biological process of concern here is introgression, that is, hybridization among distinct plant species. Evidence indicates that such genetic exchanges among wild, weed and crop plants already occur. The incidence of shattercane (Sorghum bicolor), a weedy relative of sorghum and the gene flows between maize and teosinte demonstrates the potential for crop relatives to become serious weeds. This is worrisome given that a number of U.S. crops are grown in close proximity to sexually compatible wild relatives. There are also crops that are grown near wild/weedy plants that are not close relatives but may have some degree of cross compatibility, such as the crosses of *Raphanus raphanistrum R. X Sativus* (radish) and Johnson grass X Sorghum corn (Radosevich et al. 1996).

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Reduction of Agroecosystem Complexity

Total weed removal via the use of broad-spectrum herbicides may lead to undesirable ecological impacts, given that an acceptable level of weed diversity in and around crop fields has been documented to play important ecological roles such as enhancement of biological insect pest control, better soil cover reducing erosion, etc. (Altieri 1994).

HRCs will most probably enhance continuous cropping by inhibiting the use of rotations and polycultures susceptible to the herbicides used with HRCs.

Such impoverished, low plant diversity agroecosystems provide optimal conditions for unhampered growth of weeds, insects and diseases because many ecological niches are not filled by other organisms. Moreover, HRCs, through increased herbicide effectiveness, could further reduce plant diversity, favoring shifts in weed community composition and abundance, favoring competitive species that adapt to these broad-spectrum, post emergence treatments (Radosevich et al. 1996).

Environmental Risks of Insect Resistant Crops

According to the industry, the promise of transgenic crops inserted with Bt genes is the replacement of synthetic insecticides now used to control insect pests. Since most crops have a diversity of insect pests, insecticides will still have to be applied to control pests other than Lepidoptera not susceptible to the endotoxin expressed by the crop (Gould 1994).

On the other hand, several Lepidoptera species have been reported to develop resistance to Bt toxin in both field and laboratory tests, suggesting that major resistance problems are likely to develop in Bt crops which through the continuous expression of the toxin create a strong selection pressure (Tabashnik 1994). Given that a diversity of different Bt-toxin genes have been isolated, biotechnologists argue that if resistance develops alternative forms of Bt toxin can be used (Kennedy and Whalon 1995). However, because insects are likely to develop multiple resistance or cross-resistance, such strategy is also doomed to fail (Alstad and Andow 1995).

Others, borrowing from past experience with pesticides, have proposed resistance management plans with transgenic crops, such as the use of seed mixtures and refuges (Tabashnik 1994). In addition to requiring the difficult goal of regional coordination between farmers, refuges have met with poor success for chemical pesticides, due to the fact that insect populations are not constrained within closed systems, and incoming insects are exposed to lower doses of the toxin as the pesticide degrades (Leibee and Capinera 1995).

Impacts on Non-Target Organisms

By keeping pest populations at extremely low levels, Bt crops can starve natural enemies as these beneficial insects need a small amount of prey to survive in the agroecosystem. Parasites would be most affected because they are more dependent on live hosts for development and survival, whereas some predators could theoretically thrive on dead or dying prey.

Natural enemies could also be affected directly through inter-trophic level interactions. Evidence from studies conducted in Scotland suggest that aphids were capable of sequestering the toxin from Bt crops and transferring it to its coccinellid (lady beetle) predators, in turn affecting reproduction and longevity of the beneficial beetles (Birch et al. 1997). Sequestration of plant allelochemicals by herbivores which then affect parasitoid performance is not uncommon (Campbell and Duffey 1979). The potential of Bt toxins moving through food chains poses serious implications for natural biocontrol in agroecosystems.

Bt toxins can be incorporated into the soil through leaf materials, where they may persist for 2-3 months, resisting degradation by binding to soy clay particles while maintaining toxin activity (Palm et al. 1996). Such Bt toxins that end up in the soil and water from transgenic leaf litter may have negative impacts on soil and aquatic invertebrates and nutrient cycling processes (James 1997), all aspects that deserve serious further inquiry.

Downstream Effects

A major environmental consequence resulting from the massive use of Bt toxin in cotton or other crops occupying a larger area of the agricultural landscape, is that neighboring farmers who grow crops other than cotton, but that share similar pest complexes, may end up with resistant insect populations colonizing their fields. As Lepidopteran pests that develop resistance to Bt cotton, move to adjacent fields where farmers use Bt as a microbial insecticide, may render farmers defenseless against such pests, as they lose their biological control tool (Gould 1994). Who will be accountable for such losses?

Impacts of Disease Resistant Crops

Scientists have attempted to engineer plants for resistance to pathogenic infection by incorporating genes for viral products into the plant genome. Although the use of viral genes for resistance in crops to virus has potential benefits, there are some risks. Recombination between RNA virus and a viral RNA inside the transgenic crop could produce a new pathogen leading to more severe disease problems. Some researchers have shown that recombination occurs in transgenic plants and that under certain conditions it produces a new viral strain with altered host range (Steinbrecher 1996). The possibility that transgenic virus-resistant plants may broaden the host range of some viruses or allow the production of new virus strains through recombination and transcapsidation demands careful further experimental investigation (Paoletti and Pimentel 1996).

The Performance of Field-Released Transgenic Crops

Until early 1997, thirteen genetically modified crops had been deregulated by the USDA which were already on the market or in the fields for the first time. Over 20% of the U.S. soybean acreage was planted with Roundup (gylphosate) tolerant soybean and about 400,000 acres of maximizer Bt corn were planted in 1996. Such acreage expanded considerably in 1997 (transgenic cotton: 3.5 million acres, transgenic corn: 8.1 million acres and soybean: 9.3 million acres) due to marketing and distribution agreements entered into by corporations and marketers (i.e. Ciba Seeds with Growmark and Mycogen Plant Sciences with Cargill).

Given the speed with which products move from laboratory testing to field production, are transgenic crops living up to the expectations of the biotechnology industry? According to evidence presented by the Union of Concerned Scientists, there are already signals that the commercial-scale use of some transgenic crops pose serious ecological risks and do not deliver the promises of industry (Table 1).

The appearance of “behavioral resistance” by bollworms in cotton, that is the herbivore was capable of finding plant tissue areas with low Bt concentrations, raises questions not only about the adequacy of the resistance management plans being adopted, but also about the way biotechnologists underestimate the capacity of insects to overcome genetic resistance in unexpected manners (*The Gene Exchange* 1996)

Similarly, poor harvests of herbicide resistant cotton due to phytotoxic effects of Roundup™ (glyphosate) in four to five thousand acres in the Mississippi Delta (*New York Times* 1997) points at the erratic performance of HRCs when subjected to varying agroclimatic conditions. Monsanto claims that this is a very small and localized incident that is being used by environmentalists to overshadow the benefits that the technology brought on 800,000 acres. From an agroecological standpoint however, this incident is quite significant and merits further evaluation, since assuming that a homogenizing technology will perform well through a range of heterogeneous conditions is incorrect.

Conclusions

We know from the history of agriculture that plant diseases, insect pests and weeds become more severe with the development of monoculture, and that intensively managed and genetically manipulated crops soon lose genetic diversity (Altieri 1994, Robinson 1996). Given these facts, there is no reason to believe that resistance to transgenic crops will not evolve among insects, weeds and pathogens as has happened with pesticides. No matter what resistance management strategies will be used, pests will adapt and overcome the agronomic constraints (Green et al. 1990). Diseases and pests have always been amplified by changes toward homogeneous agriculture.

The fact that interspecific hybridization and introgression are common to species such as sunflower, maize, sorghum, oilseed rape, rice, wheat and potatoes, provides a basis to expect gene flow between transgenic crops and wild relatives to create new herbicide resistant weeds. Despite the fact that some scientists argue that genetic engineering is not different than conventional breeding, critics of biotechnology claim that rDNA technology enables new (exotic) genes into transgenic plants. Such gene transfers are mediated by vectors that are derived from disease-causing viruses or plasmids, which can breakdown species barriers so that they can shuttle genes between a wide range of species, thus infecting many other organisms in the ecosystem.

But the ecological effects are not limited to pest resistance and the creation of new weeds or virus strains. As argued herein, transgenic crops can produce environmental toxins that move through the food chain and also may end up in the soil and water affecting invertebrates and probably ecological processes such as nutrient cycling.

Many people have argued for the creation of suitable regulation to mediate the testing and release of transgenic crops to offset environmental risks and demand a much better assessment and understanding of ecological issues associated with genetic engineering. This is crucial as many results emerging from the environmental performance of released transgenic crops suggest that in the development of "resistant crops," not only is there a need to test direct effects on the target insect or weed, but the indirect effects on the plant (i.e. growth, nutrient content, metabolic changes), soil and non-target organisms must also be evaluated.

Others demand continued support for ecologically based agricultural research, as all the biological problems that biotechnology aims at, can be solved using agroecological approaches. The dramatic effects of rotations and intercropping on crop health and productivity, as well as of the use of biological control agents on pest regulation have been confirmed time and time again by scientific research (Altieri 1994, NRC 1996). The problem is that research at public institutions increasingly reflects the interests of private funders at the expense of public good research such as biological control, organic production systems and general agroecological techniques (Busch et al. 1990). Civil society must demand a response to the question of whom the university and other public organizations are to serve and request for more research on alternatives to biotechnology. There is also an urgent need to challenge the patent system and intellectual property rights intrinsic to the GATT, which not only provide transnational corporations with the right to seize and patent genetic resources, but also accelerates the rate at which market forces already encourage monocultural cropping with genetically uniform transgenic varieties.

Among the various recommendations for action that non-governmental organizations, farmers organizations and citizen groups should bring forward to local, national and international fora include:

- End public funded research on transgenic crops that enhance agrochemical use and that pose environmental risks;
- HRCs and other transgenic crops should be regulated as pesticides;

Table 1. Field Performance of Some Recently Released Transgenic Crops

CROP	PERFORMANCE
Bt transgenic cotton.	Additional insecticide sprays needed due to Bt cotton failing to control bollworms in 20,000 acres in eastern Texas. The Gene Exchange, 1996; Kaiser, 1996.
Cotton inserted with Roundup Readgô gene.	Bolls deformed and falling off in 4-5 thousand acres in Mississippi Delta. Lappe and Bailey, 1997; Myerson, 1997.
Bt corn.	27% yield reduction and lower Cu foliar levels in Beltsville trial. Hornick, 1997.
Herbicide resistant oilseed rape.	Pollen escaped and fertilized botanically related plants 2.5 km away in Scotland. Scottish Crop Research Institute, 1996.
Virus resistant squash.	Vertical resistance to two viruses and not to others transmitted by aphids. Rissler, J. (Personal communication).
Early FLAVR-SAVR tomato varieties.	Did not exhibit acceptable yields and disease resistance performance. Biotech Reporter, 1996.
Roundup Ready Canola.	Pulled off the market due to contamination with a gene that does not have regulatory approval. Rance, 1997.
Bt potatoes.	Aphids sequestered the Bt toxin apparently affecting coccinellid predators in negative ways. Birch et al., 1997.
Herbicide tolerant crops.	Development of resistance by annual ryegrass to Roundup. Gill, 1995.

- All transgenic food crops should be labeled as such;
- Increase funding for alternative agricultural technologies;
- Ecological sustainability, alternative low-input technologies, the needs of small farmers and human health and nutrition should be pursued with greater vigor than biotechnology;
- Trends set by biotechnology must be balanced by public policies and consumer choices in support of sustainability;
- Measures should encourage sustainable and multiple use of biodiversity at the community level, with emphasis on technologies that promote self-reliance and local control of economic resources as a means to foster a more equitable distribution of benefits.

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