

WHY MANY FARMERS AND CONSUMERS ARE LUKEWARM ABOUT GMOs AND WHAT MIGHT CHANGE THEIR MINDS

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ABSTRACT

Agricultural biotechnology is seen by some as savior. To others it looms as a great threat to agriculture, food safety, and biodiversity. Why have so many people developed such hardened attitudes toward biotechnology? What can those who believe in the technology do to build public confidence and slow the erosion of public support.

Suggestions are offered in five areas.

- Stop Overselling the Technology
- Acknowledge Risk and Ecological Issues and Uncertainties
- Proceed Incrementally in Step with New Knowledge
- Match Solutions to the Source of the Problem
- Focus on Applications Likely to Deliver Real Benefits

The paper closes with an assessment of contemporary GMO food safety concerns – a topic on the mind of a growing number of consumers, scientists, and regulators.

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Overselling Biotechnology

One of agricultural biotechnology's problems from the beginning has been the propensity of advocates to oversell the technology. Scientists have been among the guilty. They have allowed their sincere excitement over discovery and technological progress to gloss over the need for deep thinking on the many factors that determine farm profits and food security among the poor.

Companies have also contributed, sometimes shamelessly, to the notion that biotechnology will solve all agriculture's problems. Most should know better. But the desire to drive up or sustain stock prices can understandably cloud people's thinking.

Overselling biotechnology and the life sciences corporate model reinforced already-established and created new fears. "Too good to be true" solutions created a well of skepticism in the media and general public for the same reason that most people intuitively mistrust fad diets offering to effortlessly melt away the pounds or "get rich quick" schemes. And of course, many people still remember the last generation's grandest technological false promise – electricity from nuclear power would be "too cheap to meter."

A biotech analog of "power too cheap to meter" is transgenic corn plants affixing their own nitrogen, thus solving, according to some true-believers, the need to manage soil fertility and water quality. Even if N-fixing transgenic plants become technically feasible, they will not solve all fertility and water quality problems. Indeed, they will complicate the management of some old ones – N leaching, for example -- and create some unique and new ones, like impacts on soil microbial communities and plant immune response.

Those who ask or expect too much of *any* genetic, chemical or biological technology set the stage for problems. Biotechnology does not change this age-old reality.

The benefits delivered by a transgenic crop variety, and its sustainability in a given farming system will generally be inversely proportional to the scope of change brought about by it. A contemporary example is Roundup Ready (RR) soybeans. Farmers will lose a valuable and safe herbicide if they continue to ignore the need to diversify weed management systems and adhere to well-conceived resistance management plans.

The worst case scenario is far from rare -- the planting of RR-beans and RR-corn in rotation on the same field. Such excessive reliance on Roundup is leading to shifts in weed communities and the emergence of Roundup resistance weed phenotypes across the Cornbelt. Problems may start in just a few isolated locations, just a corner of the back-forty that a farmer sprays an extra couple of times to try to get a stubborn patch of foxtail under control. And when problems arise, they may happen only because of remarkably

bad judgement and sloppy weed management, such that a farmer ends up making five or six Roundup applications in a two-year period on the same field.

But selection pressure is like water flowing downhill. It always starts small but can gain momentum quickly.²

This same herbicide-tolerant technology could prove sustainable and profitable for farmers and companies if managed in ways that avoid weed shifts and resistance. It will be a major setback for soybean growers if Roundup is lost as an effective herbicide. The loss will not be because of some inherent flaw in the molecule but the way the herbicide has been used – and abused.

The RR-example leads to an important point – the benefits of most agricultural biotechnologies to farmers *and* the ecological risks that can stem from their adoption typically have as much to do with when and how the technologies are used as their inherent properties. Both safety and efficacy are not absolute, they are conditional on the ways the technologies are used.

Companies marketing biotechnologies do not dwell on the possible consequences of excessive reliance and are, in general, anxious to gain as much market share as possible, as quickly as possible. This strategy, though, can trigger unanticipated problems, whether in the marketing of a new drug, medical device, pesticide, consumer product, or seed variety.

Acknowledge Risk and Ecological Issues and Uncertainties

The capacity of GMO plants to enhance the already-healthy exchange of genetic material among bacteria is clearly one of the most worrisome risks associated with current agricultural biotechnologies. Dr. Beatrice Tappeser and colleagues at the Institute for Applied Ecology in Germany have written –

“Horizontal gene transfer is now recognized to be the main avenue of exchange of genetic material in the microbial world, and hence also of the exchange and spread of antibiotic resistance genes” (Tappeser et al., 1998).

Recent research has shown that digestive systems of invertebrates and vertebrates - from nematodes to mice to man - are likely places where such transfers can occur. It is becoming clear that gene flows can occur in just a matter of minutes, even seconds (Brockmann et al., 1996) and that there are often multiple gene flow mechanisms that can come into play under variable conditions.

² For information on the emergence of weeds resistant to Roundup, see <http://www.biotech-info.net/herbicide-tolerance.html#soy>. Reasons why Roundup Ready soybeans have been so popular, despite their relatively higher costs are described in http://www.biotech-info.net/RR_yield_drag_98.pdf.

When biotech tools are used to move novel genes into an organism, that organism will always respond in a variety of ways. Short-term responses will largely affect whether the transformation is stable and useful relative to the desired change. Longer-term impacts and cellular responses can lead to gene silencing, codon bias, functional instability, and a range of pleiotropic effects.

Many of these adaptations will be of no consequence in most and perhaps even all circumstances. Examples include the silencing of certain genes or over-expression of a promoter somewhere in the midst of so-called junk-DNA. But under conditions of drought or pest stress or when a particular nutrient is over- or under-supplied, or when there are combinations of the above, plant physiological and immune systems will be forced into a sort of hyper-drive. These are the conditions that can unexpectedly lead to what might be called “stress induced pleiotropic impacts.”

Examples of stress induced pleiotropic effects have already been documented. Petunias engineered to produce salmon red flowers broke down under conditions of stress and the proportion of salmon red flowers steadily declined (Meyer et al., 1992). Roundup Ready cotton boll drop appears linked to weather-induced stress (Fox, 1997, http://www.biotech-info.html/cotton_drops_bolls.html), as is uneven expression of *Bt* toxins in cotton plants. Heat-induced yield problems with Roundup ready soybeans also appear to be a stress induced pleiotropic effect.

The impact of GMOs on soil microbial communities is another largely unexplored but possibly important area of ecological impacts. The first transgenic variety designed to exude a toxin through its root system - a *Bt*-corn developed by Monsanto -- may reach the U.S. market in crop year 2002, pending regulatory approvals. It is known that *Bt* from transgenic corn can last in soil for more than 120 days, retaining its toxicity to Lepidopteran larvae.

Work continues on the impacts of *Bt* crops on non-target organisms, from beneficials like lacewings to Monarch butterflies. While the acute impacts are likely to be less severe than those following an application of a broad-spectrum insecticide, the longer-term, food chain impacts may be significant.

Proceed Incrementally in Step with New Knowledge

The rapid pace of commercial adoption of *Bt* corn and cotton and Roundup Ready soybeans has worried many people because it has short-circuited the time typically used to identify and resolve problems, before millions of acres are planted.

Bt corn and cotton were approved and planted widely before scientists understood the genetics of resistance or how best to manage resistance, or even whether it could be managed. Each year the EPA has had to revisit and modify the resistance management plans required. Incrementally the agency has raised the acres that farmers must devote to refugia – an area not planted to the *Bt*-crops where *Bt*-susceptible moths will hopefully

survive and mate with any resistant moths.

But when dealing with resistance, there may be few chances to play catch-up. Once resistant genes gain a foothold in pest populations, they will proliferate quickly in the face of continued selection pressure. My sense is that resistance to *Bt*-crops is probably manageable but regrettably, we may not learn how to do it, or find ways to convince farmers to adhere strictly to science-based resistance management plans, until it is too late.

Incremental progress can also be made in reducing potential risks, yet the industry seems more interested in forging ahead with new products posing new sorts of risks. For example, just about everyone agrees now that the antibiotic marker genes in today's GMO crop varieties can and should be replaced with another marker technology. Instead of embracing this opportunity to make incremental progress – putting to bed a significant potential risk – the industry seems to be waiting until it is forced to do so.

Match Solutions to the Source of the Problem

The idea that genes are destiny worries many people. While very important on the farm, an organism's genetic inheritance obviously does not guarantee a healthy existence.

Success in farming depends on the management of complex biological systems. The goal is to push crop and animal growth close to the limits of natural and biologic resources. Stress from all sources must be managed so that genetic yield potential is not lost, to the full extent that is economically practical. Pests and diseases must also be managed so that weed competition and/or damage from insects or pathogens is kept below threshold levels.

Genetic improvement, whether through classical breeding or biotechnology is no substitute for good judgement in the design of farming systems. Skill and attentiveness in the day-to-day management of farming enterprises is equally important.

Ideally, breeders should focus predominantly on overcoming genetic limits to higher yields, rather than problems that can be readily solved through proper crop rotation, tillage and fertility management. Plus, many management-based solutions are self-financing. The cost of management system changes is made up for by reductions in the purchase of off farm inputs.

An example -- the need for and cost of fungicides to treat lodging, over-fertilized wheat is a poor reason to turn to biotechnology to breed a more resistant wheat cultivar. The use of biotech to find rust-resistance genes to move into dryland wheat cultivars is a good and proper use. The difference is the former problem is man-made and manageable without genetic change, the latter is not.

For the last fifty years breeders have mostly kept their eye on the ball. Since the early 1990s though, there has been a steady shift of emphasis toward incorporating proprietary *Bt* and herbicide tolerant traits in elite hybrids and soybean varieties.

Pest-management related traits have come to dominant seed industry priorities to a degree few people realize. In crop year 2000, just under one-half the Pioneer corn hybrids offered Illinois farmers were genetically modified. Two-thirds of the hybrids offered for the first time in 2000 were GMOs. *Bt*-hybrids accounted for 73 percent of the total number of GMO traits while herbicide tolerance accounted for another 23 percent (Benbrook, 2000, http://www.biotech-info.net/technical_paper3.pdf). Illinois corn growers were offered 23 corn hybrids by on the company's website in early 1999. Of these, 10 were *Bt*-transgenic and three were herbicide tolerant (Benbrook, 1999, <http://www.biotech-info.net/IWFS.pdf>). Pioneer listed 20 "value-added" attributes across the 23 corn varieties, of which 13 were pest management related, or 65 percent. Herbicide-tolerant soybean varieties were comparably prominent in Pioneer's crop year 1999-2000 offerings.

One might infer from Pioneer's recent breeding priorities that Lepidopteran insect pest management in corn and soybean weed management were the two areas most seriously undermining farm profitability. Not true. Most farmers live with the episodic damage of the European corn borer and indeed in 5 to 7 years out of 10, *Bt*-corn does not pay for farmers (Hyde, et al., 1999). A marketing opportunity to exploit intellectual property pushed these technologies to the front of the cue, not need nor benefits to farmers.

Focus on Applications Likely to Deliver Benefits

The tools of biotechnology have much to offer on many fronts. There is no turning back these powerful new scientific tools. But it remains an open question how they will be used to alter crop and pest management systems?

Companies jumped on the chance to move *Bt* genes into corn, cotton and potatoes because it was technically feasible and because these were large acreage crops. Few experts could argue with a straight face though that developing these *Bt* varieties was the highest and best use of biotechnology to advance insect pest management. Indeed, developing these *Bt*-transgenic crops was probably not even the best way to exploit *Bt* endotoxins.

Bt-transgenic crops are fundamentally incompatible with biointensive Integrated Pest Management systems, or BioIPM for short. This is because the *Bt*-endotoxin is expressed on all acres planted regardless of need and imposes heavy selection pressure on insects throughout the season, including many weeks when the pests are below threshold levels and pose little or no threat to yields. *Bt*-crops also have possibly serious impacts on non-target beneficials.

Bt-transgenics are, in effect, a more efficient delivery system for a pesticide-based solution. The delivery system is novel – the plant – and the technology involves a natural toxin instead of a synthetic chemical. But the desired impact is the same as spraying an organophosphate insecticide. The farmer's foot remains on the pesticide-treadmill accelerator.

To advance BioIPM, different goals must drive the technology development process. The best solutions are prevention-based and target narrow, specific changes in the interactions between the crop, its environment and pests. The most elegant solutions marginally strengthen the plant's natural defense mechanisms or somehow weaken a pest so it cannot compete as well for space, nutrients, or food sources. Such solutions are minimally disruptive to other organisms or ecological interactions, many of which play a role in managing other pests.

Fortunately, the pesticide industry is bringing to market new generations of biopesticides. These new tools are giving farmers valuable new capacity – and confidence -- to move along the continuum toward increasingly “soft” BioIPM systems.

An example -- spinosad is a new Dow AgroSciences bioinsecticide derived from the fermentation of an actinomycete species, *Saccharopolyspora spinosa*. Spinosad is already registered on over 100 crops and will soon be available to just about all fruit and vegetable growers. Within a few years, millions of farmers worldwide will use it to reduce their reliance on risky, disruptive broad-spectrum insecticides. Managed carefully to avoid resistance, spinosad could become the most important and profitable insecticide ever discovered.

The manufacturing, purification, and formulation processes for spinosad are complex. The cost of the product per acre treated now limits market growth to higher-value crops. Dow AgroSciences is responding in several ways. The company has entered into a two-year research agreement with Biotica Technology, a U.K. company, which will use genomics to improve the efficiency of the production process and the yield of the active agent (Agrow, January 1, 2000). Progress from this application of biotechnology will make it possible for the company to increase production and reduce per unit production costs, as well as costs per acre treated on the farm.

This valuable, near-zero risk use of biotechnology points to the need for more systemic, focused effort in the discovery and manufacture of low-risk and selective biochemical pesticides. Dow AgroSciences could further blur the line between biotechnology and “green” farming technologies by formulating a version of spinosad that meets the requirements of organic certifiers.

Perhaps some of you in this room will help make it possible to bring the new generation of biopesticides to the organic farmer. This breakthrough will require considerable innovation in formulation technology, since the list of organically approved inert ingredients is limited. But with the acres under organic systems growing over 20

percent per year, more and more companies will choose to make the needed investments in order to gain a foothold in the fastest growing niche market in world agriculture.

Let me offer another prediction. The skills of the formulation chemist will emerge as critical in improving the cost-effectiveness of a range of bio-based technologies. Already, experts among you are working with biopesticides like spinosad, the promising strobilurin fungicides (e.g., azoxystrobin, or Quadris), with insect growth regulators, pheromone delivery systems, and mixtures of microbial insecticides that are more stable and robust. Your focus remains traditional – finding ways to use these biopesticides with the same equipment and types of systems now built around conventional pesticides.

In the future the tool kit and strategies of the pest manager will diversify. There will be an expanded array of products, with a heavier emphasis on prevention. Some new products will work in a completely different way than any on the market today. They will be manufactured and handled completely differently and will bring new companies and technology to the field of pest management. As these new players get close to the market though, they will discover just how important your skills are, because for biologically based technologies to work, organisms and biologically active materials will need to survive the unpredictable stresses and hostile conditions found in any farm field at one point of the season or another.

For example, a leading IPM crop-consulting firm in this state is working with an Idaho-based company to formulate sprayable, freeze-dried beneficial insect diets to use in BioIPM systems. One strategy under investigation is the use of sprayable diets to tide over populations of beneficial insects when an unavoidable insecticide application causes the food-base for generalist predators to temporarily crash. Another is to use the diets to support a rapid increase in populations right before the expected period of heaviest pressure from a given insect. Many other novel ideas are forming, all of which will challenge formulation chemists to come up with ways to preserve and release biological materials in the field.

Most biopesticides work through some direct impact on the development, feeding behavior, energy metabolism or reproduction of the target pest. There are other, more elaborate mechanisms, however, such as triggering plants to emit chemicals that attract insect predators and parasitoids. Thaler was able to accomplish this goal in California tomato fields (Thaler, 1999). Applications of jasmonic acid triggered a response in the octadecanoid pathway, which appears to produce volatile chemicals that serve as a signal to certain insect predators. In this experiment caterpillar predators were attracted to treated plants and reduced feeding damage significantly.

Several teams are also looking for ways to trigger or reinforce systemic acquired resistance (SAR), a widely studied mechanism through which a plant attains the ability to overcome pathogen infection and other pest threats. There is already one chemical pesticide on the market designed to trigger SAR -- the Novartis product Actiguard, which

contains the active ingredient acibenzolar-S-methyl.

Oldroyd and Staskawicz have shown that transgene-induced SAR can broaden the spectrum of disease control possible through stimulation of SAR (Oldroyd and Staskawicz, 1998; http://www.biotech-info.net/GE_tomato.html). Many companies are working on combined approaches that entail genetic modification to enhance SAR within a cultivar in conjunction with promoter genes linked in some way to the application of a chemical trigger, like jasmonic acid or the Novartis product Actiguard.

Contemporary GMO Food Concerns

Major mechanisms through which a GMO crop or food might lead to an unanticipated adverse effect, either in the environment or in humans have been reviewed in several recent articles. The below taxonomy can serve as an introduction to the literature for those who want to learn more; the articles range from general discussions anyone can follow (Butler and Reichardt; Clark) to highly technical and fully referenced articles (Ho, Traavik).

- “Long-term effect of GM crops serves up food for thought.” (Butler D., and T. Reichardt, 1999, http://www.biotech-info.html/long_term_effect.html)
- “Too early may be too late: Some ecological risks associated with release or escape of recombinant or genetically altered nucleic acids.” (Traavik, T., 1998),
- “Gene technology and gene ecology of infectious diseases.” (Ho, M.W. et al., 1998)
- “Survival, persistence, transfer- an update on current knowledge on GMOs and the fate of their recombinant DNA.” (Tappeser et al., 1998, http://www.biotech-info.net/GMO_update.doc)
- “Genetic engineering is not an extension of conventional plant breeding: How genetic engineering differs from conventional breeding, hybridization, wide crosses and horizontal gene transfer.” (Hansen, M., 2000, http://www.biotech-info.net/wide_crosses.html)
- “Ten Reasons why farmers should think twice before growing GE crops.” (Clark, A., 1999, <<http://www.oac.uoguelph.ca/www/CRSC/faculty/eac/10reasons.htm>>)

Major concerns raised in these articles fall within the general categories of GMO food technology risks covered in Table 1. The table shows the earliest identified citation and trends in citations over time in seven areas. All searches were done using High Wire on the *Science Online* website. Keywords used in the search are shown in the table.

Table 1: Historical Trends in GMO Publication Citations						
Category	Earliest Citation	Number of Citations				Pre-1990 to 2000
		Pre-1990	1990-1993	1994-1997	1998-2000**	
Search Keywords*						
Gene Silencing						
Gene silencing	1980	1	10	35	63	109
Gene Flow and Transfer						
Codon bias	1992	0	1	3	3	7
CaMV and gene	1989	1	11	10	2	24
Viral recombination	1993	0	1	3	0	4
Foreign DNA	1984	10	16	10	14	50
Naked DNA	1979	13	17	19	22	71
Pleiotropic Effects						
Pleiotropic and transgenic	1989	2	1	4	5	12
*Searches were executed on HighWire Journals search engine at < http://www.sciencemag.org/searchall >. Journals in the following categories were selected: Biochemistry, Cell and Molecular Biology; Microbiology and Virology; Plant Sciences; Other Life Sciences; and Medical Research.						
**Searches were conducted in February 2000.						

While the table is far from comprehensive, it provides general insights regarding the status and trends in the science base supporting food safety biotech risk assessments -

- Less than 10 percent of the total number of citations covering seven major areas of risk appeared before 1990.
- About seventy percent have appeared since 1994. Accordingly, the FDA’s “substantial equivalence” policy was formed and key approvals made well before some of today’s most important risk concerns had been studied to any significant degree.
- Ninety percent of the total citations on “gene silencing” have appeared in the literature since 1994 and almost 60 percent in just the last two years. Clearly gene silencing is an important, recent concern that science has only begun to unravel and place into perspective.
- Surprisingly few studies have explored some critical concerns, e.g. pleiotropic effects.⁴

⁴ The search did not pick up papers on some pleiotropic effects such as triggering a biologically significant level of expression of allergenic proteins.

- The number of papers in some areas like codon bias and naked DNA is clearly accelerating. If current trends continue knowledge in these areas should rapidly expand.

Steps to Build Public Confidence

The only way to earn public confidence is through independent research and thoughtful, thorough and transparent assessment of the benefits, costs and risks posed by emerging biotechnologies.

“Go slow” approaches will help reassure the public that unforeseen problems will be identified and hopefully dealt with before widespread commercial adoption.

Companies need to stop marketing GMO varieties as stand-alone solutions to complex problems with roots in farming system design and management.

Marketing programs and biotech promoters need to emphasize when it is appropriate *and inappropriate* to select a transgenic variety, as well how the technology needs to be used to avoid problems such as resistance, adverse impacts on non-target organisms, gene flow, and poor returns to farmers.

When risks are documented, companies and government agencies must take decisive steps to avoid or limit problems, even in the absence of all the answers or a full assessment of the scope of problems. In such cases, a tendency toward over-reaction will serve the industry well in the long run.

Assurances of safety based on an absence of documented human health problems are not going to convince that many people. The general public understands how hard it is for medical epidemiologists to trace the causes of ill health. They know the causes of some of our major diseases are still not known with any certainty and most are convinced that diet affects health in extraordinarily complex ways.

The industry and government are going to have to invest in some careful, detailed safety and nutritional testing in laboratory animals and humans. If a series of “worst case” scenario studies conducted by respected, independent scientists consistently back up “substantial equivalence” findings, food safety controversies will subside, if no new problems emerge. If new research does point to unforeseen problems, the biotech industry will be in for a rough ride.

A range of social, institutional, trade and economic issues also will factor prominently in public attitudes. Let me touch on just a few in passing.

Ways must be found to overcome the adverse impacts of patents and intellectual property policies on the conduct of science and the exchange, use, and improvement of germplasm. North-South fairness issues also must be dealt with and are extremely complex and deep-seated.

The public and world community has come to accept great disparity in wealth and income but the same cannot be said about access to and control over seeds and genetic resources.

Pesticide companies with significant seed industry holdings need to assure that their R+D and breeding priorities are not excessively weighted toward transgenic technologies linked to sale of their proprietary products in contrast to other solutions. Their actions and annual seed offerings will be carefully monitored in this regard.

A Parting Thought

Shifting gears and restoring public confidence in agricultural innovation will be tough in the current climate. The biotech industry seems to think a hard sell and “attack the critics” strategy is needed to counteract Greenpeace and other activist groups. They obviously view the threat as serious and have pledged \$50 million annually to finance a broad-based PR campaign.

I think the return on this investment will be disappointing because the effort glosses over the real problems driving public concern. The agricultural biotech industry may succeed in planting doubts about the motives and tactics of Greenpeace, but in the interim they will make little progress dealing with the real problems and uncertainties that worry people, many scientists, and a growing number of farmers. Only time will tell.

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