# GENETICALLY ENGINEERED ORGANISMS AND THE ENVIRONMENT

*Report of the ENVS 4800 Critical Thinking 2006 Class*

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# 1. Foreword

MICHAEL PALAMARA

Even a brief glance at the current increase of genetically modified organisms in today's world, will uncover many controversial topics. In every sector of its use, from its initial implementation in farming to its inclusion in common grocery goods, there have been battles waged. Of the many, are concerns about the influences that these actions will have on natural ecosystems. For instance, should genetically modified organisms escape, how will this affect natural species populations? In addition, there are also apprehensions about the possibility of negative human health affects such as, what types of allergies will some consumers have to GMOs? Also, issues have arisen about the use of genetically modified crops in farming. When being used in these types of applications, are there more benefits than costs? There have even been questions posed as to whether or not the employment of GMOs is ethically the right thing to do.

In this paper, many of the issues surrounding the current use of genetically modified organisms will be explored. Recent, as well as past, techniques will be investigated to uncover both the concerns and those that have expressed them. Furthermore, recent political debates will be explored including: how GMOs might affect food aid to Africa, as well as the differences in viewpoints between the United States and Europe. Also, recent legislation will be examined to show the varying directions that genetically modified organisms may take in the future. For instance, what types of supervision will GMOs be subject to when placed on our grocery shelves? The final section is a piece on overall risk assessments and how the GMO issue should be evaluated given their current issues.

First, however, a look into the simple definitions of genetically modified organisms and traditional crops will be taken so basic knowledge is acquired. By obtaining this information, educated decisions can be made regarding the array of issues that will be discussed.

# 2. Defining genetically engineered organisms

BRITTNEY HOLDER

*Keywords*

*Genotype:* genetic constitution of an organism
*Phenotype:* physical expression of a characteristic of an organism, determined by both genetic constitution and environment
*Progeny:* offspring
*Gamete:* a mature male or female germ cell capable of initiating formation of a new diploid individual by fusion with a gamete of the opposite sex

Traditional breeding methods and genetic engineering (GE) are both motivated by the desire of humans to select beneficial traits for the production of crops and animals. Whether an organism gains or loses a trait, it is done by the human hand. Supporters of genetic engineering argue that GE organisms facilitate the management and control of crops by maximizing the expression of traits that tolerate biological and environmental stresses. They claim GE can produce new organisms in fewer generations with less error than traditional breeding techniques. Because of higher yielding crops, proponents suggest that GE will alleviate food shortages by increasing the amount of food for world distribution. They also maintain that existing crops are the result of thousands of years of genetic modifications; therefore, GE is just an extension of traditional breeding methods (Gepts, 2002). So, what are the differences between GE and traditional breeding techniques? To gain a better understanding of both, a basic explanation of each must be examined.

First, traditional breeding is the process of selecting an individual with a desired trait and mating it with an individual exhibiting the same or a different desired trait to produce offspring with specific physical and behavioral characteristics (Smith, 2003). This technique has been around as long as humans have been cultivating crops and raising animals for food. Humans guide procreation between members of the same or closely related species, and select for a desired expression of a trait of "phenotype". While humans act as the agents of selection, nature, the processes of recombination and sexual reproduction determine which genes are passed on to the offspring.

Genetic engineering differs from traditional breeding in the way that genetic variation is generated. GE organisms are created by

GE Phenotypes

Bt corn is a major GE crop used today. A gene from the bacteria *Bacillus thuringiensis* is inserted into corn so that it expresses the Bt protein making it resistant to corn borers. Bt is "built in pest protection" thus growers use less spray-on insecticides.

Roundup Ready crops are engineered with a gene to withstand the spraying of Roundup. This enables a grower to spray the crop and any surrounding weeds, killing the weeds and leaving the crop unharmed.

Also: other pest resistance, insect resistance, virus resistance, chemical tolerance, herbicide tolerance, reproductive modifications, nutritional quality/composition, delayed fruit ripening using biotechnology to move genes between organisms and produce novel organisms. Also, in contrast to traditional breeding, scientists select for a specific gene or "genotype" rather than a trait or phenotype. GE is the "artificial manipulation and transfer of genetic material" (UCS, 2005, p. 1). This technology process produces genetic diversity that would otherwise not be found in nature because GE can transcend reproductive barriers between species.

As mentioned above, genetic engineering and traditional breeding methods differ in the way in which genetic material is transferred to the genome. Genetic engineers can literally shoot genes into the plant cells with a biolistics gun. Or, they can introduce a pathogen that naturally transfers DNA, *Agrobacterium tumefaciens*, to the cell being engineered, or they can use other means of particle discharge (Gepts, 2002). The transferred genes produce different phenotypes depending on which genes are selected and for which traits. In contrast, traditional breeding uses the natural process of sexual reproduction between closely related species to create different traits. Creating an organism to suit the breeder may take years of trial and error, thus the process is not as rapid as genetic engineering. Once both techniques are successful, the traits show up in the organism's progeny.

A concern of many opposed to genetic engineering is the relative rapid speed of spread of GE crops. It has been argued though, that GE cultivars have spread at rates similar to those of cultivars obtained through traditional breeding in the past 100 years:

"…transgenic field crops occupied a substantial part of the total field crop area in the USA. For example, from 1996-2000 planting of herbicide-tolerant soybean surface planted went from 1 million to 43 million acres or 54% of the U.S. soybean acreage. Likewise, herbicide-tolerant cotton expanded from 10% of surveyed acreage in 1997 to 46% in 2000. … A change similar to GE is the introduction of hybrid vigor in maize. [It was shown] that hybrid maize cultivars spread quickly in the USA once the initial technical difficulties had been overcome. After approximately 5 and 10 yr, 50% of the maize area was planted to hybrid cultivars in Iowa and the USA, respectively. A similarly rapid spread was observed for wheat varieties incorporating dwarfness genes. In California, for example, the entire wheat growing area was converted to short-statured varieties in 2 yr in the 1960s. This rapid spread is not limited to the USA. High-yielding rice varieties were grown over 50% of the Philippine rice-growing area 5 yr after their introduction" (Gepts, 2002, p. 1784).

What traits can be conferred using traditional breeding and GE technology? Traditional breeding has led to organisms of greater size greater size, shorter growing time, larger yields, and many other characteristics beneficial to the producer. Specific examples of GE include; a growth hormone gene found in the sockeye salmon has been transferred to rainbow trout to increase the growth rate and food conversion efficiency in the fish. Also, Provitamin A from daffodil genes is used in the production of "golden rice"; lack of the vitamin in diets is the leading cause of blindness in children of developing countries (Gepts, 2002). Finally, to produce resistance to frost in tomatoes, strawberries, and potatoes, genetic engineers transferred an "anti-freeze" gene from the sea flounder (Antioniou, 2006).

| | | |
|---|---|---|
| Species Involved | Mainly involves very closely related species. | Genes can be altered within an individual or transferred between different species or between different types of organism e.g. from plant to animal. |
| Time Involved | Changes come about over many generations; once a trait is selected for and bred it will (ideally) show up in progeny. | Changes can be introduced very quickly over just a few generations. |
| Genes Involved | Different variations of the same genes are exchanged. | Involves the isolation, cutting, joining, and transfer of single or multiple genes between totally unrelated organisms. |
| Characteristics Involved | May change all the characteristics; there is no control over which genes recombine and which do not. | Selects for the desired characteristic in the organism to change or transfer. |

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# 3. The ethics of genetic engineering

WALTON BOLGIANO, CASSANDRA MASON, STEVEN RICE

In 1948, Aldo Leopold published one of the most widely referenced works in environmental theory. Leopold's *Land Ethic* is part of a larger work called *A* Sand County Almanac. *The Land Ethic* tries to theoretically establish a hierarchical method to measure humans' impact on, and responsibility toward, the land and the earth. Leopold is one of the fathers of the study of ecology as it exists today, and many scholars and students base their beliefs on concepts, which he first introduced into the study of the environment. He talks about what the land has given us, in terms of food, shelter and resources, and also emphasizes the value of pristine nature by reiterating human's responsibility of maintaining that. By comparing the mid- eighties, when *The Land Ethic* was published, with the 21$^{st}$ century as it is today, it can be assumed that Leopold would have new grievances had he the opportunity to study land in the present time period. One factor that is controversial among the topics of agriculture, conservation and consumption is the increasing use of Genetically Modified Organisms for farming and agriculture production.

The constant genetic alterations made on cash crops in the United States have reached an overwhelming level. As the ability for humans to modify organisms, so as to curve the crop's potential to better serve human demand, becomes more common, the quality of the crop moves further and further away from the originally organic state. The use of GMO's has effects that pertain to the environment as well as to the crop and the consumer. Human introduction of genetically engineered crops has tainted once pristine environments. The consequences of this degradation are the risk of unknown threats such as invasive species, the potential of resistance, and overall failure to acknowledge Leopold's land ethic. While many may argue that the development and current use of GE is a natural progression in agriculture as we continue to advance scientifically, these claims may not be left without including an ethical perspective. Aldo Leopold suggests that humans are not necessarily at odds with the environment, and that we need not separate ourselves completely. Rather, we would benefit from gaining perspective of our own role in the community. One may regard moral obligations from a different point than Leopold, and would see the responsibility of feeding the community abundantly, while having as little effect on agricultural land as possible. One example of a case that brings to light the contradictions between the use of GMO's and our responsibility to environmental conservation is found in Bijorn Lomborg's *Skeptical Environmentalist*, a collection of essays addressing the "state of the world."

> While the Green Revolution has been hailed by many as the era of greatest advancement in the agricultural community, many of its long term affects go overlooked. The Green Revolution is a mile stone in history, as the increased food production fed more people, but this sharp increase of production also took a toll on environments worldwide. In sub- Saharan Africa, the use of new pesticides and genetically modified seeds actually backfired and resulted in lower levels of production in the long run. When

> pesticides, fertilizers and genetically engineered crops were introduced to the area's agricultural land area, plants initially surged in growth and production. The pesticides were successful in protecting the crops for only four harvests when the insects developed enough resistance to the pesticides to once again infest the plants. By this time the entire land area that had been cultivated as a habitat for the newly introduced GE crops had been destroyed. The soil could not turn over quickly enough between harvests to accommodate the production of crops in such amount. Rather than slow the production down in order to allow time for the new crops to adapt, the native farmers increased the use of foreign fertilizers and pesticides. Today, this sub- Saharan area is deserted as the land is of no value.

Leopold does not limit our thinking to understanding our own role, but to better understand the role of other creatures which we had formerly dismissed. He mentions that shortly prior to his writing, humans thought of predators in terms of exterminating threats to them and their resources. Now we understand their roles and their benefit to our biotic system.

Stem cells are cells that have the remarkable potential to develop into many different cell types in the body. Serving as a sort of repair system for the body, they can theoretically divide without limit to replenish other cells for as long as the person or animal is still alive. When a stem cell divides, each "daughter" cell has the potential to either remain a stem cell or become another type of cell with a more specialized function, such as a muscle cell, a red blood cell, or a brain cell.

There are three categorizations of stem cells; totipotent cells have the potential to be total and give rise to all different types of cells in the body, multipotent cells give rise to a smaller number of different cell types, and finally, pluripotent cells give rise to any type of cell in the body. Pluripotent stem cells are isolated from human embryos that are a few days old. Cells from these embryos can be used to create pluripotent stem cell "lines", cell cultures that can be grown indefinitely in the laboratory. Pluripotent stem cell lines have also been obtained from fetal tissue (older than eight weeks of development).

Pluripotent stem cells, while having great therapeutic potential, face formidable technical challenges.

These challenges need for scientists to study how to control cell development into all the different types of cells in the body. Also, the cells now available for research are likely to be rejected by a patient's immune system. Another serious consideration is that the idea of using stem cells from human embryos or human fetal tissue troubles many people on ethical grounds

There are currently several limitations to using adult stem cells. Although many different kinds of multipotent stem cells have been identified, adult stem cells that could give rise to all cell and tissue types have not yet been found.

These same land use theories must be applied to new organisms created by humans. We will have to realign our thinking in many similar ways. Animal cloning and stem cell research have raised numerous ethical concerns among various groups over whether or not it is a necessary practice. Of particular concern to many people are the costs and benefits of animal cloning and stem cell research. A major dilemma regarding these practices using genetic modification is that our world is hung up on motives and context for using this technology. This holds to be especially true when dealing with stem cells since it is a relatively recent science that is not widely understood.

The ability to clone mammals became possible only one decade ago, however, the practice of cloning animals is one that has been tested and improved for an entire century. Until recently, animal cloning was a mystery and experiments included basic tools, such as plates and strands of hair. As cloning processes became successful the ease of cloning caused alternative social reactions. While some argue for the continuation of cloning development, others claim that the process is unnatural with the use of modern technology and that the more cloning is investigated, the further it will lead. This argument is comparable to the use of GMO's. The ability to produce crops in higher quantities results in environmental degradation, similar to potential threats of animal cloning. While physical threats apply to the result of unregulated animal cloning, ethical debate proves to be at the base of the controversy.

A major ethical concern with animal cloning is how these cloning procedures will affect the animal's welfare or their intrinsic value. Studies have shown that transgenic animal's are cloned successfully at a rate of one to five percent. The problems that these animals must face for example are: deformity, fatal bleeding disorders, arthritis, tumors, stomach ailments, kidney disease, diabetes, inability to nurse and reproduce, behavioral and metabolic disturbances, high mortality rates, and large offspring (progeny) syndrome. It is obvious that these do not contribute to an animals' welfare and are viewed as extreme cases of animal cruelty in the eyes of activists. In addition, by altering the genotypes of theses organisms, the argument has been made that the organism's intrinsic value has been depleted. As a result of these findings, numerous citizens have viewed animal cloning as an unjustifiable process. Even though both of these ethical concerns have proven to be true, the government still aims to further its research in the area of animal cloning by conducting more studies.

The costs of animal cloning seem to be great, but they can be countered by the benefits attributed to cloning. The benefits are viewed closely by scientists and they seem to be extremely excited about the new possibilities that cloning has brought to science. An example of a benefit could be that of an endangered species; in the case of the giant panda it may be the difference between existence and oblivion. Among the largest areas that has been affected by cloning is animal research; experiments involving animals will be much more easy to control if all the animals are physiologically homogenous. Fewer animals will be needed for experimentation, and the results will be better. The pharmaceutical industry is interested in cloning for the reason that important proteins can be added to animals then delivered through milk and other sources. These proteins can then be made into medicines that can combat some of the most problematic diseases that are present in today's society.

It is obvious that animal cloning, stem cell research and land use practices are done by humans for the benefit of humans. The ethics behind these processes are constantly questioned and both sides of the ethical issue raise good points. In order to decide if these practices should continue the costs and benefits must be weighed against each other in each discipline. Since the amount of animal cloning has not declined it can be assumed that the benefits continue to outweigh the costs. The benefit cost analysis for stem cells is yet to be determined since substantial concrete evidence is still lacking. Land use on a global scale is steadily changing because people are finally beginning to become environmentally conscious, which has lead to the implementation of sustainable practices.

# 4. The policy of genetically engineered organisms

STEPHEN KIRK, HEATHER NICHOLS

In addition to presenting unique ethical concerns, the creation and use of genetically engineered organisms (GEOs) brings new and relatively recent challenges to policy making. By the early 1980s, the United States (US) Supreme Court ruled that genetically altered life forms could be patented. In 1986 the first genetically modified crop, gene-altered tobacco plants, was approved for commercial release in the US by the Environmental Protection Agency (EPA). Then, in the early 1990s, the Food and Drug Administration (FDA) declared that genetically modified foods are "not inherently dangerous" and do not require special regulation due to their "substantial equivalence" with traditionally bred crops (AExcellence, 1999). This prompted the release of the first genetically engineered (GE) food product, the Flavr Savr tomato. Since the release of the Flavr Savr tomato, more than two-thirds of the food produced for sale in the United States contains at least some amount of genetically modified ingredients (GMOFFT, 2006). What are the current laws regulating the development and distribution of GEOs?

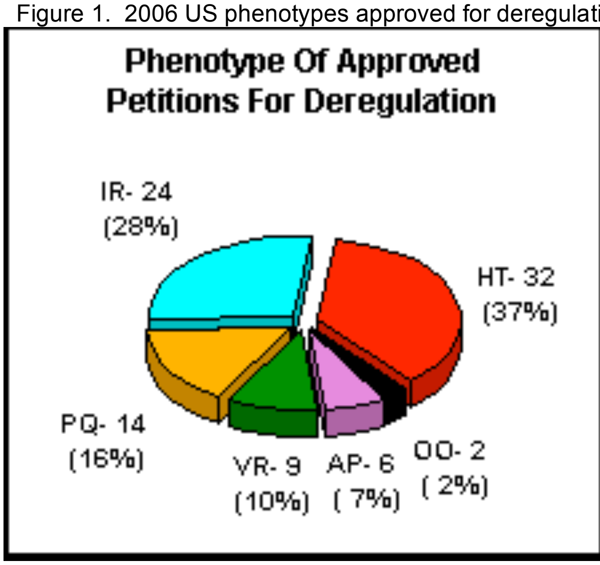
The current Federal US policy regulating the experimentation and commercial sale of genetically engineered organisms (GEOs) falls within five different laws (Federal Food, Drug, and Cosmetic Act; Federal Insecticide, Fungicide, and Rodenticide Act; Federal Plant Pest Act; Toxic Substances Control Act; Virus-Serum-Toxin Act), none of which are specific to GEOs. The regulation of genetically modified products is the responsibility of the USDA, EPA and FDA; the cooperation of these agencies is coordinated by the division of Biotechnology Regulatory Services.

The Animal and Plant Health Inspection Service (APHIS) division of the United States Department of Agriculture (USDA) has regulatory oversight over GE plant related products. The USDA-APHIS also regulates the import, handling, interstate movement, and release of these GE plants (USRAUB, 2006). Their responsibility also includes confined and field tests. A petition must be granted by APHIS to achieve a non-regulated status for a GE product. A non-regulated status grants the petitioner the right to commercially release their product and to no longer be subject to oversight by the regulatory agencies. The petitioner must supply information regarding the biology of the recipient plant, experimental data and publications, genotypic and phenotypic descriptions of the genetically modified organism, and field test reports (USRAUB, 2006). Then regulatory scientists review this information to further evaluate the potential for plant pest risk, disease and pest susceptibilities, the expression of gene products, new enzymes, or changes to plant metabolism, weediness and impact on sexually compatible plants, agricultural or cultivation practices, effects on non-target organisms, and the potential for gene transfer to other types of organisms (USRAUB, 2006).

The regulatory roles of the EPA and FDA are considerably less than the USDA. The EPA regulates GE products with a required registration process by which they acquire information in order to identify and regulate potential hazards and exposures of GE products (USRAUB, 2006). In particular, GE products which express a pesticidal effect, such as Bt corn, must be closely monitored in the field testing process. The FDA regulates GE products through the enforcement of the Federal Food, Drug, and Cosmetic Act. The FDA provides a voluntary consultation process to ensure producers will meet required standards of the law (USRAUB, 2006). Although the consultation process is voluntary, the producers must fully meet the FDA's human health and safety standards, specified on their website, before deregulation may be granted. However, currently there is a lack of any regulation mandating human testing of GE products before their commercial release.

Herbicide tolerance and insect resistance are the most common phenotypic traits expressed in GE products which were deregulated by the Biotechnology Regulatory Services in 2006 (figure 1). This is consistent with the trends of recent years. Approximately 1,000 GE products were approved for field testing each year over the last 10 years (figure 2). The most abundant GE crops, reported in 2005, to be grown commercially world wide were herbicide resistant soybeans and insect and herbicide resistant maize and cotton (figure 3).

Figure 1. 2006 US phenotypes approved for deregulation




(data from Biotechnology Regulatory Services 2006)

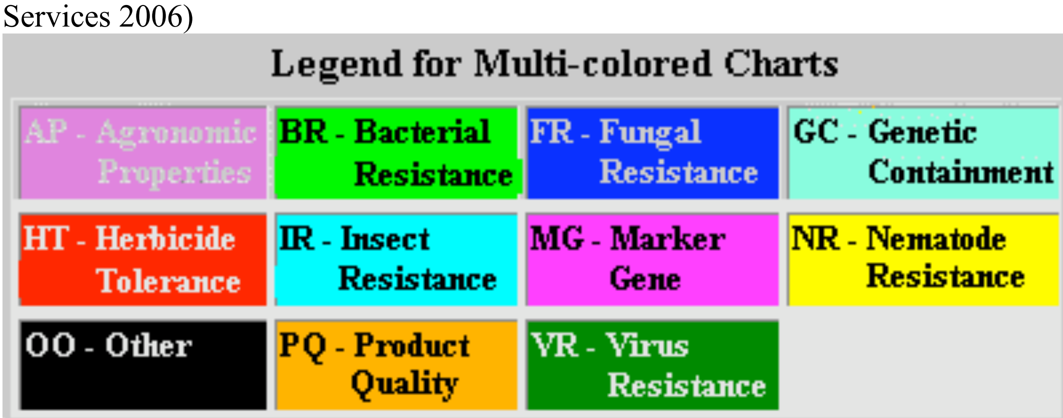
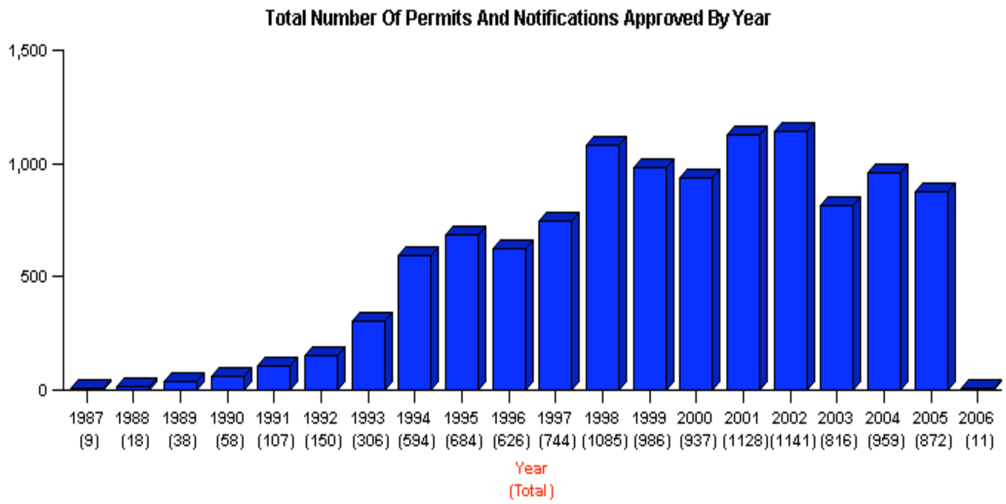



Figure 2. US total number of approvals for field testing of GE products




(data from Biotechnology Regulatory Services 2006)

Figure 3. Most abundant global GE crops

| Global area of genetically engineered crops, 1996 to 2005: By crop (million hectares) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Crop | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 |
| Soybean | 0.5 | 5.1 | 14.5 | 21.6 | 25.8 | 33.3 | 36.5 | 41.4 | 48.4 | 54.4 |
| Maize | 0.3 | 3.2 | 8.3 | 11.1 | 10.3 | 9.8 | 12.4 | 15.5 | 19.3 | 21.2 |
| Cotton | 0.8 | 1.4 | 2.5 | 3.7 | 5.3 | 6.8 | 6.8 | 7.2 | 9.0 | 9.8 |
| Canola | 0.1 | 1.2 | 2.4 | 3.4 | 2.8 | 2.7 | 3.0 | 3.6 | 4.3 | 4.6 |
| Squash | -- | -- | 0.0 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Papaya | -- | -- | 0.0 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |
| Potato | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | -- | -- | -- | -- |
| **Total** | **1.7** | **11** | **27.8** | **39.9** | **44.2** | **52.6** | **58.7** | **67.7** | **81.0** | **90.0** |
| Source: ISAAA, Clive James, 2005. | | | | | | | | | | |

Despite the laws and regulations applied to genetically engineered organisms in the United States, some controversies have arisen. One example is the genetically engineered StarLink Corn that was not approved for human consumption but only for the commercial sale of animal feed and the production of ethanol. A 660-foot buffer for the planting of this crop was required to avoid possible food contamination. After numerous reports of severe allergic reactions in people to various corn products in the U.S., tests began to detect the StarLink Corn in various foods, such as Taco Bell tacos and Kellogg brand products. The US regulatory agencies demanded that the sale of the corn end and massive food recalls were made. In the first year after the corn was withdrawn from the market, the USDA reported that 8.6 percent of samples tested positive for the StarLink Corn. The developer, Aventis CropScience, was sued by many and was forced to negotiate a 17-state settlement for $110 million (Jacobs, 2003). As a result of the containment issue indicated by this incident, the US Federal Government will no longer allow the release of a genetically engineered crop with suspected harmful human effects.

How does US policy compare to the rest of the world? The United Nations has attempted to unify the countries of the world under one policy. In 2000, the Cartagena

Protocol on Biosafety was created; its recommendation regarding GEOs takes a precautionary approach. The precautionary principle is defined as the idea that if the consequences of an action are unknown, but are judged to have some potential for major or irreversible negative consequences, then it is better to avoid that action. One-hundred thirty-two countries have ratified the protocol (UNEP, 2004), however, the United States is not one of these countries. With limited participation in the protocol, international enforcement is difficult. It was reported in 2003 that 35 countries with 3 billion people (half of the World's population, including major U.S. trade partners outside Europe) now require interstate safety approvals, segregation, and labeling of GE food (PCIT, 2003).

Indeed, the policy regarding GEOs varies throughout the world. There are typically two approaches in defining GEO policy (process vs. product based). The United States has adopted a more product based approach to their GEO policy. This approach focuses on the phenotypic characteristics of a GE product. The focus is on a desired outcome and there is little regulation on the methods (i.e. genetic engineering) that produce these results. The release of GEOs into the environment is based on a concept of familiarity: "Familiarity considers whether the GM (genetically modified) plant is comparable to its traditionally bred counterpart in environmental safety" (Nap et al, 2003, p 9). Regarding GEO labeling for human consumption, the only requirement in the U.S. applies to USDA approved organic foods in which, among other requirements, must not contain genetically engineered products.

The European Union (EU) supports the precautionary principle in guiding their GEO policy and enacted a moratorium on GE products in 1998. The procedures for developing their GEO policy are process based or focused on the actual methods of the genetic modification of organisms than the subsequent study of the effects of the GEOs. The newness of the technology and the lack of known long-term effects contribute to the EU's policy stance. The World Trade Organization (WTO) ruled in favor of the U.S. in 2004 that the EU must lift its moratorium on GEOs because it violated international trade law. Since the introduction of these new types of GE food products, the EU has adopted strict labeling requirements. The consumers in Europe seem concerned about the potential risks of GEOs and have refused to buy many GEO products.

Similar to Europe, Africa supports the UN Cartagena Protocol on Biosafety. Some countries within Africa even have bans on famine relief food that contains any GEO products. At a press conference in Washington in 2003, Amadou Kanoute, regional director for Consumers International Office for Africa (CI-ROAF) in Zimbabwe, and Dr. Drinah Nyirenda, the Zambian executive director of the Program Against Malnutrition (PAM), expressed concerns for the unknown health effects of GEOs for Africans, considering that corn and other grains, which are common GE targets, comprise 70 percent of the caloric intake of average Africans versus just 3 to 4 percent of average Americans' caloric intake (PCIT, 2003). They also expressed concerns that the environmental release of GEOs may threaten the biodiversity of Africa's fragile environments. Furthermore, if non-GM agricultural products were contaminated with GEOs and Africa's major trade partner, the EU, refused African products due to their low consumer acceptance of GEOs, the economic effects could be irreversible.

Throughout the world, GEO policy remains quite controversial. The commercial market is dominated by 5 countries (United States, Argentina, China, Canada, Brazil) (figure 4). In addition to an international policy divide over GEOs, many localized disputes have arisen. In the United States, a coalition of farmers, consumers, and environmental activists have sued the U.S. Government in February 2006 over the approval of GE alfalfa. The claim is that the government failed to properly assess the health, environmental, and economic consequences of this approval. In Canada, a group of organic farmers has appealed a case to the Supreme Court claiming the seeds of Monsanto GE canola have permanently contaminated their organic canola market share. In 2004, Monsanto Co. challenged Brazil's GEO ban due to the smuggling of Monsanto GE soy seeds from Argentina. It is estimated that about 30 percent of Brazil's soybean crops are products of these illegally obtained seeds (SLBJ, 2004). Cases like these and many more continue to challenge GEO policy around the world today.

Figure 4. GE crop distribution

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# 5. The effects of genetically engineered organisms on pesticide/herbicide use and the economy

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A big question that is often posed concerning the use of Genetically Modified Organisms is whether or not this technology will help lead to a decrease in pesticide or herbicide use. In conjunction with this issue; many are interested as to what, if any, possible influences GMOs may have on the certain sectors of the economy. In this paper we will briefly explore how pesticide and herbicide use has changed in light of GMOs, as well as what affects they have had on the US economy. We will conclude with an overview the 2003 WTO case involving GMOs, and the US vs. the EU and what impacts this has and potentially will have on GMO use in the future.

As we stand today, two genetically modified technologies account for a majority of the genetically engineered crops used in current farming. The first group is a technology known as Roundup Ready, which accounts for 2/3 of all GMs used in the United States. (Benbrook). In short, this technology allows for the application of herbicides and pesticides without damaging the overall health of the crop by creating an inherent tolerance to these types of treatments. This technique has benefits for farmers in that it increases the number of sprays they can employ, to control pest or weed populations, without hurting their own crops. From this it is easy to observe why the introduction of Roundup Ready has not decreased the amount of herbicide and pesticide use, but rather it has spurred an increase in their employment. For example, the ¼ of American farmers who switched from weed management systems to Roundup Ready soybeans actually doubled the amount of herbicides they applied to their fields. (Benbrook).

The final 1/3 of genetically modified technologies is made up of a modification known as the BT-transgenic which uses a bacterial toxin technology to serve as an insect management system. (Benbrook). Unlike Roundup Ready, the Bt toxin has shown promising results for the decrease of herbicide and pesticide use. For example, the implementation of Bt cotton in many states has initiated a decrease in pesticide use from 3 treatments per acre per year in 1995 to 0.77 treatments in 2000 for these same cotton fields. (Benbrook). It is, however, cautioned that while this may seem like a great solution to our insecticide use problem, the Bt toxin's success has been largely isolated to this single crop and has little if any effect on reducing pesticide use for other harvests. Another worry is that so-called "super-pests" are evolving a resistance to Bt crops, which may marginalize its use in the future. These final concerns serve as sobering reminders that further research is needed before the Bt toxin can be relied upon as an insecticide reducing technology.

What economic impacts have genetically modified organisms had or could they have on different sectors of the US's economy? As has been observed in many previous cases, the potential benefits of technologies can never truly be realized until it becomes financially viable for those for which it was developed. For instance, a GM crop may completely end the need for pesticide use altogether, but if it comes with a cost uneconomical to the farmer, its employment will never occur. This case exemplifies why there has been great concern in recent years over the price of GM technologies. Since their development, the prices of GM seeds have increased by roughly the same amount as pest management expenditures have fallen. (Benbrook). For example, many feel that the Bt toxin is grossly over-priced due to patents which don't allow for much economic competition. Furthermore, it is projected that the company owning Roundup Ready strawberries will soon release technologies that will be valued at upwards of $150 per acre. (Benbrook). Without the loosening of patents on GMO technologies, companies will continue monopolize market prices and the full advantages of GM crops may never be entirely appreciated. However, it seems that with every rule comes at least one exception. In this case that role is played by Roundup Ready soybeans. Since the termination of the Roundup parent patent in 1996, the price of these soybean herbicides have dropped by nearly 50% due to the increased competition in the market. (Benbrook). This case serves as an excellent example of the potential economic gains users of genetically modified crops can realize. In general, however, GM technologies will need to become more affordable to farmers before widespread use or benefits can be appreciated.

In addition to concerns about rising GM technology costs to producers, are worries that the exclusion of these crops in the marketplace will have negative economical consequences for lower-class Americans. Specifically, much debate has been centered on the sole use of organically grown crops. Lately, it has been considered, that the high cost of production of organic crops has lead to purchases of these products, throughout the US, almost exclusively by the middle and upper classes. The abandonment of genetically modified crops and the adoption of organic crops, would lead to an immense price increases on everyday foods because the increase in production costs would be seen in the enlarged price experienced by the consumer. This shift would have detrimental economic affects for those without sufficient monetary resources as they would see a drastic change in their every day lives. This case exhibits yet another instance of why price stability is essential for GM technologies. Without it, farmers are forced to utilize more expensive techniques that will eventually lead to an increase in costs to the consumer.

So how have GMOs affected international economics? One good example is the WTO case with regards to GMOs. On May 13th of 2003, the United States filed with the World Trade Organization against the moratorium placed on genetically modified foods by the European Union. (Benbrook). The US's endeavor was an attempt to stop the EU's halt on the influx of GM products from the states and to force them to except this merchandise. This action, by the European Union, was having disastrous effects on the sales of US produced genetically modified goods, and was creating a missing market for many farmers and GMO companies. The eventual verdict, by the WTO, that the EU's suspension of GMO foods was illegal, has forced Europe to now deal not with *if* these products will enter their borders, but how they should be regulated. While Europe has moved slowly in their effort to control GM products, the United States has forged ahead. Agencies such as the FDA, EPA, and USDA have all proposed rigid requirements in efforts to regulate genetically modified products. For example, the FDA has recently recommended that labeling be administered to goods indicating whether or not they have been developed using bioengineering. (Levy). This regulation is just the beginning of what will be an extensive evaluation before GMO products will be readily accepted by not only US consumers, but possibly consumers worldwide.

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# 6. The health effects of genetically engineered organisms

ELLIOTT RITTER, TYLER SPARKS

The introduction of Genetically Modified Organisms (GMOs) has given people the ability to consume food that has been altered from its natural state. There are benefits to having GMO's available for consumption, mainly additional nutritional values. Additional benefits such as the addition of vitamins, increased yield, reductions in pesticide use, reduced ground water contamination and lower mycotoxin levels all give GMOs an advantage over regular crops. On the other hand, there are also detrimental human health effects that can occur from consuming GMOs. Antibiotic resistance, allergic reaction, and unnatural breakdown of the genome can all occur after the consumption of GMO's.

In the United States, risks of genetically modified foods are assessed and managed under various statutes that have the intent of assuring that new technologies meet safety standards, which vary according to statute. These statutes were enacted during different eras and under various congressional committees and agencies, so they constitute a patchwork that has been held together via a White House "Coordinated Framework on Biotechnology." Risks related to GMOs are in the jurisdiction of three agencies, the U.S. EPA, the U.S. Department of Agriculture (USDA), and the FDA (Athertone, 2002). Problems can arise when foods are genetically modified. The overall genome is changed, either by viral promoters, transcription terminators, or antibiotic resistance markers. This genome alteration effects how the human body reacts to the food that is consumed.

Insertion of genes into the genome can result in unintended effects in the human body. DNA does not always break down in the alimentary tract, and this increases the possibility of antibiotic resistance (Athertone, 2002). When a genome is genetically modified, the sequence of DNA changes. This change in sequence may result in someone reacting negatively to the new genome of the organism. The U.S. EPA is concerned about the potential for adverse immune effects of proteins, especially regarding food allergies. Unfortunately, proteins that are allergens do not have properties that completely differentiate them from other proteins. Allergens interact with the immune system in a two-step process: sensitization and allergic reactions. Allergic reactions are associated with a spectrum of adverse effects. In young children, food allergy can cause chronic diarrhea, adversely impacting nutritional status and growth. Food allergy can also cause acute allergic reactions, called anaphylaxis. Severe anaphylaxis can cause anaphylactic shock, severe respiratory and cardiovascular symptoms that can result in death (Pusztai, 2001). Although there are no documented cases of humans dying from consuming GMO's, there are many cases where people have gotten extremely ill (Athertone, 2002). This is the main reason that some GMO's can cause allergic reactions.

Genetic modification could theoretically create unintended changes in the plant, which could result in expression of new allergens or in increased expression of endogenous allergens. This potential hazard has been a concern for Starlink Corn. The protein, or proteins, purposely expressed as a consequence of genetic modification could be allergenic. Starlink was not intended for human consumption and was somehow put into the food supply and found in taco shells and tortilla chips being sold through out the country. People reportedly were having violent reactions after consuming products that contained the altered corn. Some argue that this is not a valid case because Starlink corn was not intended for human consumption. However, it does bring up the issue of the safety of such modified crops.

There are currently several government agencies that regulate GMOs. Normally, crops are tested for known macro/micro nutrients and toxicity (Shutske, 2004). Since GMOs do not have known toxicities, it is difficult to test them on humans. There is the potential that these modified organisms we consume on a daily basis could cause serious illness, if not death. As we have seen in the past, human safety is potentially at risk. With the introduction of new GMO's on a fairly regular basis, negative reactions may occur at any time. Further studies need to be conducted to see what effects these organisms may have if consumed by humans.

While there is little scientific research on the human health impacts of GMO's, the potential benefits are countless. Economically, genetically engineered crops are less costly to farmers and make more efficient use of land. Crops engineered with GMO's require smaller amounts of herbicide and pesticide applications per acre then crops without GMO's, and provide more yield per acre. GMO's may also be used to fight severe climate conditions including drought and freezing conditions. In one well known example, genetically modified organisms were used to combat some of the world's nutrition problems, such as Vitamin A deficiency (VAD), an important nutritional problem in the developing world.

**Golden Rice:**

The region of focus for golden rice is southwest Asia, where the main source of caloric intake is rice. Much of the population in southwest Asia does not have the resources or money to acquire a healthy diet of vitamins. Those who are at a financial disadvantage rely heavily on traditional rice for their nutrition. Because traditional rice lacks vitamin A, they are at greater risk of VAD due to the absence of vitamin A in their diet. Children are the most susceptible to vitamin A deficiency. According to the *Forth Report on the World Nutrition Situation*, estimates of 2.8 to 3.3 million preschool children are diagnosed with clinical vitamin A deficiency, and an additional 75-140 million are diagnosed with sub clinical vitamin A deficiency (Dawe et al, 2002). Due to this problem, Golden Rice was created to help combat VAD on a global scale.

Vitamin A's primary physiological role is in vision and maintenance of the general health of the eye, with a myriad of secondary roles, such as maintenance of the immune system (Dawe et al, 2002). One potential solution to this problem is to genetically engineer rice with enhanced vitamin A concentrations. This engineered rice is called Golden Rice (because of its yellow color). Golden Rice was developed to provide a new, alternative intervention to combat VAD by genetically engineering rice to contain beta-carotene (which is metabolized into vitamin A) in the endosperm of the grain (Dawe et al, 2002).

In response to the VAD problem, the governments of southwest Asia have begun to seek other solutions. Food fortification and supplementation have been considered to help alleviate this problem. Fortification of food is comparable to the enhancement of foods, where the desired vitamin is in higher concentrations. An example of this is the fortification of wheat. The problem lies in the loss of these vitamins in the cooking and storing of the product. Vitamin supplementation is another good solution to VAD. Vitamin A in capsule form could have a major impact on VAD within southwest Asia. The costs of implementation and availability of supplementation to the population is expensive and requires substantial of government involvement. Golden Rice provides the same amount of vitamin A and beta-carotene as food fortification and supplementation but is much cheaper and can be widely dispersed throughout a region.

Overall, genetically modified organisms have the potential to have a positive effect on human health. If Golden Rice can prevent VAD, other foods may also be able to improve health issues in the future. Further research is required to understand additional benefits and risks of GMO's. After further research, GMO's will perhaps be of great use in improving the health of the human race. Until then, alternative methods such as fortification and supplementation should be used to improve nutrition.

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# 7. Risks of hybridization and horizontal gene transfer

OWEN MCENROE, KENDALL OLSON

As research and implementation of GMO production for agricultural purposes becomes increasingly widespread, threats to the environment become ever more apparent. One risk to the environment that can result from the use of transgenic life forms is hybridization. (Snow et al, 2005). Hybridization can occur between two different species that are similar enough to interbreed. In ecological terms, these two species would be called wild relatives.

Wild relatives of both GM plants and animals face a significant risk of receiving the traits that are exhibited by their engineered counterparts through hybridization. These traits would include among others, resistance to insects, harsh weather, and disease (Arriaga et al, 2005). While it sounds beneficial that a wild plant or animal would be able to possess these qualities, it could actually be detrimental to biodiversity and ecosystems (Snow et al, 2005). Hybridization may allow the hybrid species to dominate and thrive in an ecosystem. Potentially putting other non-related populations in jeopardy from this new, potentially "weedy" arrival (Snow et al, 2005).

The risk of gene flow from transgenic organisms to wild relatives depends on the mechanisms of the DNA spread (Conner et al, 2003). For plants, this depends on the pollination methods that could take place in an ecosystem. These processes could include pollination by wind, water and insects. Wind and water pollination would be less likely to cross a buffer zone, an area of open space that separates natural plant life from agricultural terrain. It has been measured that gene flow distance for a transgenic squash in Mexico was only 400 meters. (Arriaga et al, 2005). Insect pollinators, however, can bypass these buffer zones easily- bees can move pollen over distances beyond 1000 meters- and could possibly pollinate the wild relatives of the GM plant (Arriaga et al, 2005).

A risk assessment of the release of a transgenic squash in Mexico has raised certain questions and concerns about the potential hybridization between the GM squash and fifteen related species (Arriaga, et al 2005). This evaluation concluded that it was essential for governing bodies to utilize studies in relation to reproductive limitation between the GM squash and its wild relatives before an agricultural release takes place. This realization emerged when all of the mentioned possibilities of risk were seen to be imminent.

GM animals can also potentially cause a hazard to wild relatives in the event of a release or an escape, where the GMO would sexually reproduce with a compatible species to generate hybrid offspring (Goldburg, 2000). Hybridization does not seem to be a risk with genetically modified laboratory animals, but with the increasing technological advancement of transgenic fish, this would be a threat to biodiversity or create an invasive species.

An assessment of transgenic salmon aquaculture presented benefits as well as risks to the implementation of this technology. A key advantage is the fact that humans can make use of this fish farming as a way to decrease the need to possibly over-fish a natural ecosystem (Entis, 2000). According to Maclean and Laight (2000), a transgenic organism added to an American diet would be cheaper and "greener." Besides potential health and ethical issues, the major problem would occur only in the incident of release or escape into an ecosystem (Maclean and Laight, 2000). This could happen in the event of a flood or if birds transported the eggs to a body of water. The GM fish could possibly create hybrids with wild relatives or take over an ecosystem as an invasive species.

According to the evaluation, containment of these GM fish should be centered on making them sterile. Although sterile salmon would not be able to breed, they could still introduce competition and predation against other fish species (Goldburg, 2000), potentially affecting community and ecosystem dynamics. However, in accordance with Maclean and Laight (2000), this would only be for a certain amount of time before the competition would die off. Sterility could potentially be ensured by way of two methods, triploid induction and transgenesis (Maclean and Laight, 2005). Preventing the second meiotic division of an egg after it has been fertilized is an example of triploid induction and would produce only triploid fish, which would be unable to breed (Rottman et al, 1991). Transgenesis is another method of sterility, which would help to control escaped hybrid populations. Transgenesis techniques interfere with genes and/or proteins necessary for fertility (Maclean & Laight, 2005). Other methods of containment proposed by Maclean and Laight (2005) include geographical isolation, thermal, biological and physical control. Geographical isolation would mean producing GMO's in an area unsuitable for survival of the transgenic organism. This approach is linked with thermal and biological control by decreasing survivability, while physical containment is simply developing better restraint mechanisms, such as, escape resistant cages or transgenic fish production indoors. If sterility could not be ensured, there is a detrimental situation that could occur, called the Trojan Gene Hypothesis, proposed by Howard and Muir (1999).

This idea presents the possibility that female organisms would mate with transgenic organisms based on their noticeable heartiness. This preference for natural females mating with transgenic males would continue the hybridization process and keep it more challenging to control (Howard et al, 2003).

Hybridization is an example of Vertical Gene Transfer, in which organisms obtain all of their genetic material or DNA from their parents. In contrast, some organisms can obtain their DNA through horizontal gene transfer (HGT), where organisms can actually take up DNA from their surroundings. There are three mechanisms through which HGT can happen: transduction, conjugation, and transformation (See Fig. 1).

One important implication of HGT is the rapid spread of antibiotic resistance in pathogens. Some bacteria have evolved proteins which can pump out antibiotics. Other bacteria have developed enzymes that can break down antibiotics. These are the products of antibiotic resistance genes, so-called because they produce enzymes or proteins that allow bacteria to live in the presence of antimicrobial compounds. These genes can spread throughout nature between bacteria when other organisms take up an antibiotic resistance gene through HGT. This can, potentially, cause a chain of events causing many organisms to become antibiotic resistant.

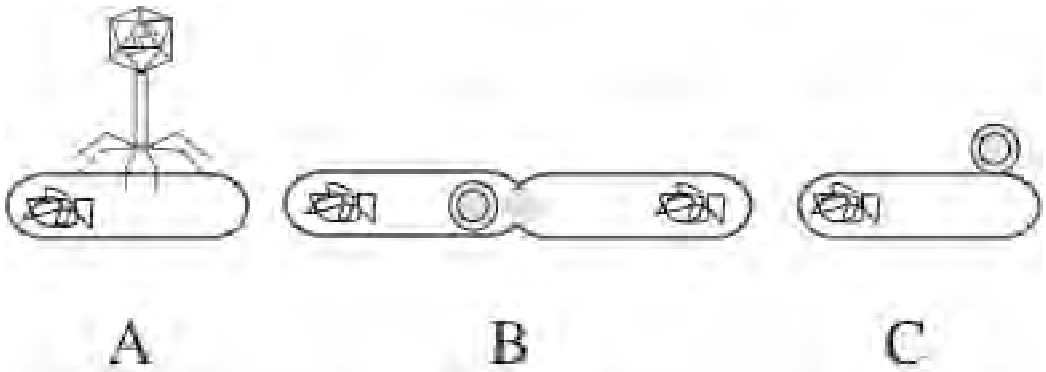


Figure 1: Three Mechanisms of HGT
A: Transduction – bacteria takes up DNA through viral infection; B: Conjugation – bacteria takes up DNA through cell to cell contact; C: Transformation – bacteria can take up “naked DNA”

Scientists often use antibiotic resistance to “mark” which organisms have incorporated other genes by physically linking the two pieces of DNA. Desired genes are often attached to an antibiotic resistance gene, since it is easier to determine whether an organism is antibiotic resistant versus looking for some specific phenotypes. Therefore, a growing concern for GMO consumption is that HGT could lead to antibiotic resistance genes being inserted into human pathogens, thus making some antibiotics useless to humans in the fight against infections. The natural bacteria that live in our body may then be able to take up this antibiotic resistance gene leading to obvious public health problems. Some scientists, however, believe that a successful transfer of DNA from GM foods into the human stomach would not happen often enough to cause human health problems. In addition, others claim point out that some antibiotics have no human clinical relevance, and therefore genes that confer resistance to these compounds pose no threat.

Has any research directly addressed the threat of the spread of antibiotic resistance from GMOs? Well, when the FlavrSavr tomato was in debate, the FDA did not know whether they should approve it because the tomato contained resistance genes to kanamycin, neomycin, gentamicin A and gentamicin B, some of which are used to combat infections in humans. The FDA tested the tomato using a simulation of the human stomach. In their test, stomach acids degraded the enzyme before it could attack orally administered antibiotics.[1] Another example of research addressing this topic is Ciba-Geigy’s Bt corn 176, which contained ampicillin (an antibiotic) resistance gene. The ampicillin resistance gene was made so that it would only be expressed (i.e. “be active”) in organisms such as bacteria, which was beneficial to the early stages of the crop. The results found that no ampicillin-inactivating protein was produced in corn plants that contained the gene, meaning that the presence of the ampicillin resistance gene was not an issue when Bt corn 176 was undergoing approval.[1] However, this does not mean that the gene is never transferred, and thus it may still be an issue.

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# 8. Risks of resistance, invasiveness and the development of superpests

JEFFREY BEAUREGARD, JACOB JANICEK

Key Words: *Resistance, invasiveness, persistence, super-pests, genetically modified organisms* (GMOs)*, Bacillus thuringiensis* (Bt)

Concern and skepticism surround the use of GMOs due to uncertainty over the potential for unintended deleterious effects on the environment. Opponents of the technology predict several disastrous scenarios; two concerns that exacerbate the challenges of using GMO technology for agriculture are: (i) hybridization between transgenic crops and their feral counterparts will create weeds or new invasive species capable of asphyxiating natural ecosystems; and (ii) evolution of insect resistance against transgenic insecticidal crops will foster ultra-resistant super-pests (Carriere *et al*. 2001; Dale *et al*. 2002; Parker and Kareiva, 1996), similar to what has resulted in some pest species from decades of conventional insecticide use. For example, the diamondback moth (*Plutella xylostella*) has developed resistance against *Bt* sprays. Such cases have given rise for concern over pest resistance against *Bt* crops, and underlie the need for developing new strategies of resistance management. Conversely, proponents of agricultural biotechnology maintain that there are no new or unknown risks associated with genetically engineering commercial crops. Consequently, consensus on the technology's safety has become increasingly hard to reach.

There are limitations to developing consensus on the risks—or lack thereof—inherent in agricultural biotechnology, which stem from the very methods used by different interest groups to assess the technology's safety. The following discussion aims to highlight these limitations, and to suggest how methods of risk assessment, experimentation, and management might be further developed in order to attain more acceptable evidence for—or against—concerns of increased resistance, invasiveness, and the creation of super-pests resulting from agricultural biotechnology.

**Invasiveness and Persistence**

Genetic engineering coupled with commercial agriculture has the potential to develop unprecedented crop plants with markedly enhanced fitness. Moreover, because many crop species have feral relatives, fitness-enhancing genes can be expected to move into wild populations via transfer of pollen by wind (Parker and Kareiva, 1996). The contamination of organic crops by wind-dispersed transgenic seed has already been realized, most notably by Percy Schmeiser,[1] so concern over accidental dispersal of transgenic pollen runs high. On the other hand, some studies have shown that transgenic crops are no more invasive or persistent than their conventional counterparts, indicating there is little risk of transgenic crops becoming agricultural weeds or invading natural

[1] Percy Schmeiser is a farmer from Bruno, Saskatchewan, whose organic canola fields were contaminated with Monsanto's transgenic Round-up Ready canola, the seeds of which were reportedly transferred to his fields via wind dispersal.

ecosystems (Crawley *et al*. 2001). Thus, the crux of the issue becomes how to accurately assess the risk of transgenic crops invading natural ecosystems and out-competing feral species. Within this context, how to measure and evaluate uncertainty and risk become critical to the task.

A number of logistical factors must be overcome before reliable risk assessment can occur. A conflict between practicality and relevance impedes experimentation aimed at assessing the risks of invasion and persistence by transgenic crops. By necessity, field trials are conducted on a small scale in semi-controlled environments. They are often limited in number and extent due to inadequate funding and lack of available space. The small scale at which field trials are conducted—often on the order of hectares—contrasts sharply with the huge scale of commercial release ultimately intended for the experimental crop(s) (Parker and Kareiva, 1996). Funding and practicality limit the size at which field trials are conducted, and the field trials in turn inadequately represent the potential behavior of experimental crops under conditions of large-scale, intensive agriculture. Moreover, post-experimental monitoring of crop plants could possibly lend greater insight into long-term variations in fitness and persistence. Experimental crops are often not tested in a wide variety of habitats. A complete assessment of invasiveness and persistence would ideally include all possible environments the plant could encounter (Parker and Kareiva, 1996), including regions with atypical climates and growing conditions.

Parker and Kareiva (1996) also suggest looking at the unmodified ancestral stock in addition to performing field trials with transgenic counterparts. If an unmodified plant shows weedy or invasive tendencies, experimentation with its transgenic counterpart should be designed to more accurately reflect these life history traits. Thus, experiments should span a variety of sites and multiple years, since population increase may be regulated by rare coincidences of favorable climatic and site physical conditions.

**Resistance and Super-pests**

Resistance is defined as the capacity of an organism to withstand the effects of a harmful environmental agent. Certain conditions influence the ability of a pest to develop resistance. One example would be strong, uniform selection on a pest population for long periods of time over large geographic areas. Modern agriculture provides these conditions through monocultures as well as heavy reliance on conventional pesticides (Snow *et al*. 2005). The risks involved with using monocultures and conventional pesticides entices scientists and farmers alike to develop new ways to prevent insect evolution of resistance against conventional sprays. Some have preferred a rotation strategy of using different conventional insecticides while others have suggested the use of *Bt* crops.

*Bt* crops were grown on more than 62 million hectares cumulatively from 1996 to 2002 enough to cover California and Iowa. These plants kill targeted insects by disrupting their mid-gut membranes. Lepidopteran (butterflies and moths) larvae are the primary targets of more than 99% of the acreage grown to *Bt* crops. According to scientists, *Bt* has records of very low mammalian toxicity and in no cases shows to be carcinogenic to humans (Tabashnik et al. 2003).

With increasing use of *Bt* crops to combat pest problems comes a concern over widespread evolution of insect resistance to these GMOs. The goal of resistance management is to delay or prevent the evolution of resistance in the target pests. There are many strategies for combating insect resistance, but we will focus on the refuge strategy because it is being implemented on a wide-scale management program in Arizona. Before explaining the refuge strategy, it is essential to clarify that the refuge model depends on the assumption that resistance comes from a recessive allele. The model is constructed with one field of Bt crops adjacent to an equal-sized field of conventional crops. Refuges with plants that do not contain *Bt* enable survival of SS (susceptible) insects. This enables both resistant and susceptible insects to survive, interact and most importantly, breed. Mating between the two insects will therefore result in three possible genotypes: susceptible homozygotes (SS), and heterozygotes (RS), as well as resistant homozygotes (RR). Only resistant RR insects survive the plants Bt plants. Large numbers of SS adults from refuges mate with rare RR survivors from the *Bt* crop. Their hybrid offspring, RS individuals, are killed by *Bt* crops. The outcome is that the R allele is eventually removed from the gene pool, which delays the evolution of resistance in the population (Carriere *et al*. 2001).

The model depends on the genetic basis of resistance, initial frequency of the resistance alleles, level of mortality caused by transgenic crops, extent of random mating between the resistant and susceptible adults, and refuge size. The fact that there are resistant insects in the model refuge fields poses some constraints to effectively implementing the method. An example of a hardship would be managing the insect population within the refuge to ensure that sufficient susceptible alleles will exist, while at the same time ensuring that damage to the refuge plants is minimized (Carriere *et al*. 2001).

Refuge strategies have not reached widespread commercial use. To efficiently combat resistance in different regions there also needs to be geographically specific resistance management regimes. There is a long way to go to ensure the efficacy of *Bt* crops for decades. To help out, the United States Environmental Protection Agency (EPA) along with the help of the University of Arizona have established with a few guidelines (see figure 1).

Figure 1. EPA mandates for implementation of refuge strategy (1996-2000).

1. Two options for non-Bt field (refuge)
    a. 3.8% of acreage is non-Bt
    b. 20% of acreage is non-Bt

2. Conventional insecticide Spraying options
    a. If 3.8% option is used, it cannot be sprayed
    b. If 20% option is used, it can be sprayed

3. Specified distances between non-Bt refuges and Bt fields
    a. If Bt accounted for >75% of cotton in a county, the 3.8% option had to be within a mile of the Bt fields
    b. No distance was specified for the 20% option
    c. If Bt accounted for <75% of cotton in a county, the distance was not specified.

The University of Arizona and the state of Arizona have implemented this strategy on a wide scale to combat the pink bollworm in *Bt* cotton fields. The pink bollworm has evolved resistance to conventional insecticides. In Arizona, *Bt* cotton accounts for 50% of the cotton acreage killing greater than 99% of pink bollworm species. The pink bollworm is a good experimental control because it completes five generations annually and it also has good potential for widespread evolution of resistance (Carriere *et al*. 2001). Unlike other insects that consume cotton, pink bollworms are specialized in that they only eat cotton. This has resulted in increased susceptibility of the pink bollworm to develop resistance to conventional insecticidal sprays and *Bt* cotton (Carriere *et al*. 2001).

The collaboration between the EPA and the state of Arizona is still ongoing. To make this experiment efficient there needs to be good communication between farmers and researchers. Evolution of resistance is inevitable, and to combat it farmers need operational and up-to-date resistance management strategies, resistance monitoring, and remedial action plans. While the EPA and the Arizona *Bt* Cotton Working Group are confident that they will come up with a formulated plan, they remain cautious and remind all farmers that they too need to be optimistic. They also remind farmers that although there is a sufficient amount of chemicals out there to combat insects, the farmers need to keep up with new mandates and new information out there to combat resistance (Carriere *et al*. 2001).

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# 9. Potential effects of genetically engineered organisms on nutrient cycling

KRISTIN JOLLY, MELISSA MORGAN

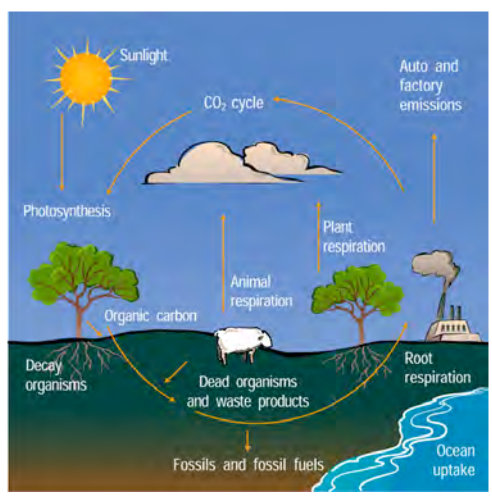
## Key Terms:

**<u>Nitrogen Mineralization</u>: Organic nitrogen is converted to ammonium and nitrate($NO_3^-$).**
**<u>Immobilization:</u> Ammonium and Nitrates are converted back into organic nitrogen.**
**<u>Denitrification:</u> oxygen is taken out of $NO_3^-$ by bacteria and the nitrogen reenters the atmosphere as gasses($N_2$ and $N_2O$).**
**<u>Bt:</u> a gene built into the plants that help protect them from insects.**

In the world of agriculture there are many factors that contribute to a healthy crop. Soil nutient status will help plants grow faster and healthier, and these nutrient cycles are very important to any crop whether it is transgenic or conventional. In recent years there has been growing concern of how some genetically modified plants can affect these soil and nutrient cycles. Many experiments have been run to test how a trangenic crop can change the concentration of carbon and nitrogen in the soil, and these works will be reviewed in further detail later. With a better understanding of nutrient cycles coupled with Bt and traditional crops, future yields could potentially have less uncertainty. We begin with an overview of nutrient cycling.

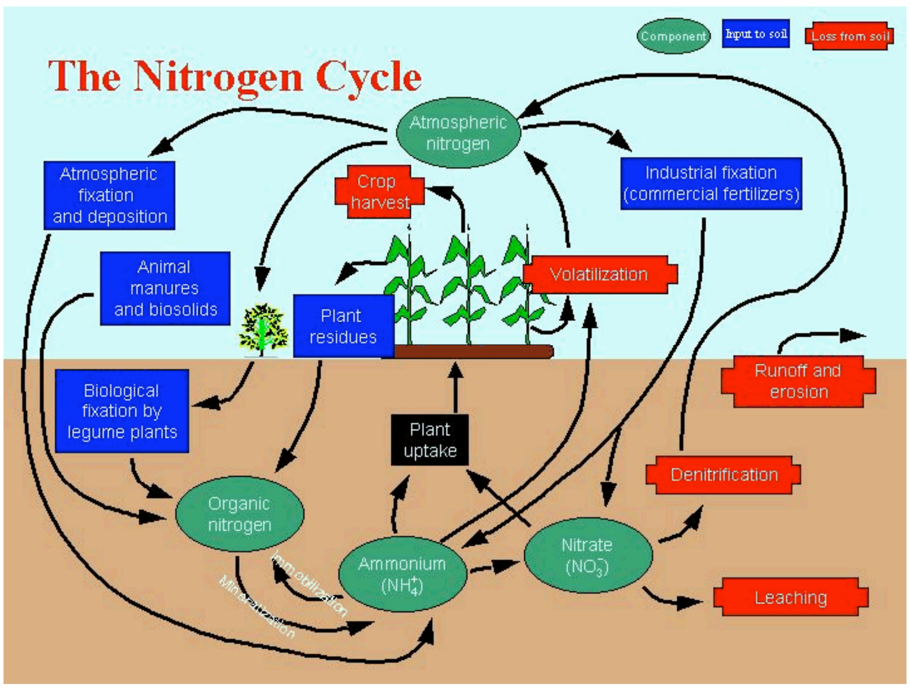
**Nutrient Cycling (Carbon):**

Plants are continually contributing to the cycling of carbon and nitrogen on our planet and in the soil. These nutrients get into the soil through many different processes. Carbon can enter the soil indirectly thru biomass decomposition. In this process living organisms take in the carbon and when they die the carbon is deposited into the soil as dead organic matter. The organic carbon in the soil is beneficial for microscopic organisms that contribute to soil health. Therefore, helping to make a suitable growing environment for crops.




**Nutrient Cycling (Nitrogen):**

Nitrogen can get into the soil in a similar way. Most of the nitrogen on the planet is located in the atmosphere and can be transferred into the soil via lightening and fertilizers. The crops planted in a field need nitrogen to grow and when the plant dies most of the nitrogen is recycled back into the soil for the next generation. This process can be disturbed when the crops are harvested, and in this case fertilizers become necessary to help the plants grow.




**Fertilizers:**

Fields can become severely nitrogen deficient when harvested many seasons in a row. With all the plants being harvested there is no way to get more nitrogen into the soil for the next generation of crops. This is where fertilizers come in. Plants require many elements to survive but they require nitrogen in much greater quantities. With a fertilizer that has high concentrations of nutrients such as carbon, nitrogen, and phosphorus the soil can be somewhat replenished even when the crops are harvested each year. However, nitrogen fertilizers can be overused. When too much fertilizer is added to a field there can be significant runoff that drains into rivers and streams. These fertilizers produce over productive plant populations, which in turn lead to over productive bacteria. The bacteria feed off the decaying organic matter left by the plants and as a result use up all of the oxygen. Most of the plants can no longer survive in a lake where most of the oxygen has been removed.

**Case Study:**

In an attempt to discover the affect that a genetically modified crop may have on these important nutrient cycles, some case studies can be looked at. Although, before diving into any case studies, it is important to make note of how soil can influence nitrogen mineralization in numerous ways. Soil properties such as particle size can have a significant effect on where nitrogen can travel in soils. Soil textures work to affect conditions for the decomposing organisms. Some of those conditions are soil to water ratio availability, nutrient availability, pore size distribution, and surface area. Finally, management practices also influence nitrogen mineralization through farmers' tillaging, which is the act of preparing a plot for seeding.

One case study, Bt versus non-Bt maize, was conducted to examine their effects on soil and nitrogen mineralization. There were three research objectives. First, they wanted to determine the difference in the composition and quantity of Bt maize and conventional maize residues grown under field conditions. Second, based in different varying soil textures (silt loam, sandy loam, silty clay) they wanted to evaluate the effect of the maize residues on nitrogen mineralization. Lastly, they wanted to, under different tillage systems, asses the effects of Bt residues vs. conventional resisdues on soil inorganic nitrogen. They performed these experiments using two methods: field study and aerobic incubation study. The field study method accomplished the first objective, while the aeroic incubation study method accomplished the second objective.

The results ended up being inconclusive. They ran this test for only two years and came up with the conclusion that Bt maize and non-Bt maize had very little differences between them, including yield amounts from both years. Also no significant differences were observed in nitrogen mineralized from Bt and non-Bt maize leaves, stems, and roots in the different soils (Figure 1). Future studies that could be conducted to make these results better would be to run it for a longer period of time and in varying climates.

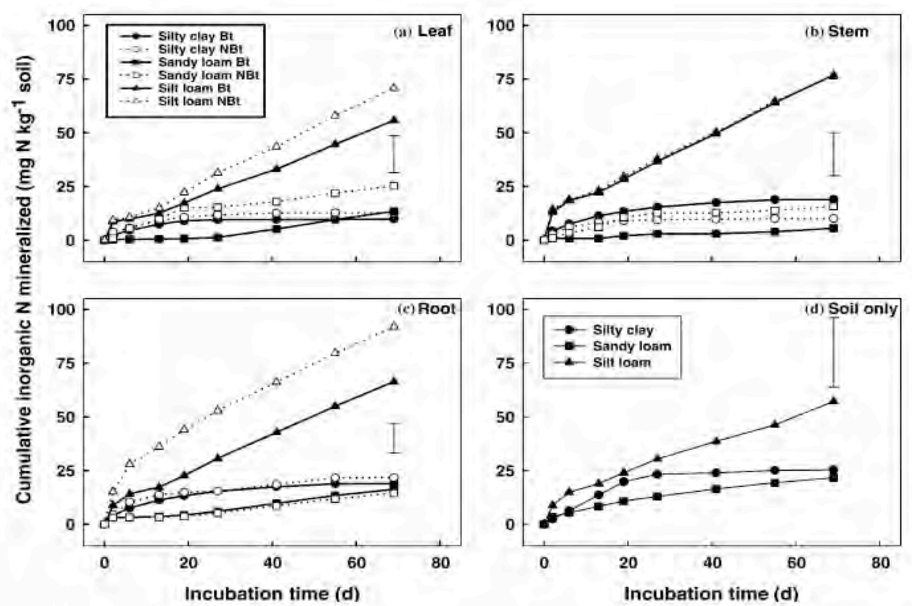



*Figure 1.* Cumulative total N mineralized in a 69-day aerobic incubation of Bt and non-Bt corn materials in soils of differing soil textures (a) leaf (b) stem and (c) root material and (d) unamended soil. Bars indicate LSD ($P < 0.05$) values at 69 days of incubation.

Further studies conducted regarding effects to the soil from crops, aside from this paper's experiment, has shown that no-tillage practices have many more benefits than this paper suggested. One paper mentions that no-till benefits include ". . .reduced pesticide (70%) and water runoff (69%), reduced greenhouse gases due to improved carbon sequestration" (Sankula, Marmon, Blumenthal, 2005). Sankula et. al's paper also mentions that carbon sequestration hints that Bt crops are actually carbon sinks and not carbon contributors. The benefit of having Bt crops be carbon sinks is that less carbon would be released into the air, thereby helping to slow global warming. However, are the benefits of decreasing carbon in the air, thereby lowering greenhouse gases, enough of a sway to not look at other risk assessments?

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# 10. Risk Assessment and management of genetically engineered organisms

ADAM BRIGGLE, MATTHEW KRUSE, RICHARD VARNER

New technologies and innovations in plant breeding have successfully increased the performance of crops today. We see dramatic improvements in yield, resistance to diseases and pests, the ability to adapt to environmental problems, as well as certain new characteristics to crops that are demanded by farmers as well as consumers (Insert Chapters). The new technology of GM crops allows agriculture to more quickly adapt to the increasing demand of a skyrocketing world population. However, GM crops are not always as good as they first appear there are risks and undesired impacts that need to be considered when looking at these GM crops such as invasion of ecosystems, horizontal gene transfer, super pests, biodiversity and human health impacts (Insert Chapters). The publics concern over GM crops is a very heated debate and in Europe the acceptance of GM crops is little to none. It becomes important at this point to set out calculating the specific harms that GM crops could bring to the public as well as the environment. Risk assessment becomes the basic tool for doing so.

Risk assessment is the first part of risk analysis. Where risk assessment (a scientific baseline for calculation of harm) leads to risk management (policy decisions) through risk communication. It is appropriate to set out a baseline for review of the risk. In this case of risk assessment, it would be the risk of GM crops as compared to a baseline of the impact of non-GM crops.

A common description of risk is the probability of harm or in its mathematical form:

**Risk=probability x consequence**
**=likelihood of event x (negative) impact of event.**

This form of risk above states that by managing the two constituents of risk probability and consequence we are able to influence the risk. When scientists look at risk they are calculating three basic questions:

**Question 1**: what can go wrong (or the possibility of harm)?
**Question 2:** how likely is that to happen (or the probability of harm)?
**Question 3:** what are the consequences if it happens (or the severity of harm)?

It is important to note that the probability of harm becomes the more relevant question than the possibility of harm. This difference in relation to GM crops is very often neglected. Probability is the true question that risk assessment looks at in trying to calculate the actual harm. Peoples' perceived notions of risk are often used more than a probabilistic calculation of risk assessment. The idea of newsworthiness adds to this problem as the news often portrays the harms of a GM crop over any benefits that they many bring. This idea of perceived or possibility that risk could happen brings forth the concept of the precautionary principal which was first brought up during the 1992 Rio Declaration, specifically in the Convention on Biological Diversity. This concept states in one of its more extreme versions that if there is doubt do not do anything. This is the basic premise behind the regulation of the EU.

Anthony J Connor states that "It may be worthwhile to have the precautionary principle work both ways and require its application to the overall situation of potential costs vs. potential benefits" (Connor, 22) So in this level of risk assessment we again ask the three basic questions from above, however, a fourth question is added to the assessment in which we add

**Question 4**: what are the consequences if we do NOT allow this GM crop?

Risk assessment is an important tool that permits some degree of calculation of probability. This provides decisionmakers with more useful information than mere lists of possible harms. However, uncertainty often remains due to the complex nature of the social and ecological systems impacted by GMOs as well as the complex behavior of those organisms and their genetic makeup. Thus, a crucial issue becomes one of communicating risks with varying degrees of uncertainty to risk managers. In characterizing risks, risk assessors must consider how to present the results of their work (derived from field or lab trials or computer models). They can do so quantitatively (e.g., there is a 40% probability) or qualitatively (e.g., the risk is moderate). These communication decisions will impact the way in which risk managers interpret the risk, thus impacting the decisions that are ultimately made. Another important variable here is the differences that often exist between risk perceptions held by the public and scientists. It may be that at times the public has an exaggerated view of the "real" risks of GMOs (those discerned by scientific risk assessors). In these situations, should risk managers strive to make policies that are receptive to the publics' concerns or should they defer to the authority of scientists?

The term "risk management" refers to the process of weighing alternatives and making decisions (policies) about risk. Risk managers must consider the costs and benefits of competing alternatives, including the status quo (i.e., decide not to act). Broadly speaking, they can make four types of decisions. First, they can avoid the risk altogether such as the EU did during its roughly four year moratorium on the importation and approval of GM crops. Second, risk managers can reduce risks as the EPA did, for example, in mandating refuges of crops not containing GM pesticides (e.g., Bt corn) in order to reduce the risk of pest resistance. Third, they can transfer risks onto other institutions or sectors of society, which agribusiness often do through insurance policies that mitigate the losses they may incur from lawsuits pertaining to any harms caused by GM crops. Finally, risk managers can choose to accept the level of risk determined through risk assessment processes, as often happens when GM crops are approved for release into the environment.

A variety of decisionmakers act as risk managers in the diverse patchwork of GMO policy. They span the spectrum from executives in the private sector to individual consumers to federal regulatory agencies. The decisions to be made about GMOs can be thought of in four broad stages, each involving different actors (people and institutions) and occurring at different scales (see Table 1). The first stage is the research and development phase of GMOs. Here decision makers face questions about whether GMOs should be created, how much money should be spent on which activities, and how the safety of lab works can be secured. The second stage concerns decisions regarding release of GMOs into the environment. Risk managers at this stage must consider the potential risks and benefits for humans and the environment. The third stage involves questions about whether and how GM-containing products and GMOs should be traded and brought to the market. Of special importance here are the trade rules established by the World Trade Organization and the conflicting international treaties made under the rubric of the U.N. Cartagena Protocol on Biosafety. Finally, risk management decisions must be made about the processing and consumption of GM-containing foods. Regulatory agencies must decide whether to give special scrutiny to such products in terms of health and safety regulations. Another important issue here is whether GM-containing foods should be labeled, which can provide information for individual consumers to make their own risk management decisions. Risk managers in different countries have made oftentimes widely divergent decisions at all of these stages, which has created a diverse patchwork of regulations around the globe.

**Table 1 Decision Matrix: The Many Forms of Risk Management**

| **Decision Type** | **Actors (general)** | **Scale** | **Actors (specific)** | **Goals** |
|---|---|---|---|---|
| Research and development | Federal gov, private sector | National, International | Monsanto, NSF, RAC, IRBs, etc. | Profit, knowledge, safety |
| Release into environment | Federal gov | National | USDA, EPA | Efficacy, Safety |
| Trade and marketing | Nat'l and int'l govs, private sector, NGOs | International | WTO, UN, Monsanto, Greenpeace | Economic growth, safety, sovereignty |
| Processing and consumption | Individuals, nat'l gov, private sector | Local, National | FDA, retailers, Wholesalers, consumers | Safety, nutrition, price, profit, company image |

*Key to acronyms: NSF = National Science Foundation; RAC = Recombinant DNA Advisory Committee; IRB = Institutional Review Board; USDA = United States Department of Agriculture; EPA = Environmental Protection Agency; WTO = World Trade Organization; UN = United Nations; FDA = Food and Drug Administration.*

## Applying Risk Assessment and Management

In chapters 1-9 we have discussed a number of different case studies presented that have intrinsic amounts of risk. By examining cases from some of these studies we can explore and interpret the different types of risk and recommend management strategies. These cases have already been addressed in public and some specific strategies for management have been adopted. However we wish to use these examples as a foundation for understanding risks and management in the world today and provoke thought on what can be done in the future.

Risks can be found in a number of separate areas concerning GMOs. An excellent example of the various types of risk involved with just one particular organism would be GM-Canola and the Percy Schmeiser[2] case. Following risk assessment procedure we must outline the risks involved. The risks associated with GM canola and its spread present excellent examples of both economic and social risks. There is a risk with spreading GM crops that farmers could be sued for patent infringement and become bankrupt. Another related risk would be bankruptcy of the farmer because he cannot maintain the “Organic” label. Organic farmers also might not know that their crop has been compromised and the organic market would then be spoiled. There is an economic risk of the organic market collapsing and pushing organic farmers out of their livelihood. With the risks and their consequences identified now we must decide on probability. From the Percy Schmeiser case we know that the risk of GM spread is highly probable. If spread is likely, than so is contamination of the organic market, resulting in the loss of the farmer’s livelihood. If the farmer is forced out of the organic market he must complete against the large agro-firms in the regular market. The overall bankruptcy and collapse of the organic market are rather unlikely but the consequence is severe so risk remains relatively high. Appropriate mitigation techniques may include creation of refuges around GM crops and periodic testing as well as statues preventing lawsuits against farmers growing unknown GMOs.

Another great study that was mentioned earlier is the transgenic salmon (Maclean and Laight, 2000). The risks associated with transgenic salmon represent mainly scientific risks and consequences. When dealing with a live transgenic organism in the outside world there is always risk for escape into the surrounding environment. Transgenic salmon are no different so their risk of escape must be assessed and managed. There are also implicit risks to be accounted for if they do escape. What is the possibility of hybridization and destroying the natural gene pool? Will the GM salmon out-compete the threatened native salmon or even eat them? Then to follow the identification of risk and consequence, the probability must be explored. Based on what we have learned probability for escape is extremely high in open sea fisheries. However, little is known about the probabilities concerning predation and compromise of the gene pool. Based on our consequence and probability calculation we can propose specific measures to decrease the risks. First, a more in depth study of escaped salmon and their tendencies once released to the wild. Second, creating a fish that would die once in an exposed environment, or making all the GM salmon sterile would prevent interbreeding. The last available measure for protection would be to raise all GM salmon indoors in sterile facilities where the escape of fish or genetic material is highly unlikely.

Bt corn and cotton also incur risk that must be managed. There are possibilities of human health effects both known and unknown, pesticide dependence, insect resistance, superpest evolution and the loss of nutrients in the carbon and nitrogen cycles. There is also the question four risk of “What is the risk of not using Bt corn and cotton?” With

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[2] Percy Schmeiser is a farmer from Bruno, Saskatchewan, whose organic canola fields were contaminated with Monsanto’s transgenic Round-up Ready canola, the seeds of which were reportedly transferred to his fields via wind dispersal.

the risks identified steps can be taken to measure the consequences should risk become reality. Consequences for the risks regarding Bt crops include allergic reactions in humans, compromise of wild varieties of maize, loss of entire crop yields due to resistance or super pests and the inability of fields to cultivate crops because of altered nutrient cycles. The probabilities of these risks are intermediate. It is unlikely the implementation of Bt crops will create a super pest to wipe out an entire crop. However, it is known that resistance is not uncommon especially in cotton bollworms. The probability also exists for human health effects to GM corn. The accidental release of Starlink corn into the market is a prime example. Therefore, the risks of Bt crops must be mitigated through refuge, monitoring insects for resistance and careful processing procedures to ensure these crops are not spread and do not contaminate other markets.

## Conclusion

As it refers to decision making processes that bring together science, policy, ethics, politics, and economics, risk management can be seen as a natural culmination for our assessment of GMOs. It raises to the fore several fundamental questions that have motivated this work. First, should we create, release, trade, and/or eat GMOs? Oftentimes the answer to these questions is yet another question: How safe are GMOs? We desire to know whether they will have a positive or negative impact on things that we value such as human and environmental health as well as social justice. This is why scientific reports and summary papers (such as this one) are so vital to helping us understand the possible ramifications of agricultural biotechnology. Yet given the enormous complexity of GMOs and the human and environmental systems they interact with, we oftentimes cannot have certainty about the outcomes of different decisions. How, then, should we act when confronted with uncertainty? Furthermore, this uncertainty often takes the form of conflicting reports from different experts. When this happens, we are confronted with yet other questions: Whose information do we trust? What are the reliable sources of knowledge? Who should have the authority to make which decisions? If we grant too much power to the scientists and engineers, we may cede the base value of popular sovereignty. Yet if we ignore scientific findings about probable futures, we may make foolish decisions. It is within this contested space and vital give-and-take between science and policy that many of the most important questions about GMOs come to life.

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