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# Experiences and Prospects of Genetically Engineered Crops

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The debate about genetically engineered (GE) crops has become increasingly polarized in the United States, Europe, and some developing countries. The debate polarization has not been resolved in and by the complex and seemingly divergent literature that examines the impacts of the actual and potential adoption and commercialization of GE crops in industrialized and non-industrialized countries. To better understand the rich literature accumulated over the past twenty years, the National Academies of Sciences, Medicine and Engineering (NAS) established a committee of experts to compile existing questions and issues from the public, collect and assess existing evidence and draw a set of findings, conclusions and recommendations to help the public and policy makers understand better the complex landscape.

The NAS Committee objective was to review the accumulated literature to better assess the purported positive and negative impacts of GE crops, as well as the institutional framework in which these technologies have been released. The analysis also included assessing the potential role that emerging genetically engineered technologies will play on future crop improvement efforts and their impact on long term goals such as food security. This article summarizes the U.S. National Academies Report. In addition, the article provides the current article author's personal clarification notes about the content of the NAS Report. Furthermore, while the NAS Report has a global focus, this article directs attention to the most important issues discussed in policy dialogues in the United States, while highlighting relevant issues and aspects from other countries.

## The Experiences

In 2015 there were an estimated 180 million hectares—or 445 million acres—planted to GE crops in 23 countries, representing roughly 12% of the world's total cropland. Almost all GE crops planted worldwide are corn, soybean, cotton, or canola engineered to tolerate specific herbicides or resist certain insect species. Other cultivated crops have been engineered for virus resistance and other traits, namely papaya, beans, squash, potatoes, and apples.

### Environmental Safety

The insect-resistance trait introduced into GE crops is based on genes taken from *Bacillus thuringiensis* (Bt), a soil-borne bacteria that produces proteins that are toxic to specific insects including a variety of crop-damaging lepidopteran insects. Evidence collected in the NAS Report indicates that Bt cotton and maize in the United States, China, and India have been effective in reducing the pressures posed by targeted insect pests. While the research is still limited, Pakistan can be added to the list of countries contemplated in the NAS report.

The NAS report documented evidence that in the United States and other countries, applications of synthetic pesticides have decreased as a result of farmers adopting Bt maize and cotton, thus providing an environmental benefit. There is also evidence that in some instances, farmers who did not adopt may have benefitted from overall reductions in local pest populations.  However, the failure to pursue resistance management strategies by farmers in some countries created the conditions for Bt resistance to emerge more quickly than the expected long term emergence of resistance, thus reducing the effectiveness of the technology over time. Although, Bt has proven effective against its target pest, it does not control other types of insects that can damage the crop, thus requiring farmers to pursue additional management strategies to deal with secondary pests as their populations built up over time. The NAS report indicates that this has been an agronomic problem only in a few instances.

The herbicide-tolerant trait allows farmers to spray specific herbicides such as glyphosate to control weeds without damaging the crop itself. Application of glyphosate and other herbicides allowed the possibility of substituting other weed control chemicals. This outcome can be construed as an environmental benefit. Consider that a number of authors in the literature have indicated that the substitution of other herbicides for glyphosate, caused a reduction in the overall toxicity load as glyphosate has a lower toxicity than the herbicides used before.

The NAS report describes evidence over the last twenty years showing increases in the use of herbicide tolerant traits in crops and in the adoption of improved soil management practices (specifically, zero or minimum tillage cultivation) that require retention of crop residues from previous crops. The NAS report indicates that establishing causal relationships between the two is difficult. As expected for an herbicide tolerant GE crop, the NAS Report found evidence in the United States and other countries of declines in the level of other herbicides used in agricultural production during the first years of adoption, and an increase in the herbicide for which tolerance was incorporated as a trait.

However, evidence in the NAS report also indicates that the decline in herbicide use has leveled off in many instances. In the case where glyphosate is used extensively, weeds susceptible to the herbicide have been replaced by those less susceptible to the herbicide thus requiring higher herbicide application rates and/or an increase in the number of applications of herbicide. Furthermore, there is evidence for the United States and other countries that some weeds have evolved resistance to glyphosate over time. This gradual process introduced more pressures for increased herbicide use. To address these issues the NAS Report identified the need for better herbicide management strategies to help delay the emergence of herbicide resistance and thus extend the technology's life cycle.

## Human and Animal Safety

The track record of GE crops regarding human and animal health safety has been widely studied. National authorities test GE crops using three approaches including animal testing, nutritional composition analysis, and allergenicity assessments. Although the NAS report found that there is a need to improve the design and analysis of animal testing protocols, findings confirm reasonable evidence of no harm to animals in the multiple studies evaluated. In the case of nutritional composition, in some instances there were statistically significant differences between a GE crop and conventional counterparts, although these differences were within the observed range of variation that naturally occurs within each crop.

Due to the expressed concern over the potential impact of GE crops consumption on a number of health issues, the NAS report examined the level of incidence in selected countries. The NAS report describes its examination of long term epidemiological datasets from the United States, Canada, United Kingdom, and Western Europe for evidence of health issues including cancer, obesity, gastrointestinal tract illnesses, kidney disease, and allergenicity. The NAS report found no pattern of difference after the introduction of a GE crop during the 1990s in the countries examined.

## Agronomic and Crop Improvement

The NAS report also reviewed evidence on the extent to which GE crops contribute to reducing damage by insects, yield improvement, and other associated productivity gains. When viewed from a broad perspective, the NAS Committee indicates that there is no evidence to suggest an increase in average rate of yield growth in historical trend data from the United States and other countries for cotton, maize, or soybeans that might be attributable to the adoption of GE crops.

As discussed in the NAS report and in the literature, many other factors beyond GE crop adoption help explain long-term yield growth. These include genetic gains achieved through conventional plant breeding, improvements in plant breeding tools and techniques, better crop and resource management practices on the farm, changes in the use-efficiency of inputs such as fertilizers and agrochemicals, access to infrastructure such as roads and irrigation, and changes in the incentives provided by market signals and public policy, among other issues.

Some first generation GE traits introduced in crops to date are engineered to embody resistance to pests, weeds, and disease. This means that the intended effects are to protect the crop from damage in a more cost-effective way than conventional methods such as insecticide applications and not to increase the crop's potential yield per se. In the case of herbicide tolerance, GE traits allow substituting weeding by hand or machine for chemical control and to introduce additional time flexibility in terms of when chemical weeding can be done. In effect, this means that replacing conventional control methods with GE crops should not be a reason to expect yield increases per se when compared to its conventional counterpart.

## Economic and Social Impacts

Evidence reviewed in the NAS Report indicated that in the case of maize, soybeans, and cotton embodied with insect-resistance and/or herbicide-tolerance traits, the financial and economic outcomes have been generally favorable for adopting farmers. Outcomes range from reductions in production costs to increases in crop revenues to increases in time available to pursue other activities, such as off-farm employment and income. Each GE technology comes with a wide range of costs and benefits that vary between the large mechanized farms in industrialized countries to smallholder farms in developing countries and within locations and over time.

Despite concerns that GE seeds would be a costly burden to farmers—especially farmers who plant saved seeds from previous harvest—the NAS Report found limited evidence to support this contention, while evidence of farm-level analyses supports the notion that higher seed costs are offset in many cases by revenue increases from reductions in crop damage and cost savings from lower input use, resulting in positive economic outcomes.

The NAS Report indicates that future adoption patterns are likely to be determined by how farmers assess these costs and benefits in the context of their own situations, including the affordability of GE seeds and complementary inputs, their access to markets and price information, and their ability to manage the GE crops effectively. The NAS report  recommended more research into the adoption, diffusion and impact of GE crops on smallholder farmers including those access limitations such as seed cost, access to productive inputs and institutional constraints such as credit and extension services.

In the case of herbicide tolerance, the NAS report found evidence that the trait provides management flexibility and reduced time required to manage the crop. In some instances in the United States, some evidence shows that additional time has been invested by family farm members in securing off-farm employment. These findings help explain the high adoption rates of herbicide tolerant GE crops in spite of no yield differences and small to no direct economic benefits in existing assessments of such crops in the United States. In all instances, the evidence presented in the NAS report shows that the utility of a specific GE crop trait is directly connected to the farm and household context and the performance and cost of GE crop seeds.

## International Trade

In the trade of agricultural commodities between countries, GE crops have introduced what is commonly referred to as "regulatory asynchronies" into international trade flows. Consider the case of countries that have invested significantly in developing and regulating GE crops such as the United States, Canada, Argentina, and Brazil. In all of these countries, GE crops—particularly maize and soybean—have been approved under domestic biosafety regulatory systems as safe for consumption for food and feed. Commodities produced using approved GE crops in a country may be exported to countries where biosafety regulatory approvals have been issued. This allows the importing country to reject shipments containing unapproved GE crops based on biosafety laws and regulations. Furthermore, some countries have introduced unilateral moratoriums and bans on GE crops trade and even cultivation.  These types of actions can disrupt international trade and put undue pressure on countries that pursue different decision-making approaches or are at different stages in developing their domestic regulatory systems and capabilities. As the international trade in GE commodities increases, greater cooperation between and among countries will be needed to address these challenges.

As more GE crops are introduced and internationally traded, in many cases with multiple traits combinations, the expectation is that trade disruptions related to GE crops will increase. If this situation is not resolved through international cooperation, this may become a very expensive development, with implications of significant cost increases for exporting and importing countries.

The disruptions resulting from regulatory delay issues may be compounded by variations in how different countries approach the issue of GE labeling. The NAS report review of the evidence shows that both mandatory and voluntary labeling approaches have their own set of advantages and disadvantages. A major disadvantage of the mandatory approach is that it tends to impose a cost on those consumers that do not require or are not willing to pay significantly higher food prices. In particular, certain countries have mandated labeling for all GE crops that express a GE trait beyond some threshold or tolerance level. That level may have an impact on the cost of the labeling scheme: more restrictive tolerance levels—that is, those close to zero—tend to be more expensive and more difficult to implement.

Voluntary labeling approaches address this issue by allowing consumers to pay a price premium that may be associated with non-GE crops that may be valued by some consumers segments. Voluntary approaches require coordinated action and compliance among producers which adds complexity, such as increased knowledge and information flows, to the value chain. The increased complexity may thus become a disincentive to provide desired information about a food required by some consumers. There are other considerations as well, such as consumers' right to know about the nature of their food, as well as ethical, religious, and philosophical dimensions of food—all of which warrant discussion at the community and national levels.

### Contributions to Food Security

The NAS Report indicates that that there is little evidence to suggest that GM crop adoption has improved long-term food security in a broad sense. This is not particularly surprising as decades of accumulated evidence have demonstrated that a single suite of technologies alone are insufficient to end hunger and malnutrition at a global scale. This does not imply that technology cannot play a significant role in addressing multiple and increasingly complex challenges compounded by climate change to help address sustainable intensification. From the standpoint of valuable GE crops, it is important for this technology to remain as a valuable tool that may contribute to addressing current and future productivity limitations.

## Prospects for GE crops

The NAS Report indicates that newer GE tools and technologies, such as gene editing, will likely lead to a wide range of benefits including direct yield increases, improvements in crop protection against pests and diseases, greater crop tolerance to abiotic stresses such as drought and extreme temperatures, improved efficiency from photosynthesis, or any combination of these and other traits. But the realization of these gains will be highly dependent on the world's ability to address policy and institutional constraints that may otherwise limit innovation.

## The U. S. Innovation System

The NAS Report discussed evidence that investments in public research for crop improvement, GE crops and other areas of R&D has declined over time. The implication is that there may be underinvestment in crops of a public interest, which may not provide significant market returns to developers. The NAS report recommends reversing this trend. Investments in crops of a public nature may be facilitated by an intellectual property (IP) regime that supports innovation.

The NAS report shows that there is disagreement in the literature on the impacts of intellectual property tools, such as patents. These may support or deter innovation and knowledge sharing. In some situations patents, including utility patents, may be used as a strategic tool to block competition. This may be the case for larger firms which may have the needed resources to secure patents and thus exclude smaller firms and plant breeders who may not have sufficient resources to cover licensing fees and challenge patents that may not have been properly granted in the first place.

In contrast, the NAS report also highlights a small set of studies presenting evidence from developing countries, where patenting and other IP systems may have helped promote private sector investments in plant improvement practices. Due to the conflicting literature, the NAS report recommends more research into understanding the way that IP may facilitate innovation in crop improvement while granting access to improved germplasm and seeds especially by small farmers in developing countries.

Access to seeds usually is supported by a competitive seed sector. The NAS report presents evidence that in the United States there are some indicators showing increased concentration in the seed market. However, there is not enough clarity as to the effect of market structure and conduct on seed prices. The NAS report recommends that more research is needed to understand the relationship between market concentration, conduct, and performance, and how pricing mechanisms work especially with the advent of multiple traits being stacked into a single crop.

## The U. S. Regulatory Landscape

Unlike conventional crops, GE crops have to comply with biosafety regulations designed to evaluate their potential impact on human and animal health and to the environment prior to commercial release. Competent regulatory authorities determine whether a specific GE crop technology is safe for release to the public. In the United States, the competent authorities are the EPA, USDA-APHIS, and the FDA. In other countries, national biosafety committees and regulatory agencies play a similar role of examining GE crops' safety.

The evidence consulted in the NAS Report shows that all methods used to improve crops can introduce changes that have the potential of becoming a safety issue. A critical recommendation in the NAS Report is that regulatory systems overseeing GE crops should not focus their attention on a specific GE crop based on how it was researched and developed, rather the focus should be on whether the trait in the product is novel. This is the approach taken by Canada in its biosafety regulatory system. Furthermore, the NAS Report recommends that any new crop variety that introduces a novel trait undergo biosafety evaluations.

Even though the biosafety system in the United States is technically product based, in practice USDA and the Environmental Protection Agency (EPA) determine what products to regulate in part based upon the process by which the crop is developed. This approach is becoming outdated and with the new emerging technologies, the distinction between a GE and conventionally bred crop will diminish dramatically to the point of being indistinguishable.

In addition to pursuing trait novelty as a regulatory trigger, the NAS report also recommends a tiered integrated approach that incorporates novelty and a focus on assessing intended and unintended effects, but also includes considerations such as potential hazard and exposure. Potential hazard identifies the impact and a level in which a negative outcome may occur, while potential exposure identifies how much a consumer will indeed be in contact with a potential hazard. It is therefore worthwhile exploring different risk based regulatory assessment models to further improve regulatory systems in the United States and in other countries especially as the new plant breeding GE techniques blur the distinction of GE crops with conventional breeding approaches.

As the policy and regulatory environment has been affected by polarization in the public opinion debate, policy makers and regulators are well advised to significantly increase their public communication efforts using strategic approaches that may help address public concerns. Researchers and product developers are also well advised to pursue communication strategies that build trust based on openness and transparency to ensure effective science-based communication. This approach is unlikely to resolve the existing polarization but will help address consumers' and the general public's issues and concerns.

## Institutional Issues Paramount

An overall conclusion that we can draw from the NAS report is that the institutional context in which GE crops have been and will be researched, developed, deployed, and adopted is paramount to their contribution to improving society's welfare and sustainability. The multiple institutional issues affecting GE crops were, indeed, a major item identified during the course of the public consultations and in the literature review for the NAS Report. Institutional issues such as intellectual property regimes, seed systems, market coordination, and integration, access to credit and financial services, access to productive inputs and to knowledge and information about technology use and markets, ability to access infrastructure may not be binding constraints in the United States and other industrialized countries, but can be real constraints in developing countries especially for smallholder farmers.

GE crop developers—especially those in the public sector—are advised not only to focus on the technical performance of such technologies, but also focus on the overall development strategies which may have an impact on the proper deployment and eventual success of such technologies. As described in the NAS Report, in some developing countries, much of observed success of GE crops adoption can be directly tied to a receptive and often coordinated value chain and institutional context. Not taking the institutional context into account may increase the likelihood of failure for a technology that has the potential of addressing many productivity issues, even those not directly addressable by existing technologies. Paraphrasing Gouse (2008) it is prudent for society to avoid the situation with GE crops where we may have "technological triumphs and institutional failures."

## Research and Policy Lessons for the Future

Consumers, Non-governmental Organizations (NGO), and special interest groups have taken more proactive roles in driving the food system discourse since 1996, when GE crops were first released. The original business model focused on farmers and in improving farmer productivity through the release of performance improving technologies that had been so successful, will need to change dramatically. Certainly, science-based approaches and evidence will play a major role in shaping the future landscape for crop improvement efforts, whether for GE or any other type of crops, but also consumer concerns and social, ethical, and in some cases religious concerns are now part of the debate. The expectation is that the research and development, policy, and regulatory communities will be able to recognize this challenge and to proactively develop new business models to ensure the proper deployment of existing and future technologies that may be valuable to ensure foods security and other short and longer terms goals.

One of the important overall lessons we can draw from the NAS Report is the need to recognize that there are many gaps, uncertainties and methodological issues related to existing assessments of GE crops in the literature. This is not a surprising state of affairs in the technology evaluation literature. Researchers, policy makers, and other public stakeholders are encouraged to embrace diversity and uncertainty in order to pursue multi-pronged approaches to the evaluation of GE crops and any other technology. This is a prudent approach that can help temper the conclusions from any evaluation effort. It is also prudent to focus on the strength of the evidence but it is equally necessary to address all public concerns and issues and to carefully evaluate the evidence.

This approach may be able to build up trust through enhanced transparency and proper consideration of biases and conflicts of interest as they may even affect the choice of evaluation methods. The current debate underscores the importance to acknowledge that the framing of many issues raised about GE crops have very little to do with science and are more drawn from ethics, religion, philosophy, and personal perceptions and biases. Finding robust and consistent methodologies to address the latter continues to be a challenge.

The NAS Report compiles existing evidence that support the finding that there are no known substantial concerns about environmental and human/animal health aspects of existing GE crops. Newer GE crops may bring additional challenges but also opportunities in terms of their ability to address productivity constraints while contributing to ensuring food security. To realize this potential it is necessary to enhance innovation, regulatory approaches and evaluation processes. Above all there is a need to improve the ability to properly frame the technology in its societal context that has become more complex over time. Only in this contextual framework will GE crops continue to be a powerful tool with much potential to improve society's welfare.

## For More Information

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