Finding Common Ground to Expand the Impacts and Potential of Agricultural Innovation

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1. Introduction

For centuries, the agriculture sector has played a critically important role in sustaining society and its needs – including the population's desire for a wide array of healthy and nutritious food sources, as well as supporting its clothing and lifestyle needs (e.g., sustainable sources for plastics, access to alternative fuels, etc.).

Throughout time, the public and private sectors ability to discover and deliver continuous innovation within agriculture has enabled farmers to keep up with the growing demands of society and deliver more harvestable yield from each acre of farmland. The last several decades have demonstrated that agriculture can make enormous progress in increasing food production per acre. For instance, cropland per capita which expanded globally from 1700 to 1950 has been reduced ever since. Importantly, between about 1980 and today, society has had to put only a small amount of incremental land into agricultural production. This has occurred at the same time that the world's population has grown from 5 billion people to 7 billion people.

Innovation on the farm has been the key and it will continue to be. In 1960, one acre of farm land supported the food production needs of one person. By 2050 – because of the planet's increasing population, dietary changes due to a growing global middle class, a changing climate and the implications for agriculture – more food will have to be grown on less land: about a third of an acre per person.

Central to unlocking the productivity gains both in the past as well as in the future will be the farmer's utilization of a wide variety of agricultural innovations and practices. Key developments in agriculture innovation include plant selection and breeding, continuous innovation in farming equipment, as well as plant biotechnology, to name just a few.

Over the last three decades, the application of plant biotechnology in agriculture and its development of genetically-engineered (GE) crops (also commonly referred to as genetically modified (GM) crops) have provided an important innovation to support agriculture's ability to mitigate on-farm challenges presented by pests and the environment.

This paper will discuss the adoption and benefits associated with GE cropping systems, focus on its safety profile and the review of the science by regulatory agencies throughout the world, discuss the pest challenges that some farmers have seen, highlight how the science is now contributing to new innovations within agriculture, and explore the role that poor quality science can have on broader public perception.

2. Adoption and Benefits of GE Technology

Since GE crops were commercially introduced in 1996, farmers around the world have rapidly adopted the products and realized a broad range of benefits from their application on-farm. Between 1996 and 2013, acres planted to GE crops increased 100-fold, growing from 4 million acres in 1996 to more than

430 million acres in 2013. In 2013, 18 million farmers grew GE crops in 27 countries throughout the world.

GE crops provide real and important benefits to farmers. Extensive field studies demonstrate that GE crops coupled with ecologically sound practices help farmers to make food production more sustainable[1]. GE crops increase productivity, protect biodiversity, reduce the environmental and human health impacts of insecticides and herbicides, facilitate the adoption of no-till and conservation tillage systems and the related environmental and ecological benefits, enable adaptation to the effects of climate change, and help farmers of all sizes to grow crops more profitably. A recently published meta analysis of 147 studies reported on average GM technology adoption has reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68%[2]. These findings are consistent with the growing weight of evidence supporting the benefits of GE cropping systems. GE crops have been demonstrated to:

Increase productivity. From 1996 to 2012, GE crops are estimated to have contributed to an additional global production of 231 millions tons of maize, 122 million tons of soybeans, 18.2 million tons of cotton, and 6.6 million tons of canola[3]. GE crops have contributed to yield increases of as much as 30%, and can contribute to poverty reduction and food security in developing countries[4]. On average, since their use began in 1996, yields have been increased by +10.4% for insect resistant corn and +16.1% for insect resistant cotton[3].

Protect biodiversity. GE crops increase productivity on existing agricultural land and protect biodiversity by sparing forests, wetlands, and prairies from conversion to farmland[5]. In 2012 alone, if GE crops were not available to farmers globally, maintaining production at 2012 levels would have required additional plantings of 12.1 million acres of soybeans, 17.0 million acres of corn, 7.7 million acres of cotton and 0.5 million acres of canola, an area equivalent to 9% of the arable land in the US[3]. In addition, insect-protected GE crops have negligible impacts on non-target beneficial organisms and require less insecticide sprays, which help predatory species to attack crop pests and prevent yield loss[6].

Reduce the environmental and human health impacts of insecticides and herbicides. Farmers have reduced pesticide spraying (1996-2012) in GE corn, soybean, cotton, canola, and sugar beet by 1.12 billion pounds (-8.8%) and as a result decreased the environmental impacts of herbicide and insecticide use by 18.7%[3]. In countries, including China, South Africa and India, these GE crops have lessened farm worker exposure to pesticide sprays, and reduced cases of pesticide poisoning and healthcare costs[7,8].

Facilitate the adoption of no-till and conservation tillage systems and the related environmental and ecological benefits. Since the first glyphosate-tolerant GE crops were introduced in 1996, no-till or reduced tillage systems have increased by about 50% in the U.S.[9] and more than 300% globally[10], due in large part by growth in North America and South America (77% of global total) where glyphosate-tolerant GE crops are cultivated. Conservation tillage reduces soil erosion, increases soil organic matter, improves water quality, conserves soil moisture, provides habitat for wildlife, reduces soil compaction, reduces fuel use and greenhouse emissions by eliminating tilling, increases the number of beneficial soil organisms and beneficial insects, and increases the number of birds and other wildlife in and around the field[3,11-14]. Importantly, GE crops have helped to reduce greenhouse gas emissions through the reduced use of fossil fuels on farm and additional soil carbon storage from reduced tillage, which was equivalent to removing 27 billion kg of carbon dioxide from the atmosphere or equal to removing 11.9 million cars from the road[3] in one year (2012).

Enable adaptation to the effects of climate change. GE technology can be combined with advanced breeding techniques to accelerate crop improvement in response to increased risk of abiotic and biotic stress, and facilitate growth of conservation tillage systems that have higher adaptability to climate change[10]. During the U.S. drought of 2012, the combination of GE crops, advanced breeding and agronomic techniques helped keep corn yields nearly 40 bushels per acre higher than they were the last time the U.S. Corn Belt experienced a similar drought, which was in 1988. The benefits of GE cropping systems in mitigating challenges presented by climate change are just beginning to be understood. The introduction of drought-tolerant corn to U.S. farmers in the Western Great Plains is now delivering new ways to sustain yields on farm.

Help farmers of all sizes to grow crops more profitably. On average, GE crops increased farmer net incomes by $47 per acre in 2012 (77% of the total income gains) and farmers received an average of $3.33 for each dollar invested in GM crop seeds. For the 17 year period (1996-2012), the global farm income gain was $116.6 billion[3]. Importantly, GE crops are helping millions of small holder farmers in developing countries to farm more efficiently, productively and sustainably. Ensuring a positive dialogue and tone related to innovation and technology in developed countries helps to deliver benefits to smallholders today and in the future.

3. Focus on safety and regulatory approaches throughout the world

Since their introduction in the 1990s, GM crops have been tested and reviewed more than any other crops in the history of agriculture and have been shown to be as safe as conventional crops. After 30 years of research and assessments, the safety of GM crops is strongly supported by the global scientific community.

GM crop developments have been used safely in the food supply for more than 20 years and have been the subject of intensive research and assessment since the first GM crops were developed in the early 1980s. Every credible U.S. and international food safety authority that has studied GM crops has found that they are safe and no health effects attributable to their use have been found. In fact, since 1996, when the first GM crops were widely commercialized, at least 60 different countries have granted over 2,800 commercial use approvals on 336 different GM traits in 27 crops[15]. In many countries there are multiple regulatory authorities (up to seven in one country) with the responsibility of assessing a particular aspect of safety. In the United States, there can be as many as three agencies involved in reviewing food safety (FDA), crop safety (USDA) and environmental safety (EPA). Thus, GM crops are routinely subjected to review by literally hundreds of independent risk assessors and scientists across a wide range of disciplines. In comparison, no other currently commercial food innovation is as widely assessed as commercial GM crop products. This includes products widely used across both conventional and organic farming systems.

The science and safety behind GM crops are well established and strongly supported by the scientific community. Credible and independent public health societies and experts around the world have conducted their own studies and reviewed the scientific evidence and determined that food grown from GM crops is safe to eat. The safety of biotech crops has been confirmed by numerous third-party organizations, including the American Medical Association, the Society of Toxicology, the National Academy of Sciences in the United States, the Royal Society of the United Kingdom, the World Health Organization, the French Academy of Medicine, the Food and Agriculture Organization of the United Nations and the European Union Commission.

These conclusions have been based on years of research and assessments. For instance, for each GM crop candidate, research teams conduct years of field trials and comprehensive testing to be scientifically certain the new trait and genetic modification have not affected the safety of the crop. Specifically, tests are conducted on the genetics, efficacy, nutritional composition, potential allergenicity or toxicity, animal performance, animal health, agronomic performance and environmental safety of each potential product, following the requirements of scientific regulatory agencies and the guidelines of international agencies such as the Organization for Economic Cooperation and Development (OECD) and Codex Alimentarius Commission, a global food standards setting body that is jointly sponsored by the World Health Organization (WHO) and Food and Agriculture Organization (FAO). These guidelines, developed by the international scientific community, establish the principles that drive science-based, pre-market risk assessments that are performed on every new GM crop to evaluate both direct effects (from the inserted gene) and unintended effects that may arise as a consequence of inclusion of the inserted gene. Using these international standards, GM crops are tested to determine whether they contain the same components and nutrients as conventional varieties; evaluating levels of protein, carbohydrate, fat, amino acids, fiber and vitamins as well as a variety of other components. The gene added to the GM crop is thoroughly studied, in terms of how it works and whether it – or the protein it produces – generates any health concern. This evaluation includes thorough testing to assess whether introduced proteins pose any threat of allergenicity or toxicity. Because existing food crops are recognized as safe, these tests on the GM crop must demonstrate that it is as nutritious and not substantially altered from non-GM crops in terms of its use as food or feed, or in terms of its potential impact on the environment.

Pre-market safety reviews on these products have also been validated by the more than four billion cumulative acres of GM crops cultivated worldwide and trillions of meals and 100 billion animals[16] fed GM crops over the past 20 years without one adverse health incident having been reported.

4. Challenges of Insect and Weed Resistance

Agricultural productivity has always been threatened by insect pests and weeds; and innovations have been introduced over time to help mitigate these challenges. Over the last century, insecticides and herbicides have been used by farmers to manage pest outbreaks and weed competition that reduces crop quality and yield. Today, farmers employ a variety of integrated management approaches, including chemical (e.g., crop protection chemicals and GE crops with insecticidal traits or GE crops with herbicide tolerance traits), cultural (e.g., crop rotation, planting date, planting density, cover crops), mechanical (e.g., cultivation and tillage practices) and biological methods (e.g., use of beneficial organisms to aid the control of pests) to preserve the benefits of these pest management strategies[17].

Resistance to agricultural chemicals by insects and weeds is a significant challenge in agriculture. Insects have become resistant to virtually all classes of insecticides with the first case dating back to 1914 and weeds have developed resistance to herbicides shortly after their introduction in the 1950's. Over-reliance on single products for pest management year after year in the absence of other methods of management can lead to resistance[18]. Resistance can be managed or delayed through the use of diverse agricultural practices (e.g., chemical, cultural, mechanical, and biological), and by using chemicals with different mechanisms of action on the target pest[17,18]. Technology stewardship programs are essential for encouraging implementation of more sustainable pest management on the farm. Companies are working closely with professional organizations (e.g., WSSA, HRAC) to provide education and training programs to farmers and advisors on best management practices, resistance monitoring programs, and the benefits of proactive verses reactive mitigation approaches. As a result, farmers are increasingly adopting more sustainable, diverse management systems to combat the threat of resistant insects and weeds[19].

Insect resistant GE cotton, corn and recently soybean, have enabled farmers to reduce insecticide applications in North America, South America, Africa and Asia[3]. At the same time, over-reliance on single insecticidal traits with low to moderate dose protection, and inadequate adoption of refuges has led to resistance in several pests. The private sector has continued to develop and combine new complementary GE traits, including various complementary insecticidal proteins from *Bacillus thuringiensis*, to provide farmers with effective pest management. In addition, to ensure adequate refuge, companies have introduced seed mixtures that include the required refuge within the bag to ensure adequate refuge and durable product performance.

Since the mid-2000s, farmers of herbicide tolerant GE crops have diversified weed management systems by using other herbicides in combination with glyphosate to proactively combat weed resistance and to preserve the benefits of conservation tillage. Similarly, farmers of conventional crops also have begun using multiple herbicides with complementary modes of action. Importantly, while the adoption of more diversified practices has increased herbicide use in some cases[19], herbicide tolerant GE crops continue to deliver significant economic and environmental benefits for U.S. farmers.

The continued development of new pest management approaches, including use of GE technologies, is a necessary and appropriate strategy to ensure sustainable pest management. Monsanto is developing a GE corn expressing a dsRNA that specifically targets corn rootworm species. This new GE trait will be combined with existing GE traits to ensure sustainable pest management in corn. Similarly, GE crops with tolerance to 2,4-D, dicamba, glufosinate, HPPD and PPO herbicides, in addition to glyphosate, will provide farmers with more tools to improve management of difficult to control weeds and to customize diversified practices for the local landscape, environmental conditions, crops and markets. These new GE crops will contribute to sustainable weed management practices, sustain the benefits of conservation tillage systems, and preserve farm productivity.

5. Opportunities and Barriers for the Expanded Development of Input and Output Traits

While GE crops and broader plant biotechnology applications in agriculture have been largely defined by the successful introduction and adoption of insect resistant and herbicide tolerant GE crops, there remains untapped potential for the science of biotechnology and its applications throughout agriculture to this day.

Public and private sector scientists are currently using the science to develop GE crop solutions to address challenges that have not been attainable through any other ag innovation or science application developed to date. Some of the current and future research on GE crops focuses on solutions to agronomic, environmental and societal challenges. This work, which is underway across many input and output traits and at many institutions, is utilizing the science as an application to help address issues that face non-row crops like vegetables, fruits, bioenergy and forestry crops, as well as working add new value to row crops. Today, there is work underway throughout the public sector institutions and private sector companies located all around the world, including in markets such as China, France, Israel, and South America to name just a few.

Research examples on input traits near commercialization and/or under development across these sectors include: next-generation applications for weed control; next-generation applications for insect management; plant disease management; higher-yielding output; drought-tolerance; flood tolerance; nitrogen-efficiency, etc.

Research examples on output traits near commercialization and/or under development across these sectors include: sustainable, plant-based source of long-chain Omega-3 fatty acids; products with improved oil profiles for consumers; vitamin-A enrichment; non-browning apples; low acrylamide potatoes; reduced lignin alfalfa, etc.

The potential to apply biotechnology to deliver multiple, needed improvements in numerous crops to improve food security in developed and developing countries is both remarkable and grim. Research currently underway in the public and private sectors has the potential to expand the number of input and output traits, and this represents enormous opportunity for benefiting people around the world. At the same time, high regulatory costs make pursuit of small or specialty market crops unfeasible and excessive precaution exacerbated by fear campaigns promotes distrust of science; both are substantial barriers to innovation.

6. Role of Poor Quality Science and Public Perception

Policy and regulatory decisions involving GE crops are intended to be based on a rigorous evaluation of the potential risks and a full assessment of the weight of available safety evidence; however such decisions are increasingly influenced by politics and public opinion[20]. Traditional information sources, such as scientific authorities and quality peer-reviewed research publications, are no longer as relevant for helping the public to accept and value new technologies. Instead, numerous, readily available, social media outlets routinely distribute misleading and unreliable information based on poor quality science and bias. Advocacy groups leverage misleading information to draw the public's attention and raise concern about GE crops. As a result, there is growing science illiteracy within the general public and a lack of understating of what constitutes reliable science[21]. Compounding this issue is the developing mistrust for the peer review process which can further perpetuate perceptions and distrust of scientists. This apprehension is partly justified by the growing number of journals that are either considered predatory or lack Editorial Boards that are capable of doing adequate peer reviews[22,23].

People who are opposed to the role of GE science in agriculture take advantage of this lack of science literacy and general chemophobia to influence the public conversation. Central to this discussion is the rapid rise in subpar scientific manuscripts[24]; many reports with an obvious slant against GM crops fall into this category. Amplification through social media venues effectively and rapidly disseminates the conclusions of these reports. A large majority of people accept this form of "science news" at face value, and too often are unwilling or unable to critically review the underlying research. Consequently, the rapid spread of misleading information can go unchecked for sometime before any form of credible rebuttal appears. By the time other experts indentify flawed study methods or conclusions, public opinion is firmly established.

Controversies surrounding science issues in the media are not just a GE crop phenomenon. The science of climate change and the perceived impact of vaccines on autism are two recent examples. The MMR vaccine example is especially relevant because claims regarding the risks of the MMR vaccine continue to be promoted by advocates and persist in the public even though the *Sunday Times* journalist Brian Deer conclusively reported that the author of the original research paper had multiple undeclared conflicts of interest[25-28], had manipulated evidence[29], and had broken other ethical codes, all of which resulted in retraction of the paper.

Identifying subpar scientific publications can be a challenge; mainly because such papers can look highly scientific. Furthermore, many of the prevailing claims infecting social networks and popular conversations do not originate from journal articles but from blog posts, which have no peer review process and little to no accountability regarding content. Often these posts contain data, and due to the prevalent scientific illiteracy, it is believed to be credible. However, these subpar scientific publications and reports are often not hypothesis driven, and provide only vague methods, improper controls, and poor analysis, and often make claims without citing references. Sometimes, they provide no data at all[30]. Instead, the emphasis is placed on well-crafted titles and abstracts wrought with claims that are not supported by the study, photos/info graphics that add little or nothing to the data set (if there is data), the liberal use of superlatives and suppositions, and conclusions of causation based on correlation. Furthermore, many of the reports rely on a carefully selected list of subpar scientific studies while blatantly ignoring the prevailing, and much larger, body of literature that support GE crop benefits and safety. Additionally, the careful selection and quotation of statements extracted ("cherry picked") from the surrounding context is employed in a deliberate effort to mislead. The outcome is a ready supply of fodder for the social media frenzy in the form of misleading sound bites and pictures.

These coordinated campaigns fueled by the conclusions of these subpar scientific reports often coincide with crucial moments in the regulatory process (e.g., product registrations and renewals). The consequences are significant and costly to society; as evidenced by the untimely delivery new products to the marketplace with substantial benefits to growers and consumers.

7. Summary and Recommendations

GE crops have provided farmers with a safe, proven application that has played an important role in helping to meet the growing demands of society. GE crops have delivered a wide range of agronomic, economic and environmental benefits to farmers regardless of the number of acres they farm. Furthermore, the future applications of GE crops, including those which are currently in field trials and/or under development throughout the world, are broad and poised to present a new set of compelling characteristics or means through which agriculture can continue to mitigate the challenges presented by a changing climate. These innovations have never been more important.

The United Nations notes that the world's population, which has been climbing rapidly for more than a century, is expected to increase by about 2 billion more people by 2050, growing to between 9 billion and 10 billion. Most of this growth will occur in developing regions, especially Africa. To put this into perspective, adding 2 billion people to our planet is the equivalent of adding the entire population of India, all the countries of the European Union and the United States combined. As a result of this growth, our planet will see the greatest surge in middle class growth in world history. It's anticipated that about 3 billion more people will join the middle class over the next 35 years, most of them in India and China. This new era of middle class prosperity will lead to a demand for better diets – including a greater demand for meat-based proteins, which will drive more grain demand globally.

Consequently, global food demand actually will increase much more quickly than population. According to the UN's Food and Agriculture Organization (FAO), food demand will increase about 70 percent. The convergence of these challenges means that will have to produce more food in the next 30 years than we've done in the last 10,000 years combined.

Meeting this greatly increased demand will require that society consider how it can continue to improve productivity on our planet's existing farmland. These demands will also come at a time when agriculture faces the challenges of climate change which will make farming more difficult for both smallholder farmers and large scale production operations alike. While there's still a lot to learn in this area, many of the threats that climate change poses to agriculture are clear today. They include access to water; excessive heat; and new threats from bugs, weeds and diseases caused by even the slightest variations in temperature.

Mitigating these global challenges will require an unprecedented level of collaboration across agriculture, across the public and private sector, across the food value chain and across society. In order to do this, society must also continue to support innovations in agriculture to ensure a sustainable footprint for the next-generation. Simply put, society cannot afford to let its disagreements over the use of one agricultural practice distract or delay it from pursuing common ground to meet the dynamic challenges of feeding more our than 9 billion people in 2050.

In conclusion, in order to realize this potential, the scientific community and leaders across the public and private sector must continue to work towards common ground solutions and further identify ways to address the growing science illiteracy within the general public and the general lack of understating of what constitutes reliable science. This is critical so that subpar scientific studies do not create an unnecessary barrier which would prohibit the current or future benefits of GE crops to be realized or attained. The role of the National Research Council in underscoring the benefits of GE crops, the worldwide scientific consensus around the safety of the science and its potential applications moving forward has never been more important.

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