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The Future of Genetically Modified Crops

Lessons from the Green Revolution

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Summary

The world now sits at the cusp of a new agricultural revolution—the "Gene Revolution" in which modern biotechnology enables the production of genetically modified (GM) crops that may be tailored to address agricultural problems worldwide. This report investigates the circumstances and processes that can induce and sustain such an agricultural revolution. It does so by comparing the current GM crop movement with the Green Revolution of the latter half of the 20th century. We assess not only the scientific and technological differences in crops and in agricultural methods between these two movements, but more generally the economic, cultural, and political factors that influence whether a new agricultural technology is adopted and accepted by farmers, consumers, and governments. Our historical analysis of the earlier Green Revolution provides lessons about whether and how genetically modified crops might spread around the world. Whether the latter movement will develop into a global Gene Revolution remains to be seen.

Genetically modified crops created by modern agricultural biotechnology have attracted worldwide attention in the past decade. Cautious voices warn that the health and environmental effects of GM crops are uncertain and that their cultivation could have unintended adverse consequences. Alternatively, supporters of the technology assert that GM crops could revolutionize world agriculture, particularly in developing countries, in ways that would substantially reduce malnutrition, improve food security, and increase rural income, and in some cases even reduce environmental pollutants.

Can the GM crop movement develop into an agricultural revolution on the scale of the Green Revolution? To answer this question, first, it is important to consider what an agricultural revolution entails. Viewed historically, movements that come to be considered agricultural revolutions share the following features:

1. The movements gave farmers incentives to produce—i.e., the technologies provided a net benefit to farmers.
2. The movements substantially improved agricultural production, food nutrition, or both; or they substantially decreased necessary inputs such as fertilizer or water.
3. People were generally willing to adapt culturally and economically to the new technologies, and consumers accepted the products of the agricultural movement.
4. There was cooperation among those that provided the technologies, regulated the technologies, and used the technologies.
5. The movements were sustainable, eventually without public subsidization.

On a regional scale, GM crops might indeed be considered revolutionary—that is, they could meet all five criteria for an agricultural revolution. In the United States, Canada, China, and Argentina, for example, genetically modified varieties of soybeans, corn, and cotton now make up from about a third to 80 percent of total plantings of those crops, and provide benefits for growers such that these GM varieties will likely continue to make up a substantial portion of total plantings in the foreseeable future. Likewise, policymakers and the general public in these nations are accepting of this new technology. Adoption of these GM crops has led to improved yield, decreased use of pesticides or particularly harmful herbicides, and, in some cases, improved food quality.

While farmers in other nations, such as India and South Africa, have more recently begun to plant GM crops and experience the beginnings of a potential Gene Revolution, the revolution has yet to occur on a global scale. It has stalled because consumer and environ-

mental concerns, along with precautionary regulations, have limited its spreading to the countries that could benefit from it most, notably much of sub-Saharan Africa where famine continually threatens the population.

As stated above, the purpose of this report is to better understand whether and how this GM movement might become an authentic agricultural revolution by comparing it with an earlier agricultural movement that did reach nearly the entire world. The Green Revolution that had its origins in the 1940s, and reached its peak in the 1970s, continues to affect agricultural practices today. By analyzing the Green Revolution's objectives, science and technology, sources of financing, regulatory environment, and ultimate successes and failures, we offer an assessment of the ongoing GM crop movement—whether and how it might make a revolutionary impact on world agriculture.

The stated objective of the Green Revolution was to increase food production in regions of the world facing impending massive malnutrition. In the post-World War II era, scientists and policymakers considered those regions to be Latin America and Asia. Some argue, in retrospect, that this geographic choice was also motivated by Cold War politics: a largely U.S.-supported effort to prevent the spread of communism by ensuring adequate food supplies in at-risk countries.

Regardless of its motivation, the introduction of high-yield varieties (HYVs) of crop seed, along with pesticides, fertilizers, and irrigation systems, transformed agriculture on those two continents. With initial funding from the Rockefeller Foundation, individuals including U.S. plant breeders, agronomists, entomologists, soil scientists, and engineers worked in developing nations while training local agricultural scientists to extend the work in their own locales. The World Bank, Food and Agricultural Organization of the United Nations (FAO), United States Agency for International Development (USAID), and other national and international organizations later joined the Rockefeller Foundation to make this effort succeed. And succeed it did, in terms of increasing food production in Asia, Latin America, and even parts of the industrialized world such as Great

Britain. In Africa, however, where the movement came later, the Green Revolution has yet to improve food production in a sustainable way. As such, this movement provides several important lessons for understanding the possible course of the Gene Revolution.

We compare the Green Revolution and the current GM crop movement in four basic areas: science and technology, funding sources, where the movement occurred or is occurring, and the policies and political motivations surrounding each movement.

Science and Technology

The Green Revolution presented a considerable advance in agricultural technologies for farmers in the developing world, and, to a limited extent, in industrialized countries as well. For the first time, scientists and plant breeders integrated their research with farming practices in traditional agriculture to tackle problems that were constraining crop yield. High-yield seeds for rice, wheat, and corn were introduced in parts of the world where these crops made up a significant portion of the daily diet, and subsequently of food exports. Pesticides, chemical fertilizers, and irrigation systems were also introduced to aid farmers in controlling previously unmanageable pests, dealing with low-quality soil, and delivering water to crops according to their requirements.

The Gene Revolution, propelled by genetic engineering, allows previously unheard-of combinations of traits across species to achieve pre-specified objectives. For example, daffodil and bacterial genes can be introduced into the rice genome so that the rice produces beta-carotene, the precursor of vitamin A. The benefits of the current varieties of GM crops include yield increase, reduced agricultural inputs such as pesticides and fertilizers, reduced vulnerability to the whims of nature, and improved nutritional content. For the most part, these benefits have been limited to parts of the industrialized world to which current GM crop development and marketing have been targeted and, among those, to countries that have allowed their cultivation. Other GM crops are now being developed that survive on less

water, that survive in soil heavy in salt or metals such as aluminum, that convert or "fix" nitrogen from the air, and that produce vaccines against common diseases such as cholera and hepatitis B (Byrne et al., 2004).

A fundamental challenge in this newest agricultural movement that did not arise during the Green Revolution is the definition and treatment of intellectual property (IP). IP issues are central to the Gene Revolution because whereas science and technology move forward through the sharing of ideas and resources, IP ambiguities and restrictions can often limit the valuable diffusion of science and technology. Commercial application of biotechnology has taken place primarily in the United States and primarily through the private sector. The issue of who "owns" a particular *event* (the successful transformation) of a genetically modified crop and who can develop it further has become so economically important and contentious that numerous cases involving this issue are being litigated (Woodward, 2003). Some observers consider IP issues to be among the most important impediments to the development and adoption of GM crops in the developing world (Shoemaker et al., 2001; Cayford, 2004). Patent rights that universities may have on their sponsored research, corporate profit interests, and the ability of farmers to buy IP-protected seed are salient IP issues.

Funding

Philanthropic organizations, i.e., the Rockefeller and Ford Foundations, provided the backbone of early funding for the Green Revolution (Perkins, 1997; Pinstrup-Andersen and Schioler, 2001). The scientists who created high-yield seeds and their associated pesticides and fertilizers worked in conjunction with, and were funded by, these foundations along with the governments of Mexico, India, and several other countries. In 1971, while the Green Revolution was bearing its first fruits in many parts of the world, the Consultative Group on International Agricultural Research (CGIAR)—a system of 16 Future Harvest Centers working in more than 100 countries—was cre-

ated. With the creation of CGIAR, support for developing world agriculture became more broad-based and included European nations, Canada, and Japan.

Genetically modified crops are largely the product of private industry. This is partly because new technologies are far more costly than existing ones, and the biotechnology industry was able to gather the necessary funds to develop these technologies long before public awareness of GM crops could lead to publicly generated funding for GM crop development (Pinstrup-Andersen and Schioler, 2001). Successful companies typically focus on their markets with the intent of generating profit. With regard to agricultural biotechnology, companies in the United States and elsewhere have thus far created primarily seeds that farmers in industrialized countries can and will purchase: corn and soybeans that can tolerate a particular herbicide, corn and cotton that are resistant to particular pests, and food crops that last longer on the supermarket shelf. Because of the "technology fee" that growers pay to use these crop seeds (including recoupment of industry's research and development costs as well as profit), and because the seeds are designed particularly for their planting situations, the targeted farmers in industrial countries have generally found it worthwhile to buy these seeds and have been willing to pay the technology fee (Wu, 2004). Thus, in industrialized nations, GM crop technology has had the potential to revolutionize farming. However, the current GM crop seed varieties are neither affordable nor useful to most of the poorer farmers in the world; hence, their revolutionary impact in the developing world has been limited thus far. Indeed, there seems to be a mismatch of setting and technology, due to the funding sources of basic research.

Some agricultural biotechnology companies have recently expressed interest in working with regional research institutions to develop crops that would be profitable and affordable for farmers in developing countries. In addition, they are willing to donate a substantial portion of their scientific knowledge, such as genomes of key food crops, to increase agricultural knowledge in the developing world. In this way, the challenges related to IP may be lessened.

Where the Revolution Was and Is Taking Place

The Green Revolution was a success, in terms of its stated objectives, in Mexico and the rest of Latin America, India, and much of Southeast Asia. On the other hand, the Green Revolution has had little significant impact in most areas of Africa. Two prominent hypotheses for this outcome are that the technology package that was so useful in some parts of the world was not applicable to African farms, and that rural transportation systems are ill-designed to deliver either the technologies or their resulting products.

The technologies introduced in Asia and Latin America in the Green Revolution generally required not more land, but chemical fertilizer and well-timed water. Farmers who could access these inputs did well while others did not. To the extent that large landholders also had access to fertilizer and irrigation, they tended to adopt the new technologies early and successfully.

It may be too early to predict the varying adoption rates and benefits of yet undeveloped Gene Revolution technologies given the differing characteristics of farmers and regions. What can be said from the Green Revolution experience is that farmers will not adopt and utilize technologies over the long term that do not cost considerably less than current technologies, produce considerably more than current technologies, or substantially reduce the variability of cost or production in their own locales. As opposed to the Green Revolution, the key component of the Gene Revolution technology is improved seed. This being the case, all farmers, small or large, should be able to take advantage of the Gene Revolution; theoretically, the Gene Revolution is scale-neutral, providing that one can pay for the seed. However, cultural factors may deter farmers from embracing the new science; genetically modified crops have already become a stigmatized technology in some parts of the world because of concerns about manipulating organisms in seemingly "unnatural" ways and fears of unintended adverse impacts on the environment or human health.

Policies and Politics

At the time the Green Revolution was first seriously considered, the United States and the rest of the developed world feared that food crises in developing countries would cause political instability that could push those countries over to the Communist side (Perkins, 1997). Partly as a result of this issue, the U.S. government was highly concerned about agricultural science in the developing world and worked with foundations and scientists in the post-World War II decades to bring about the Green Revolution in regions subject to famine.

As of yet, there does not appear to be a strong political motivation for genetically modified crops to succeed in the developing world. Communism is no longer a threat, and famines, while still a problem in parts of the world, appear to be more the result of localized weather, politics, and war conditions than a sweeping threat that commands sustained government and public attention in industrial countries. Instead, public concerns and national and international regulations are now the driving force behind whether GM crops are adopted or rejected in various parts of the world, because wider public scrutiny and the newness of the science have led to concerns about environmental and health risks of GM crops that must be dealt with at the policy level.

The battle between U.S. and European Union regulations, which feature very different stances on the acceptance of GM crops in food and feed, has been the major determinant of this outcome. In addition, a variety of nongovernmental organizations (NGOs) that are concerned about the influence of multinational corporations, environmental degradation, crop diversification, food safety, globalization, and the influence of U.S. interests are prominent and influential in both the industrialized and developing countries. These NGOs were not nearly as influential during the Green Revolution.

Lessons from the Green Revolution

What can we determine about the prospects for the Gene Revolution by studying the Green Revolution's successes and failures? The Gene Revolution thus far resembles the Green Revolution in the following ways: (1) It employs new science and technology to create crop seeds that can significantly outperform the types of seeds that preceded it; (2) the impact of the new seed technologies can be critically important to developing world agriculture; and (3) for a variety of reasons, these technologies have not yet reached the parts of the world where they could be most beneficial. On the other hand, the Gene Revolution is *unlike* the Green Revolution in the following ways: (1) The science and technology required to create GM crop seeds are far more complicated than the science and technology used to create Green Revolution agricultural advancements; (2) GM seeds are created largely through private enterprises rather than through public-sector efforts; and (3) the political climate in which agricultural science can influence the world by introducing innovations has changed dramatically since the Green Revolution.

The similarities and differences between the Green and Gene Revolutions lead us to speculate that for the GM crop movement to have the sort of impact that would constitute an agricultural revolution, the following goals still need to be met and the related challenges overcome.

1. Agricultural biotechnology must be tailored toward, and made affordable to, developing-world farmers. Unless these conditions are met, farmers may not see that it is in their best interest to use GM crops at all despite the unique benefits those crops could provide.

2. There is a need for larger investments in research in the public sector. Numerous studies have shown the importance of public-sector research and development to aiding agricultural advancements, including the Green Revolution. Partnerships between the public and private sectors can result in more efficient production of GM crops that are useful to the developing world and can expand

the accessibility of those crops and their associated technologies to developing-world farmers.

3. To garner the level of public interest that can sustain an agricultural revolution, agricultural development must once again be regarded as being critically important from a policy perspective in both donor and recipient nations. As population numbers continue to increase today, agricultural development is more necessary than ever to eliminate malnutrition and prevent famine, particularly in sub-Saharan Africa. GM crops are seen by many as a means for addressing those problems. However, policymakers worldwide are far from being a combined force on this issue.

4. Policymakers in the developing world must set regulatory standards that take into consideration the risks as well as the benefits of foods derived from GM crops. This goal is crucial to the cooperation of the many stakeholders that are affected by GM crops and also for the sustainability of the GM crop movement in the foreseeable future. Without regulations that explicitly take into account potential benefits to both farmers and consumers, those nations that might stand to benefit most from GM crops may be discouraged from allowing them to be planted.

Revised regulations on genetically modified crops must accompany widespread collective policy efforts to revitalize agricultural development. And before developing world farmers and consumers can benefit from GM crops or any other type of enhanced crop breeding, the technologies must be affordable and farmers must understand how to use them.

The GM crop movement must overcome an intertwined collection of challenges before it can have an impact beyond those regions of the world that already produce excesses of food. If the GM crop movement can overcome these challenges, while proving itself to be acceptably free of adverse health and environmental impacts, it has the potential to provide benefits to farmers and consumers around the globe in previously inconceivable ways, while mitigating the need to use potentially harmful chemicals or scarce water supplies for agriculture. It can then indeed become a true "Gene Revolution."