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Feeding the Next Generation: Science, Business, and Public Policy

Edited by Calestous Juma, Josh Drake, and L. Val Giddings

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Belfer Center for Science and International Affairs
Harvard Kennedy School
79 JFK Street
Cambridge, MA 02138
Fax: (617) 495-8963
Email: belfer_center@harvard.edu
Website: http://belfercenter.org

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FEEDING THE NEXT GENERATION:
Science, Business, and Public Policy

Editors:
Calestous Juma, Josh Drake, and L. Val Giddings

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FOREWORD

Denise Dewar[1]

By the year 2050 planet Earth is expected to hold some nine billion people, the majority living in cities. This fact has a number of implications, one of which is that between now and then global agricultural production needs to double. If there is to be any land left for wilderness and biodiversity, this doubling will have to take place through enhanced productivity, rather than expansion in the area devoted to production.

The challenge of feeding the world's population is an old one—but with the anticipated population growth, the world's farmers are hard-pressed to find a quick solution. Today, in our increasingly connected world, international and domestic policies must complement each other to help ensure food security and smooth international trade, as well as ensure farmer access to innovative technologies and to markets. Meeting this challenge will be no small task. The purpose of this volume is to explore some of the potential solutions to address this important challenge.

The inspiration for this volume came in February 2010, when CropLife International, together with the Biotechnology Industry Organization (BIO) and the Council of Agricultural Science and Technology (CAST), brought together a world-renowned panel of experts on agricultural policy to participate in a global town hall to explore these issues. The event provided an opportunity to engage a global audience in a dialogue about the agricultural challenges facing farmers, policymakers, and consumers. Individuals from every continent watched the event live via the Internet, voicing their opinions and sharing their questions via Twitter, Facebook, email, and videos. The panel shared its thoughts and perspectives on how to achieve food security through sustainable methods, while maintaining and preserving the environment and biodiversity.

Participants discussed possible solutions to some of humanity's most pressing challenges:

- How will we feed nine billion people by 2050?
- How can we simultaneously grow enough food and preserve our land and water for future generations?
- What new pressures will farmers need to tackle as they work to produce food in the face of a changing climate?
- How can we help improve the incomes and quality of life of resource-poor farmers?
- How can we find ways to make developing countries more food secure?

[1] Executive Director, Plant Biotechnology, CropLife International.

Although no single solution can answer these questions, it is clear that we must continue Dr. Norman Borlaug's legacy. Dr. Norman Borlaug received his Nobel Peace Prize in 1970 for using innovative breeding techniques to increase crop yields, empower farmers, and feed billions of people. It is incumbent on each of us to continue the late Dr. Borlaug's pioneering and tireless work to save millions from hunger.

CropLife International and its members are committed to continuing Dr. Borlaug's legacy by providing safe, effective, and robust tools to farmers to help them meet the challenge of feeding a growing population, while protecting and sustaining natural resources. The participants of this world-renowned panel have come together again to author this volume and urge the world to press on in fulfilling Dr. Borlaug's legacy by battling hunger in the twenty-first century.

INTRODUCTION

Calestous Juma[2] & L. Val Giddings[3]

The numbers are by now familiar to anyone paying attention to the problem of how to feed the world. Today, three of ten people on the planet rely on others to grow their food and 900 million remain chronically food insecure. By 2050 the global demand for agricultural production is expected to double. Half of the global population will live in cities and will need to be fed through market channels. In the next 50 years we will need to produce more food than we have in the last 10,000 years.[4] Meeting these demands will require significant increases in agricultural productivity. Enhanced productivity is all the more important as the future is likely to bring additional pressures on food supply from climate change and environmental limits on cultivated land. Modern, science-driven farming including genetically modified crops represents our best chance of generating the increases in agricultural productivity necessary to feed our future.

Governments across the world have been slow to adopt policies that adequately reflect the climbing pressure on global food supply. Investments in agricultural research and development have dropped decade after decade, leading to dangerous gaps in the innovation necessary to enhance crop yields. Without renewed investment in agricultural innovation, science, and biotechnology, our collective future is bleak. The widespread food insecurity that the original Green Revolution helped reduce may return, and the food riots and price spikes we experienced briefly in 2007, 2008, and today may become more commonplace. To address these deficiencies, the late Dr. Norman E. Borlaug, Nobel Peace Prize winner and longtime agricultural researcher, has called for a "Second Green Revolution."[5]

Meanwhile, small but highly vocal advocacy groups, mainly in Western Europe and North America, are pushing for organic agriculture and agroecology as potential alternatives to biotech crops and technological innovations such as no-till farming, drip irrigation, and the precision application of fertilizer. Writing in support of the Council for Agricultural Science and Technology's (CAST's) 2010 publication on "Agricultural Productivity for the Future," contributors to this volume have reasonable observations and suggestions on: 1) the regulation of agricultural biotechnology products, 2) the use of genetically modified crops in Africa, and 3) the link between science-based agricultural productivity and environmental sustainability. Some points to keep in mind while reading this volume are as follows:

<u>Regulation of Agricultural Biotechnology:</u>

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[2] Professor of the Practice of International Development; Director, Science, Technology, Globalization, Belfer Center for Science and International Affairs, Harvard Kennedy School of Government.
[3] Senior Fellow, Information Technology and Innovation Foundation, www.itif.org. Email: vgiddings@itif.org.
[4] Borlaug, Norman E. (2010), Preface in "Agricultural Productivity Strategies for the Future: Addressing U.S. and Global Challenges," Council for Agricultural Science and Technology, CAST Issue Paper 45.indd. Page 2.
[5] Borlaug, N. E. 2002. *The Green Revolution Revisited and the Road Ahead*. September, http://nobelprize.org/ (24 November 2009)

- If modern science is to contribute to the agricultural productivity in coming decades, it is imperative to get beyond the cultural and political biases some have against molecular crop modification, assess the safety record of genetically modified (GM) crops, and ease the regulatory barriers to their development and deployment.

- Europe's overly precautionary regulatory system denies European farmers access to productivity-enhancing biotechnology, which European research has shown to be safe.[6] Meanwhile, the regulatory system has added new delays, costs, and uncertainties to the marketplace, discouraging innovation and investment in biotechnology, particularly for agriculture.

<u>African Agriculture and GM Crops:</u>

- Given the absence of additional risks from GMOs and the fact that 60 percent of Africans are still farmers, it is particularly shocking that African governments have been so hesitant to accept GMOs.

- African farmers stand to benefit greatly from the development and deployment of genetically modified crops, but are being denied these productivity-increasing inputs by overly precautionary government regulations modeled off the European system.

<u>Environmental Sustainability:</u>

- When it comes to environmental sustainability, it is only through highly productive farming that the world's food needs can be met at a reduced cost to the natural environment. The best way to cut excessive input use in modern farming is not to invest less in science-based productivity enhancement, but to invest more.

As editors, academics, and practitioners in agricultural innovation, we recognize that biotechnology and genetically modified crops remain controversial to some eyes, despite the robust safety and productivity record of GM crops currently on the market. We do not ask readers of this volume to accept blindly the positions its authors advance, nor even the volume's overall conclusion that genetically modified crops can and should play a critical role in agricultural productivity. Our primary concern is that scientific findings and analysis remain the key driver of global agricultural research and policy, not manipulated popular opinion or perceptions. The following papers are grounded in that tradition, and offer a roadmap for those interested in objectively evaluating both the risk and benefits of biotechnology in agriculture.

[6] See EU JCS report 2010 & European Commission, Press Release of 8 October 2001, announcing the release of a fifteen-year study including 81 projects and 400 teams at a cost of 70 million Euros. See http://ec.europa.eu/research/fp5/eag-gmo.html and http://ec.europa.eu/research/fp5/pdf/eag-gmo.pdf.

AGRICULTURAL PRODUCTIVITY STRATEGIES FOR THE FUTURE:
Addressing U.S. and Global Challenges

Gale A. Buchanan

A Second Green Revolution

U.S. agriculture faces strong demands not only to provide the food we eat, the feed for our livestock and companion animals, fiber for our clothes and homes, and "flowers" for the landscape and the environment, but also to contribute to meeting the energy needs of the planet. In addition to these expectations, agriculture today is being called on to help mitigate global climate change. When CAST proposed the idea of revisiting the topic of his earlier paper, Dr. Borlaug encouraged and agreed to write the preface. He wrote the preface just before his death in September 2009. I would like to quote one statement from his preface:

"In the next 50 years we are going to have to produce more food than we have in the last 10,000 years, and that is a daunting task. I therefore have called for a 'Second Green Revolution.'"

The principal drivers of global agricultural demand include a growing world population, higher expectations for standard of living, increases in disposable income, and greater energy needs.

Enhanced Productivity

Given the finite nature of land, water, and some plant nutrients, and the myriad constraints on agricultural production, agriculture will only be able to meet future demands through enhanced productivity. That enhanced efficiency can be achieved only through research that provides new information, knowledge, and technology that is focused on sustainable agricultural productivity. Agriculture can provide the food, feed, fiber, flowers, and fuel we need, but only if countries invest, develop, and deploy new, productivity-enhancing information, knowledge, and technology. Research can generate that information, knowledge, and technology if there is adequate public support. The public will also have to actively support political action on such broad issues as global climate change, regulations on the welfare of animals in agriculture, utilization and conservation of natural resources, and enhanced support for agricultural research.

The interrelations between U.S. and global agriculture are considerable. Four countries or regions are particularly relevant to agricultural productivity considerations for the twenty-first century. China and India will generate the major fraction of future global agricultural demand from both income and population growth for the foreseeable future. Brazil, already an agricultural power, will become an even greater center of agricultural production in the future. Conversely, in sub-Saharan Africa a significant portion of the population lives very close to the

edge of hunger and has not been able to increase its agricultural production to keep pace with its needs.

This panel considered some of the current and emerging constraints on the future success of agriculture. Many of these have been with us for a long while, such as soil erosion, availability of water, and fertilizer resources. Others are still emerging, such as animal welfare, endangered species, and global climate change. Of course, the lack of universal acceptance of genetically modified crops is a very serious constraint.

We then examined strategies to meet future needs for agricultural output. We concluded that helping to build infrastructure and enhancing institutional support is a fundamental step in helping developing countries. We must continue providing humanitarian aid in time of crisis. But we must continue to help build institutional support and work to jointly address such major issues as global climate change; land, water, and air degradation; and the protection of endangered species.

Several promising, "big" scientific approaches are suggested that could foster the next green revolution, including: substantially improving the quality of soil; improving the efficiency of plant photosynthesis; developing nitrogen fixation capacity in nonlegumes; incorporating apomixis[7] into crop plants; improving pest resistance in plants; and improving energy, water, and nutrient efficiency of plants. In the animal area, "big" scientific approaches that would contribute to fostering the next green revolution could include: effectively and efficiently capturing all animal waste, eliminating common respiratory diseases in livestock, and utilizing the power of genomics and biotechnology to improve food animals.

Political Will

Fulfilling Dr. Borlaug's vision for a second Green Revolution will require a sustained commitment to agricultural research, development, and deployment by the United States as well as all of the world's countries. Given the cumulative demand for agricultural output, this creates "a perfect storm" brewing in the future. To avert or at least to overcome this storm, we must invest now to ensure future maximum agricultural output to meet the needs and expectations of the people on this planet.

[7] Apomixis is a natural process by which some plants are able to replicate themselves without sexual reproduction. If this could be harnessed by plant breeders it could make it much easier to preserve and pass on valuable complex traits for crop improvement.

TECHNOLOGICAL ABUNDANCE FOR GLOBAL AGRICULTURE:
The Role of Biotechnology[8]

Calestous Juma

Introduction

Science and innovation have always been the key forces behind agricultural growth in particular and economic transformation in general. More specifically, the ability to add value to agricultural production via the application of scientific knowledge to entrepreneurial activities stands out as one of the most important lessons of economic history. The Green Revolution played a critical role in helping to overcome chronic food shortages in Latin America and Asia. The Green Revolution was a result of both the creation of new institutional arrangements aimed at using existing technology to improve agricultural productivity, as well as new scientific breakthroughs leading to superior agricultural inputs, particularly improved strains of wheat and rice.

In the wake of the recent global economic crisis and continually high food prices, the international community is reviewing its outlook on human welfare and prosperity.
Much of the current concern on how to foster development and prosperity in developing countries reflects the consequences of recent neglect of sustainable agriculture and infrastructure as drivers of development. But all is not lost. Instead, those developing countries that have not yet fully embraced agricultural technology now have the chance to benefit from preexisting scientific advances in agriculture, particularly in biotechnology. Areas of the developing world lagging in the utilization and accumulation of technology have the ability not only to catch up to industrial leaders in biotechnology, but also to attain their own level of research growth.

The Critical Role of Biotechnology

Biotechnology—technology applied to biological systems—has the promise of leading to increased food security and sustainable forestry practices, as well as improving health in developing countries by enhancing food nutrition. In agriculture, biotechnology has enabled the genetic alteration of crops, improved soil productivity, and enhanced natural weed and pest control. Unfortunately, such potential has largely been left untapped by many developing countries, particularly in Africa.

In addition to increased crop productivity, biotechnology has the potential to create more nutritious crops. About 250 million children suffer from vitamin A deficiency, which weakens

[8] Article adapted from *New Harvest: Agricultural Innovation in Africa,* Oxford University Press, 2010, "Chapter 2: Advances in Science, Technology, and Engineering."

their immune systems and is the biggest contributor to blindness among children.[9] Other vitamins, minerals, and amino acids are necessary to maintain healthy bodies, and a deficiency will lead to infections, complications during pregnancy and childbirth, and impaired child development. Biotechnology has the potential to improve the nutritional value of crops, leading to both lower health care costs and higher economic performance (because of improved worker health).

Tissue culture has not only helped produce new rice varieties in Africa and South Asia but has also helped the Western Hemisphere, East Africa, and South Asia produce pest- and disease-free bananas at a high rate. The method's ability to rapidly clone plants with desirable qualities that are disease-free is an exciting prospect for current and future research on improved plant nutrition and quantities. Tissue culture has also proved to be useful in developing vaccines for livestock diseases, especially the bovine disease rinderpest. Other uses in drug development are currently being explored.

In East Africa, tissue culture of bananas has had a great impact on the region's economies since the mid-1990s. Because of its susceptibility to disease, bananas have always been a double-edged sword for the African economies such as that of Uganda, which consumes a per capita average of one kilogram per day. For example, when the Black Sigatoka fungus arrived in East Africa in the 1970s, banana productivity decreased by as much as 40 percent. Tissue culture experimentation allowed for quick generation of healthy plants and was met with great success. Since 1995, Kenyan banana production has more than doubled, from 400,000 to more than one million tons in 2004, with average yield increasing from 10 tons per hectare (ha) to 30–50 tons.

Marker-assisted selection helps identify plant genome sections linked to genes that affect desirable traits, which allows for the quicker formation of new varieties. This technique has been used not only to introduce high-quality protein genes in maize but also to breed drought-tolerant plant varieties. An example of a different application of this method has been the development of maize resistant to maize streak virus. While the disease has created a loss of 5.5 million tons per year in maize production, genetic resistance is known and has the potential of greatly raising production. The uptake of genetically modified (GM) crops is the fastest adoption rate of any crop technology, increasing from 1.7 million hectares in 1996 to 134 million hectares in 2009, an 80-fold increase over the period.[10]

Recent increases among early adopting countries have come mainly from the use of "stacked traits" (instead of single traits in one variety or hybrid). In 2009, for example, 85 percent of the 35.2 million hectares of maize grown in the United States was genetically modified, and three-quarters of this involved hybrids with double or triple stacked traits. Nearly 90 percent of the

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[9] I. Potrykus, "Nutritionally Enhanced Rice to Combat Malnutrition Disorders of the Poor," *Nutrition Reviews* 61, Supplement 1 (2003): 101–104.

[10] C. James, *Global Status of Commercialized Biotech/GM Crops: 2009.* ISAAA Brief No. 41. Ithaca, NY: International Service for the Acquisition of Agri-biotech Applications.

cotton growth in the United States, Australia, and South Africa is GM and, of that, 75 percent has double-stacked traits.

Increasing Adoption of GM Crops

In 2009, there were 14 million farmers growing GM crops in 25 countries around the world, of whom over 90 percent were small and resource-poor farmers from developing countries. Most of the benefits to such farmers derive from cotton. For example, over the 2002–08 period, Bacillus thuringiensis (Bt) cotton added US$5.1 billion worth of value to Indian farmers, cut insecticide use by half, helped to double yield, and turned the country from a cotton importer into a major exporter.[11]

Countries once left outside, or willingly avoided genetically modified crops, are steadily joining the biotechnology revolution. In Africa, the continent where the adoption of GM crops has been the slowest, South Africa's GM crop production in corn stood at 2.1 million hectares in 2009, an increase of 18percent from the previous year. Burkina Faso grew 115,000 hectares of Bt cotton the same year, up from 8,500 in 2008. This was the fastest adoption rate of a GM crop in the world that year. In 2009, Egypt planted nearly 1,000 hectares of Bt maize, an increase of 15percent over 2008.[12]

Many of the countries that have been slow to adopt GM crops are now, by virtue of being latecomers, enjoying the advantage of using second-generation GM seed. Monsanto's Genuity™ Bollgard II® (second generation) cotton contains two genes that work against leaf-eating species such as armyworms, budworms, bollworms, and loopers. They also protect against cotton leaf perforators and saltmarsh caterpillars. Akin to the case of mobile phones, African farmers can take advantage of technological leapfrogging to reap high returns from transgenic crops while reducing the use of chemicals. In 2010 Kenya and Tanzania announced plans to start growing GM cotton in light of the anticipated benefits of second-generation GM cotton. The door is now open for revolutionary adoption of biotechnology that will extend to other crops as technological familiarity and economic benefits spread.

There is also a rise in the adoption of GM crops in Europe, which has also been slow to enjoy their benefits. In 2009, six European countries (Spain, Czech Republic, Portugal, Romania, Poland, and Slovakia) planted commercial Bt maize. Trends in Europe suggest that future decisions on GM crops will be driven by local needs as more traits become available. For example, crops that tolerate various stresses such as drought are likely to attract interest among farmers in Africa. The Water Efficient Maize for Africa project, coordinated by the African Agricultural Technology Foundation in collaboration with the International Centre for the Improvement of Maize and Wheat (CIMMYT) and Monsanto and supported by the Howard

[11] Ibid.
[12] Ibid.

Buffett Foundation and the Bill and Melinda Gates Foundation, is an example of such an initiative that also brings together private and public actors.[13]

This case also represents new efforts by leading global research firms to address the concerns of resource-poor farmers, a subtheme in the larger concern over the contributions of low-income consumers.[14] Other traits that improve the efficiency of nitrogen uptake by crops will also be of great interest to resource-poor farmers. Other areas that will attract interest in developing new GM crops will include the recruitment of more tree crops into agriculture and the need to turn some of the current grains into perennials.[15]

Regulating GM Crops

Trends in regulatory approvals are a good indicator of the future of GM crops. By 2009, some 25 countries had planted commercial GM crops and another 32 had approved GM crop imports for food and feed use and for release into the environment. A total of 762 approvals had been granted for 155 events (unique DNA recombinations in one plant cell used to produce entire GM plants) for 24 crops. GM crops are accepted for import in 57 countries (including Japan, the United States, Canada, South Korea, Mexico, Australia, the Philippines, the European Union (EU), New Zealand, and China). The majority of the events approved are in maize (49), followed by cotton (29), canola (15), potato (10), and soybean (9).[16]

Because of pest attacks, cotton was, until the early 1990s, the target of 25 percent of worldwide insecticide use.[17] Recombinant DNA engineering of a bacterial gene that codes for a toxin lethal to bollworms resulted in pest-resistant cotton, increasing profit and yield while reducing pesticide and management costs.[18] Countries such as China took an early lead in adopting the technology and have continued to benefit from reduced use of pesticides.[19]

Although GM crops have the potential to greatly increase crop and livestock productivity and nutrition, a popular backlash against GM foods has created a stringent political atmosphere under which tight regulations are being developed. Much of the inspiration for restrictive

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[13] C. Pray, "Public-Private Sector Linkages in Research and Development: Biotechnology and the Seed Industry in Brazil, China and India," *American Journal of Agricultural Economics* 83, no. 3 (2001): 742–47.

[14] R. Kaplinsky et al., "Below the Radar: What Does Innovation in Emerging Economies Have to Offer Other Low-income Countries?" *International Journal of Technology Management and Sustainable Development* 8, no. 3 (2009): 177–97. Indian entrepreneurs have figured ways of doing more with less based on the principles of affordability and sustainability: C. P. Prahalad and R. A. Mashelkar, "Innovation's Holy Grain," *Harvard Business Review* , July–August (2010): 1–10.

[15] J. D. Glover and J. P. Reganold, "Perenial Grains: Food Security for the Future," *Issues in Science and Technology* 26, no. 2 (2010): 41–47.

[16] James, *Global Status of Commercialized Biotech/GM Crops: 2009.*

[17] A. M. Showalter et al., "A Primer for Using Transgenic Insecticidal Cotton in Developing Countries," *Journal of Insect Science* 9 (2009): 1–39.

[18] D. Zilberman, H. Ameden, and M. Qaim, "The Impact of Agricultural Biotechnology on Yields, Risks, and Biodiversity in Low- Income Countries," *Journal of Development Studies* 43, no. 1 (2007): 63–78.

[19] C. E. Pray et al. "Five Years of Bt Cotton in China—The Benefits Continue," *Plant Journal* 31, no. 4 (2000): 423–30.

regulation comes from the Cartagena Protocol on Biosafety under the United Nations Convention on Biological Diversity.[20] The central doctrine of the Cartagena Protocol is the "precautionary principle" that empowers governments to restrict the release of products into the environment or their consumption even if there is no conclusive evidence that they are harmful.

These approaches differ from food safety practices adopted by the World Trade Organization (WTO) that allow governments to restrict products when there is sufficient scientific evidence of harm.[21] Public perceptions are enough to trigger a ban on such products. Those seeking stringent regulation have cited uncertainties such as horizontal transfer of genes from GM crops to their wild relatives. Others have expressed concern that the development of resistance to herbicides in GM crops results in "super-weeds" that cannot be exterminated using known methods. Some have raised fears about the safety of GM foods to human health.[22] Other concerns include the fear that farmers would be dependent on foreign firms for the supply of seed.

The cost of implementing these regulations could be beyond the reach of many low-income countries.[23] For example, in Africa such regulations have extended to many countries, and this tends to conflict with the great need for increased food production. As rich countries withdraw funding for their own investments in agriculture, international assistance earmarked for agricultural science has diminished.[24]

In June 1999, five European Union members (Denmark, Greece, France, Italy, and Luxembourg) formally declared their intent to suspend authorization of GM products until rules for labelling and traceability were in place. This decision followed a series of food-related incidents such as "mad cow disease" in the UK and dioxin contamination in Belgium. These events undermined confidence in regulatory systems in Europe and raised concerns in other countries. Previous food safety incidents tended to shape public perceptions over new scares.[25] In essence, public

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[20] R. Falkner, "Regulating Biotech Trade: The Cartagena Protocol on Biosafety," *International Affairs* 76, no. 2 (2000): 299–313.

[21] L. R. Ghisleri et al., "Risk Analysis and GM Foods: Scientific Risk Assessment," *European Food and Feed Law Review* 4, no. 4 (2009): 235–50.

[22] T. Bernauer, *Genes, Trade, and Regulation: The Seeds of Conflict in Food Biotechnology.* Princeton, NJ: Princeton University Press, 2003. Most of the studies on the risks of agricultural biotechnology tend to focus on unintended negative impacts. But evidence of unintended benefits is emerging. See, for example, W. D. Hutchison et al., "Areawide Suppression of European Corn Borer with Bt Maize Reaps Savings to Non-Bt Maize Growers," *Science* 330, no. 6001 (2010): 222–25.

[23] C. E. Pray et al., "Costs and Enforcement of Biosafety Regulations in India and China," *International Journal of Technology and Globalization* 2, nos. 1–2 (2006): 137–57 ; C. E. Pray, P. Bengali, and B. Ramaswami, "The Cost of Regulation: The India Experience," *Quarterly Journal of International Agriculture* 44, no. 3 (2005): 267–89.

[24] R. Paarlberg, *Starved for Science: How Biotechnology Is Being Kept Out of Africa.* Cambridge, MA: Harvard University Press, 2008, 2.

[25] E. van Kleef et al., "Food Risk Management Quality: Consumer Evaluations of Past and Emerging Food Safety Incidents," *Health, Risk and Society* 11, no. 2 (2009): 137–63.

reactions to the GM foods were shaped by psychological factors.[26] Much of this was happening in the early phases of economic globalization when risks and benefits were uncertain and open to question, including the very moral foundations of economic systems.[27]

Much of this debate occurred at a time of increased awareness about environmental issues and there had been considerable investment in public environmental advocacy to prepare for the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. These groups teamed up with other groups working on issues such as consumer protection, corporate dominance, conservation of traditional farming practices, illegal dumping of hazardous waste, and promotion of organic farming to oppose the introduction of GM crops. The confluence of forces made the opposition to GM crops a global political challenge, which made it easier to try to seek solutions through multilateral diplomatic circles.

The moratorium was followed by two important diplomatic developments. First, the EU used its influence to persuade its trading partners to adopt similar regulatory procedures that embodied the precautionary principle. Second, the United States, Canada, and Argentina took the matter to the WTO for settlement in 2003.[28] Under the circumstances, African countries opted for a more precautionary approach partly because they had stronger trade relations with the EU and were therefore subject to diplomatic pressure. Their links with the United States were largely through food aid programs.[29]

In 2006, the WTO issued its final report on the dispute; the findings were largely on procedural issues and did not resolve the root cause of the debate, such as the role of the "precautionary principle" in WTO law and whether GM foods were substantially equivalent to their traditional counterparts.[30] But by then a strong anti-biotechnology culture had entrenched itself in most African countries.[31] For example, even after developing a GM potato resistant to insect damage, Egypt refused to approve it for commercial use. This resistance grew to the point that Africa ceased to accept unmilled GM maize from the United States as food aid. A severe drought in 2001–02 left 15 million Africans with severe food shortages; countries such as Zimbabwe and Zambia turned down shipments of GM maize, fearing that the kernels would be planted instead of eaten. Unlike the situation in rich countries, GM foods in developing countries have the potential to revolutionize the lots of suppliers and consumers. In order to

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[26] L. J. Frewer et al., "What Determines Trust in Information about Food-related Risks? Underlying Psychological Constructs," *Risk Analysis* 16, no. 4 (1996): 473–85.
[27] P. Jackson, "Food Stories: Consumption in the Age of Anxiety," *Cultural Geographies* 17, no. 2 (2010): 147–65.
[28] S. Lieberman and T. Gray, "The World Trade Organization's Report on the EU's Moratorium on Biotech Products: The Wisdom of the US Challenge to the EU in the WTO," *Global Environmental Politics* 8, no. 1 (2008): 33–52.
[29] N. Zerbe, "Feeding the Famine? American Food Aid and the GMO Debate in Southern Africa," *Food Policy* 29, no. 6 (2004): 593–608.
[30] I. Cheyne, "Life after the Biotech Products Dispute," *Environmental Law Review* 10, no. 1 (2008): 52–64.
[31] E. J. Morris, "The Cartagena Protocol: Implications for Regional Trade and Technology Development in Africa," *Development Policy Review* 26, no. 1 (2008): 29–57.

take full advantage of the many potentials of biotechnology in agriculture, Africa should consider whether aversion and overregulation of GM production are warranted.[32]

In Nigeria, the findings of a study on biotechnology awareness demonstrate that although respondents have some awareness of biotechnology techniques, this is not the case for biotechnology products. Most of the respondents are favorably disposed to the introduction of GM crops and would eat GM foods if they are proven to be significantly more nutritious than non-GM foods. The risk perception of the respondents suggests that although more people are in favor of the introduction of GM crops, they do not consider the current state of Nigeria's institutional preparedness satisfactory for the approval and release of genetically modified organisms (GMOs).[33]

It is important, however, to consider that farmers will not grow successful crops if prices are low or dropping. Additionally, in far too many countries complications with regulation and approval of GM crops make obtaining commercial licenses to grow certain crops difficult. In some regions, neighboring countries must often approve similar legislation to cover liabilities that might arise from cross-pollination by windblown pollen, for example. Biosafety regulations often stall developments in the research of GM crops and could have negative impacts on regional trade.[34]

Benefits of GM Crops

For these reasons, approval and use of potentially beneficial crops are often difficult. Despite potential setbacks, however, biotechnology has the potential to provide both great profits and the means to provide more food to those who need it in Africa. Leaders in the food industry in parts of Africa prefer to consider the matter on a case-by-case basis rather adopt a generic approach to biosafety.[35] In fact, the tendency in regulation of biotechnology appears to follow more divergent paths reflecting unique national and regional attributes.[36] This is partly because regulatory practices and trends in biotechnology development tend to co-evolve as countries seek a balance between the need to protect the environment and human safety and fostering technological advancement.[37]

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[32] D. Wield, J. Chataway, and M. Bolo, "Issues in the Political Economy of Agricultural Biotechnology," *Journal of Agrarian Change* 10, no. 3 (2010): 342–66.
[33] J. O. Adeoti and A. A. Adekunle, "Awareness of and Attitudes towards Biotechnology and GMOs in Southwest Nigeria: A Survey of People with Access to Information," *International Journal of Biotechnology* 9, no. 2 (2007): 209–30.
[34] E. J. Morris, "The Cartagena Protocol: Implications for Regional Trade and Technology Development in Africa," *Development Policy Review* 26, no. 1 (2008): 29–57.
[35] C. Bett, J. O. Ouma, and H. Groote, "Perspectives on Gatekeepers in the Kenya Food Industry toward Genetically Modified Food," *Food Policy* 35, no. 4 (2010): 332–40.
[36] D. L. Kleinman, A. J. Kinchy, and R. Autry, "Local Variations or Global Convergence in Agricultural Biotechnology Policy? A Comparative Analysis," *Science and Public Policy* 36, no. 5 (2009): 361–71.
[37] J. Keeley, "Balancing Technological Innovation and Environmental Regulation: An Analysis of Chinese Agricultural Biotechnology Governance," *Environmental Politics* 15, no. 2 (2000): 293–309.

Advancements in science have allowed scientists to insert characteristics of other plants into food crops. Since the introduction of GM crops in 1996, over 80–90 percent of soybeans, corn, and cotton grown in the United States today comes from GM crops. Despite their widespread use, there are limited data on their environmental, economic, and social impact.[38]

Herbicide-resistant GM crops have fewer adverse effects on the environment than natural crops, but often at the cost of farming efficiency. The growth of most crops requires the use of toxic chemical herbicides, but GM crops utilize an organic compound called glyphosate to combat weeds. While less dangerous toxins are entering the environment, weeds are developing a resistance to glyphosate in soybean, corn, and cotton crops, reducing farming efficiency and raising prices on these goods.

GM corn and cotton have helped reduce the amount of insecticides entering the environment. Insecticides are harmful to most insects, regardless of their impact, positive or negative, on crops. Genetically engineered corn and cotton produce Bacillus thuringiensis (Bt) toxins, which kill the larvae of beetles, moths, and flies. New genetic hybrids are introduced frequently to reduce the threat of a Bt-resistant pest. Since 1996, insecticide use has decreased while Bt corn use has grown considerably. Although the environmental benefits are clear, GM crops pose a threat to farmers who rely on nonengineered crops. Interbreeding between crops is difficult to stop, so regulatory agencies must set clear standards on how much GM material is allowed to be present in organic crops.

The rapid adoption of GM crops seems to indicate that they offer great economic benefits for farmers. In general, farmers experience lower production costs and higher yields because weed control is cheaper and fewer losses are sustained from pests. GM crops are safer to handle than traditional chemical pesticides and herbicides, increasing worker safety and limiting the amount of time workers spend in the field. Although the supply-side benefits for farmers are clear, it is not completely understood how genetic modification affects the market value for these crops. Holding technological achievement constant, any gains tend to dissipate over time.

The United States has benefited by being among the first adopters of GM crops. In a similar vein, it is not clear what economic effects planting GM crops will have on farmers who do not adopt the technology. Livestock farmers are one of the largest customers of corn and soybean for feed and should receive the largest benefits of the downward pressure on prices from transgenic crops, yet no study has been conducted on such effects. Similarly, it is possible that the growing use of GM crops leaves many pests resistant to chemicals to ravage the fields of nonadopters, forcing them to use higher concentrations of dangerous chemicals or more expensive forms of control. In the future, new public policy will be needed to develop cost-effective methods of controlling the growing weed resistance to glyphosate.

[38] National Research Council. *Impact of Genetically Engineered Crops on Farm Sustainability in the United States.* Washington, DC: National Academies Press, 2010.

It is important to recognize that developing countries face a separate set of risks from those of industrialized countries. For example, new medicines could have different kinds and levels of effectiveness when exposed simultaneously to other diseases and treatments. Similarly, "new technologies may require training or monitoring capacity which may not be locally available, and this could increase risks associated with the technology's use."[39] This has been demonstrated where a lack of training in pesticide use has led to food contamination, poisoning, and pesticide resistance. In addition, the lack of consistent regulation, product registration, and effective evaluation are important factors that developing Africa will need to consider as it continues its exploration of these platform technologies. Probably the most significant research and educational opportunities for developing countries in biotechnology lie in the potential to join the genomics revolution when the costs of sequencing genomes drop. When James Watson, co-discoverer of the DNA double-helix, had his genome sequenced in 2007, the price tag was US$1 million. A year later a California-based firm, Applied Biosystems, revealed that it had sequenced the genome of a Nigerian man for less than US$60,000. In 2010 another California-based firm, Illumina, announced that it had reduced the cost to about US$20,000.

Dozens of genomes of agricultural, medical, and environmental importance to countries in the developing world have already been sequenced. These include human, rice, corn, mosquito, chicken, cattle, and dozens of plant, animal, and human pathogens. The challenge facing many low-income countries and regions, most notably sub-Saharan Africa, is building capacity in bioinformatics to understand the location and functions of genes. It is through the annotation of genomes that scientists can understand the role of genes and their potential contributions to agriculture, medicine, environmental management, and other fields.

Technology monitoring, prospecting, and research

Much of the debate on the place of Africa in the global knowledge economy has tended to focus on identifying barriers to accessing new technologies. The basic premise has been that industrialized countries continue to limit the ability of developing countries to acquire new technologies by introducing restrictive intellectual property rights. But more critically, the focus on new technologies as opposed to useful knowledge hindered the ability of developing countries to create institutions that focus on harnessing existing knowledge and putting it to economic use.

In fact, the Green Revolution and the creation of a network of research institutes under the Consultative Group on International Agricultural Research (CGIAR) represent an important example of technology prospecting. Most of the traits used in the early breeding programs for rice and wheat were available but needed to be adapted to local conditions. This led to the creation of pioneering institutions such as the International Maize and Wheat Improvement

[39] G. Conway and J. Waage, *Science and Innovation for Development.* London: UK Collaborative on Development Sciences, 2010, 54.

Center (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines.[40]

Today, the challenge for most developing countries is not technological scarcity but rather the management of an abundance of scientific and technological knowledge. Moreover, technology assessments must now take into account social impacts, a process that demands greater use of the diverse disciplines.[41] Given the high rate of uncertainty associated with the broader impact of technology on environment, it has become necessary to incorporate democratic practices such as public participation in technology assessments.[42] Such practices allow the public to make necessary input into the design of projects. In addition, they help to ensure that the risks and benefits of new technologies are shared widely.

Conclusion

Reliance on imported technology, including GM crops, is only part of the strategy. Low-income countries are just starting to explore ways to increase support for domestic research. If low-income, developing countries intend to catch up with agricultural industry leaders, they will need to create more permissive regulatory regimes that allow for the research, development, and use of genetically modified crops. They will also need to harmonize these policies regionally, and consider joint investments in domestic scientific capacity, which will help them evaluate and adapt outside technology as well as generate new, local innovations.

[40] J. Perkins, *Geopolitics and the Green Revolution: Wheat, Genes, and the Cold War.* New York: Oxford University Press, 1997.
[41] W. Russell et al., "Technology Assessment in Social Context: The Case for a New Framework for Assessing and Shaping Technological Development," *Impact Assessment and Project Appraisal* 28, no. 2 (2010): 109–116.
[42] L. Pellizoni, "Uncertainty and Participatory Democracy," *Environmental Values* 12, no. 2 (2003): 195–224.

GENETIC MODIFICATION OF CROPS:
Past, Present, and Future

Nina V. Fedoroff[43]

Introduction

The world has experienced a succession of shocks over the past two years: a global food crisis, spiraling energy costs, accelerating climate change, and a financial meltdown. The food crisis sparked riots in countries on every continent.[44] Unfortunately, the food crisis is not a transient phenomenon. The current situation developed over a long period of time as a result of relentlessly increasing demand pushing against a shrinking natural resource base, even as investment in agricultural research and development declined decade by decade. The oil price spike combined with widespread droughts in 2007 and 2008 sought to aggravate the underlying trends and send grain prices upwards. Although prices have come down since, the overall upward trend persists. Indeed, the adequacy of the food supply may be the most critical issue of the twenty-first century.[45]

Food security is a very old concern. Thomas Malthus's famous "Essay on Population," published in 1798, crystallized the problem of balancing food and human population.[46] Curiously, Malthus penned his essay at about the time that science began to play a major role in boosting agricultural productivity. Late eighteenth-century milestones included Joseph Priestley's discovery that plants emit oxygen[47] and Nicholas-Théodore de Saussure's definition of the chemical composition of plants.[48] Malthus could not have envisioned the extraordinary increases in productivity that the integration of science and technology into agricultural practice would stimulate over the ensuing two centuries.

Both organic and mineral fertilization of plants have been practiced since ancient times. Long before the reasons were understood, people knew that certain chemicals, such as saltpeter and lime, as well as a wide variety of biological materials ranging from fish and oyster shells to manure and bones stimulated plant growth.[49] In the early nineteenth century, Justus von Liebig identified the major chemical requirements for plant growth, laying the foundation for the

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[43] Evan Pugh Professor, Penn State University and Distinguished Visiting Professor, King Abdullah University of Science and Technology.
[44] http://www.time.com/time/world/article/0,8599,1717572,00.html
[45] Pinstrup-Andersen, P., Pandya-Lorch, R. and Rosegrant, M. W. (1999). World food prospects: critical issues for the early twenty-first century. Food Policy Report of the International Food Policy Research Institute.
[46] Malthus, T. R. (1798) An Essay on the Principle of Population, 1798 1st edition, anonymous through J. Johnson (London).
[47] Priestley, J. (1774) Experiments and Observations on Different Kinds of Airs, W. Bowyer and J. Nichols (London).
[48] De Saussere, N.-T. (1804) Recherches chimiques sur la végétation. Nyon (Paris)
[49] Hear, F. A. (1938) Theory and Practice in the Use of Fertilizers, 2nd edition. Chapman and Hall (London).

modern chemical fertilization methods.[50] Although it was known by mid-century that biological sources of nitrogen could be replaced by chemical sources, supplying nitrogen in the forms that plants use remained a major limitation until the development of the Haber-Bosch process for fixing atmospheric nitrogen early in the twentieth century.[51] Today agriculture in the developed world relies primarily on chemical fertilizers.

Crop domestication

Although the term "genetically modified" or "GM" is used today exclusively for organisms modified by recombinant DNA techniques, people practiced genetic modification long before chemistry entered agriculture, transforming inedible wild plants into the crop plants that feed people and their animals today. Corn, or maize (*Zea mays*), remains one of humanity's most spectacular feats of genetic modification. Its huge ears, packed with starch and oil, provide one of humanity's most important food and feed crops. Corn bears little resemblance to its closest wild relative, teosinte. Indeed, when teosinte was first discovered in 1896, it was assigned to a different species and named *Euchleana mexicana.* By the 1920s, it was known that teosinte and corn have the same number of chromosomes and readily produce fertile hybrids, yet controversies about their relationship and about the origin of corn continued throughout most of the twentieth century.

The work of Dr. John Doebley and his colleagues, commencing with the genetic analysis of maize-teosinte hybrids, has made substantial progress in identifying the genetic changes that transformed teosinte into modern corn.[52] Doebley's more recent work with the evolutionary geneticist Svante Paabo traced the key genetic changes that transformed teosinte into corn to the Balsas River Valley in Mexico and dated them to roughly 6–10 thousand years ago. It has become apparent that the difference between teosinte, a grass with hard, inedible seeds, and modern corn resides in just a handful of genes that control plant architecture and the identity of reproductive organs. Remarkably, once this handful of mutations had been brought together, the suite of genetic modifications stayed together and spread rapidly, so that the same group of alleles had already penetrated into the American Southwest more than 3,000 years ago. Fossilized cobs recovered from caves in Mexico and dated as more than 6,000 years old already possess the multirowed character of the modern corn ear, as do almost 4,000 year-old cobs from the Ocampo Caves in northeastern New Mexico.[53]

Perhaps the most important insight that has been gained through the molecular analysis of crop domestication is that people have markedly changed wild plants to make them suitable as crop plants and that this has been done over many thousands of years. All such heritable alterations are genetic. Each crop has its own interesting history, but one of the most fundamental traits distinguishing wild from domesticated plants is the retention of mature

[50] Liebig, J. (1840) Organic chemistry in its application to agriculture, Playfair (London).
[51] Russel, D. A. and Williams, G. G. (1977) History of chemical fertilizer development. Soil Sci. Soc. Am. J. 41, 260-265.
[52] http://teosinte.wisc.edu/publications.html
[53] Fedoroff, N. V. Prehistoric GM corn. Science 302, 1158-59.

seeds on the plant. Plants have a variety of mechanisms for dispersing their seeds, central to which are the shattering of the seed structure upon maturation. It is much easier for people to harvest seeds that remain attached to the plant; hence the selection of mutations that prevent seed dispersal is thought to be among the earliest steps in crop domestication.[54]

Among the many other traits altered during domestication are the size and shape of foliage, tubers, berries, fruits, and grains, as well as their abundance, toxicity, and nutritional value. There are many underlying genetic differences that distinguish a domesticated crop plant from its wild progenitors, but molecular analysis reveals that key changes are often in genes that encode transcription factors, which are proteins that regulate the expression of many genes.[55] Differences in nutrient composition among varieties of the same crop are attributable to mutations in genes coding for proteins of certain biosynthetic pathways. For example, mutations in genes for enzymes involved in the conversion of sugar to starch gave rise to sweet corn varieties.

Modern crop improvement

Crop improvement benefited from both the Mendelian and the molecular genetic revolutions of the twentieth century. Austrian monk Gregor Mendel's pioneering observations on inheritance, published in 1865, were made independently by Dutch botanist Hugo de Vries. Only then did Mendel's observations gain the interest of other geneticists.[56] A simple demonstration project to illustrate Mendelian inheritance led to the discovery of hybrid vigor, a phenomenon whose incorporation into crop breeding resulted in a dramatic expansion of the corn ear and, thereby, crop yield. The discovery is attributed to George Harrison Shull, working at the Carnegie Institution of Washington's Station for Experimental Evolution. He was asked by the Station's director to develop a demonstration of Mendel's rules of inheritance. In the course of these experiments, he observed that some kinds of corn made more rows of kernels than others. Curious about the genetic basis of this difference, he inbred the respective varieties and then crossed them to see whether the row number trait would segregate according to Mendel's simple rules. He found that when he crossed the inbred lines to each other, the F1 progeny were taller, more robust plants with bigger ears.[57] This phenomenon, called hybrid vigor or heterosis, is the basis of today's extraordinarily productive hybrid corn varieties.[58]

When corn hybrids were first introduced in the United States during the 1930s, however, they faced resistance and criticism similar to that faced by GM crops today. The hybrids were complex to produce and agriculture experiment stations were not interested. Eventually a

[54] Fedoroff, N. W. and Brown, N. M (2004) Mendel in the Kitchen: A Scientist's View of Genetically Modified Foods. Joseph Henry Press (Washington, DC).
[55] Doebley, J. F., Gaut, B. S. and Smith, B. D. (2006) The molecular genetics of crop domestication. Cell 127, 1309-1321.
[56] Carlson, E. A. (1966) The Gene: A Critical History. Saunders (Philadelphia)
[57] Shull, G. H. (1909) A pure line method in corn breeding. Am. Breeders Assoc. Reports 5, 51–59.
[58] Crow, J. F. (1998) 90 years ago: the beginning of hybrid maize. Genetics 148, 923-928.

company was formed to produce hybrid seed. But farmers accustomed to planting seed from last year's crop saw no reason to buy it. It was only when farmers realized the yield benefits and the drought-resistance of hybrid corn during the 1934–36 dust-bowl years that hybrid corn was rapidly adopted.[59]

Techniques for accelerating mutation rates with radiation and chemicals and through tissue culture were developed and widely applied in the genetic improvement of crops during the twentieth century.[60] Such techniques introduce mutations rather indiscriminately and require the growth of large numbers of seeds, cuttings, or regenerants to detect desirable changes. Nonetheless, all of these approaches have proved valuable in crop improvement and by the end of the twentieth century more than 2,300 different crop varieties, ranging from wheat to grapefruit, had been developed using radiation mutagenesis.[61]

Mechanization of agriculture

A major development whose impact Malthus could not have envisioned is the mechanization of agriculture. Human and animal labor provided the motive force for agriculture throughout most of its history. Early tractors powered by steam engines were large and unwieldy, but the invention of the internal combustion engine at the turn of the twentieth century led to the development of smaller and more maneuverable machines. The mechanization of plowing, seed planting, cultivation, fertilizer and pesticide distribution, and harvesting accelerated in the United States, Europe, and Asia following World War II.[62] Agricultural mechanization drove major demographic changes virtually everywhere. In the United States, 21 percent of the workforce was employed in agriculture in 1900.[63] By 1945, the fraction had declined to 16 percent and by the end of the century the fraction of the population employed in agriculture had fallen to 1.9 percent. At the same time, the average size of farms increased and farms increasingly specialized in fewer crops.

The Green Revolution

Malthus penned his essay when the human population of the world stood at less than a billion. The population tripled over the next century and a half. As the second half of the twentieth century began, there were Malthusian predictions of mass famines in developing countries that had not yet experienced science- and technology-based advances in agriculture. Perhaps the

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[59] Crabb, A. R. (1947) The Hybrid-Corn Makers: Prophets of Plenty. Rutgers University Press (New Brunswick, NJ).
[60] Maluszynski, M., Ahloowalia, B. S. and Sigurbjörnsson, B. (1995) Application of *in vivo* and *in vitro* mutation techniques for crop improvement. Euphytica 85, 303-315.
[61] Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects. National Academies Press (Washington), 2004.
[62] Binswanger, H. (1986) Agricultural mechanization: A comparative historical perspective, Res. Obs. 1, 27-56.
[63] Dimitri, C., Effland, A., and Conklin, N. (2005). The 20th Century Transformation of U. S. Agriculture and Farm Policy, Economic Information Bulletin Number 3, Economic Research Service, USDA.

best known of the mid-century catastrophists was Paul Ehrlich, author of *The Population Bomb*.[64]

The predicted Asian famines were averted by the dedicated work and extraordinary accomplishments of several scientists and their teams, principally plant breeders Borlaug, Swaminathan, and Khush.[65] The Green Revolution was based on the development of rice and wheat varieties with mutations in genes that controlled their growth rate, resulting in dwarf varieties able to respond to fertilizer application without lodging (falling over). Subsequent breeding for yield increases continued to improve productivity of these crops by as much as 1% per year. Instrumental in these discoveries were the first two institutes established by the Consultative Group on International Agricultural Research (CGIAR), the International Rice Research Institute (IRRI)[66] in the Philippines and the International Maize and Wheat Improvement Center (CIMMYT).[67] Perhaps most remarkably, the Green Revolution of the late twentieth century reduced the fraction of the world's hungry from half to less than a sixth, even as the population doubled from 3 to 6 billion.

Molecular genetic modification (GM) of crops

The molecular genetic revolution that began in the 1960s led to the development of new methods of crop improvement. Research in the 1950s and 1960s identified the existence of bacterial plasmids that could replicate independently of the bacterial chromosome (11). Other discoveries led to the identification of restriction enzymes and ligases, making it possible to insert and link a piece of genetic material from a completely different organism into a plasmid, then replicate it in bacterial cells. Amplification of such "recombinant" plasmids in turn made it possible to develop the DNA sequencing techniques that underlie today's genomic revolution. Additional techniques were developed for the introduction of genes into plants using either the soil bacterium *Agrobacterium tumefasciens*, which naturally transfers a segment of DNA into wounded plant cells, or mechanical penetration of plant cells using tiny, DNA-coated particles.[68] This combination of techniques has made it possible to transfer genetic material from either the same or a related plant or from a completely unrelated organism into virtually any crop plant.

Several crop modifications achieved using these methods are now in widespread use. Perhaps the best known of these are crop plants carrying a gene from the soil bacterium *Bacillus thuringiensis*. This bacterium had long been used as a biological pesticide because it produces a protein that is toxic to the larvae of certain kinds of insects, but not to animals or humans.[69] The gene coding for the toxin is commonly called simply "the Bt gene," although there is

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[64] Ehrlich, P. (1968) The Population Bomb. Ballantine Books, Random House (New York).
[65] Khush, G. S. (2001) Green revolution: the way forward. Nature Rev. Genet. 2, 815-822.
[66] http://www.irri.org/
[67] http://www.cimmyt.org/
[68] Birch, R. G. (1997) Plant transformation: Problems and strategies for practical application. Annu. Rev. Plant Physiol. Plant Mol. Biol. 48, 297-326.
[69] http://www.extension.umn.edu/distribution/cropsystems/DC7055.html.

actually a family of Bt toxin genes, which encodes a group of related proteins. Bt genes have been introduced into a number of different crops, primarily corn and cotton. In the United States and Europe, pest-protected crop varieties are produced almost exclusively by companies such Monsanto, DuPont, and Syngenta. In other parts of the world, including in China and India, such crop modifications are being performed by both the public and private research sectors.

Another widely accepted crop modification is the introduction of genes that confer resistance to herbicides, which are commonly compounds that inhibit biosynthetic pathways unique to plants.[70] Among the most widely used today are compounds that interfere with the production of amino acids that plants synthesize, but animals do not.[71] Herbicide-tolerant crop plants, which make it possible to control weeds with an herbicide without damaging the crop, have been derived through natural and induced mutations, as well as by introduction of genes from either bacterial sources or modified genes from plant sources. Today, herbicide-tolerant varieties of many crops, most importantly soybeans and canola, are widely grown.

Papaya varieties resistant to papaya ringspot virus (PRSV) are a public-sector GM achievement that saved the Hawaiian papaya industry.[72] PRSV is a devastating insect-borne viral disease that wiped out the papaya industry on Oahu in the 1950s, forcing its relocation to the Puna district of the big island. By the 1970s, the Puna district was producing 95 percent of Hawaii's papayas. PRSV was first detected in the Puna district in 1992; by 1995 it was widespread and threatening the industry. Dennis Gonsalves and his colleagues at Cornell University began a project in 1985 to introduce a viral gene into papayas based on the observations made in Roger Beachy's laboratory at Washington University that introducing a viral gene could make a plant resistant to the virus from which the gene came.[73]

The first transgenic papaya plants expressing a PRSV gene were ready in 1991; small field tests began in 1992; and large-scale field tests began in 1994. Approvals from the Animal Plant Health Inspection Service (APHIS) of the U.S. Department of Agriculture (USDA), as well as the Environmental Protection Agency (EPA) and the Food and Drug Administration (FDA) for release of the seeds to farmers took another three years, by which time many papaya farmers had gone out of business. Transgenic seeds were released in 1998, and by 2000 the papaya industry had come back to pre-1995 levels. Although it was not known at the time, recent studies have shown that the resistance is attributable to post-transcriptional gene silencing.[74] This

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[70] www.hort.wisc.edu/cran/pubs_archive/.../How**Herbicide**Work.pdf

[71] Tan, S., Evans, R., and Singh, B. (2006) Herbicidal inhibitors of amino acid biosynthesis and herbicide-tolerant crops. Amino Acids 30, 195-204.

[72] Gonsalves, D., Gonsalves, C., Ferreira, S., Pitz, K., Fitch, M., Manshardt, R., and Slightom, J. (2004) Transgenic virus resistant papaya: from hope to reality for controlling papaya ringspot virus in Hawaii. APSnet, http://www.apsnet.org/online/feature/ringspot/.

[73] Powell, A. P., Nelson, R. S., De, B., Hoffmann, N., Rogers, S. G. Fraley, R. T. and Beachy, R. N. (1986) Delay of disease development in transgenic plants that express the tobacco mosaic virus coat protein gene. Science 232, 738-743.

[74] Tennant, P., Fermin, G., Fitch, M. M., Manshardt, R. M., Slightom, J. L. and Gonsalves, D. (2001) Papaya ringspot virus resistance of transgenic Rainbow and SunUp is affected by gene dosage, plant development, and coat protein homology. Euro. J. Plant Pathol. 107, 645-653.

remarkable method of crop protection enhances a mechanism present in plants that is responsible for protecting a virus-infected plant from subsequent infection by the same and closely related viruses, much as the development of immunity protects people and animals from reinfection by pathogens.

Adoption of GM crops

Although the use of molecular modification techniques in crop improvement engendered controversy from the beginning, GM crops have experienced unprecedented adoption rates since their initial introduction in 1996. By 2008, roughly 10 percent of cropland was planted in GM crops: transgenic crops were grown on more than 300 million acres in 25 countries by more than 13 million farmers, 90 percent of whom were smallholder, resource-poor farmers.[75] The vast majority of transgenic cropland is devoted to just four crops: cotton, maize, soybean, and canola, but the list of commercialized transgenic crops is growing and already includes papaya, tomato, poplar, petunia, sweet pepper, squash, alfalfa, and sugar beet.

Few of the widely anticipated adverse effects have materialized. Although some resistance to the Bt toxin has developed, it has not been as rapid as initially feared, and second-generation, two-Bt gene strategies to decrease the probability of resistance are already being implemented.[76] Predicted deleterious effects on nontarget organisms, such as monarch butterflies and soil microorganisms, have either not been detected at all or are insignificant. Moreover, beneficial insects are more abundant in fields of Bt crops compared with fields of pesticide-treated conventional crops.

The many studies that have been done to assess the safety of foods containing or consisting of GM crops have reached the conclusion that GM foods are at least as safe as non-GM foods.[77] This is in part because of the close scrutiny paid during product development to the potential for toxicity and allergenicity of the proteins encoded by genes being added. But more important, it is because of the greater precision of the genetic modifications introduced by recombinant DNA technology compared with earlier methods used in plant improvement, such as chemical and radiation mutagenesis, tissue culture, and wide crosses.

To date, the unexpected effects have been beneficial. For example, many grains and nuts, including corn and peanuts, are commonly contaminated by mycotoxins, toxic compounds made by fungi that follow boring insects into the plants. Two of these, fumonisins and aflatoxin, are extremely toxic and carcinogenic. Bt corn, however, shows as much as a 90 percent

[75] James, C. (2008) Global Status of Commercialized Biotech/GM Crops. ISAAA Brief 39.
[76] Lemaux, P. G. (2009) Genetically engineered plants and foods: a scientist's analysis of the issues (part II). Annu. Rev. Plant Biol. 60, 511-59.
[77] Lemaux, P. G. (2008) Genetically engineered plants and foods: a scientist's analysis of the issues (part I). Annu. Rev. Plant Biol. 59, 771-812.

reduction in mycotoxin levels because the fungi that follow the boring insects into the plants cannot get into the Bt plants.[78]

There is evidence as well that planting Bt crops reduces insect pressure in other crops growing nearby. Bt cotton has been widely planted in China. Analysis of the population dynamics of the target pest, the cotton bollworm, showed that Bt cotton not only controls the bollworm on transgenic cotton designed to resist this pest, but also reduces its presence on other host crops and thereby decreases the need for insecticide sprays in general.[79]

Future challenges in agriculture

The scientific and technological advances in agriculture of the nineteenth and twentieth centuries have been extraordinary. Since Malthus's time, the human population has expanded more than six-fold. In the developed world, agriculture has become far less labor-intensive and has kept pace with population growth worldwide. Today, less than 1 in 50 citizens of developed countries grows crops or raises animals for food. This means that most people in developed countries live in cities and find livelihoods that pay higher wages than farming. Those remaining on farms often also work in off-farm jobs, raising average farm income. This also means, however, that most citizens of developed countries have little understanding of what it takes to create the foods that stock contemporary supermarkets.

Moreover, after a half-century's progress in decreasing the fraction of humanity experiencing hunger from half to less than a sixth, the food crisis and the more recent global financial crisis have begun to swell the ranks of the hungry again.[80] Population experts anticipate the addition of another 2–4 billion people to the planet's population within the next 3–4 decades,[81] but the amount of arable land has not changed appreciably in more than half a century, increasing by only about 10 percent.[82] And it is not likely to increase much in the future because we are losing it to urbanization, salinization, and desertification at least as fast as we are adding it.

Another variable that is becoming critical is the availability of fresh water for agriculture. Today, about a third of the global population lives in arid and semi-arid areas, which cover roughly 40% of the land area. Climate scientists predict that in coming decades, average temperatures will increase and dryland area will expand.[83] Even now, inhabitants of arid and semi-arid regions of

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[78] Munkvold, G. P. (2003) Cultural and genetic approaches to managing mycotoxins in maize. Annu. Rev. Phytopathol 41, 99-116.
[79] Wu, K.-M., Lu, Y.-H., Feng, H.-Q., Jiang, Y.-Y. and Zhao, J.-Z. (2008) Suppression of cotton bollworm in multiple crops in China in areas with Bt toxin-containing cotton. Science 321, 1676-1678.
[80] Hunger on the rise: Soaring prices add 75 million people to global hunger rolls. Briefing paper, FAO (Rome), 2008.
[81] Cohen, J. E. (2003) Human population: The next half century. Science 302, 1172-1175.
[82] The Land Commodities Global Agriculture and Farmland Investment Report 2009; www.landcommodities.com.
[83] Climate Change 2007: Impacts, Adaptation and Vulnerability, IPCC Fourt Assessment Report, http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm.

all continents are extracting ground water faster than aquifers can recharge and often from fossil aquifers that do not recharge.[84]

Thus the challenges to agriculture in the twenty-first century are profound: to increase agricultural productivity on land largely already under cultivation at higher temperatures and using less water. Can it be done? There are biological, political, and cultural impediments.

The major crops that now feed the world—corn, wheat, rice, soy—require a substantial amount of water. For example, the production of a kilogram of wheat requires between 500 and 2,000 liters of water, most of which is lost through transpiration.[85] But almost half of the grain currently produced worldwide is fed to animals and the amount of water required to produce a kilogram of meat is 5–10 times greater than that required to produce a kilogram of grain.

The optimal growth temperature to produce maximal yields of our major crop plants is determined by the temperature optimum for photosynthesis, the process by which plants convert solar energy into chemical energy, and other physiological processes. Yield is also determined by the temperature range that supports optimal development of the harvested storage organs (grain, bean, kernel).[86] A recent study reports that yields increase with temperature up to 29° C for corn, 30° C for soybeans and 32° C for cotton, but then decline precipitously at higher temperatures.[87] This study predicts that yields of these crops in their current growing areas will decline by 30–46 percent by the end of the twenty-first century under the most moderate climate change scenario and by 63–82 percent under the most rapid warming scenario.

The expected pressures on water availability and increasing temperatures present critical challenges to agricultural researchers to increase crop water efficiency and heat tolerance. Whether our current highly productive food and feed crops can be modified and adapted to be even more productive at the higher temperatures expected or at more northern latitudes is simply not known. It is therefore imperative to increase research not just on the salt, drought, and temperature tolerance of existing crop plants, but also to invest in research on plants that are not now used in agriculture, but that are capable of growing at higher temperatures and using brackish or salt water for irrigation. Indeed, the array of molecular tools and knowledge available today may make it possible to design a wholly new kind of agriculture for a more arid, hotter world.

But even though the molecular tools, physiological knowledge, and genomic information available today are extraordinary, there are also political and cultural barriers to their

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[84] Giordano, M. (2007) The Agricultural Groundwater revolution: Comprehensive Assessment of Water Management in Agriculture. International Water Management Institute.
[85] Water Policy Briefing 25, International Water Management Institute; http://www.unwater.org/downloads/WPB25.pdf
[86] M. M. Qaderi, D. M. Reid (2009) Crop responses to elevated carbon dioxide and temperature. in S. N. Singh (ed.), *Climate Change and Crops*, Springer-Verlag, pp. 1-19.
[87] W. Schlenker, M. J. Roberts, *Proc. Natl. Acad. Sci. USA* **106,** 15594 (2009).

widespread use in crop improvement. Although scientific communities worldwide largely recognize the safety of GM crops, the political systems of Japan and most European and African countries remain opposed to growing GM crops. Many countries lack GM regulatory systems or have regulations that prohibit growing and even, in some countries, importing GM food and feed. Moreover, even where there exist regulatory frameworks that support the testing and introduction of GM crops, the regulatory process is both complex and expensive. Given the excellent safety record of the GM crops introduced to date, their widespread adoption, and 13-year history in commercial production, it is increasingly evident that the regulatory burden is excessive.

Perhaps the most unfortunate consequence of such excessive regulation has been that university and other public sector researchers in most countries are not able to bring GM crops to farmers because they cannot afford the cost of compliance with the regulations. Productivity gains based on earlier scientific advances can still increase food production in some countries, particularly in Africa. But such productivity gains appear to have peaked in most developed countries and recent productivity gains have been made largely through molecular modification. If modern science is to contribute to the agricultural productivity increases required in coming decades as the climate warms and the human population continues to grow, it is imperative to get beyond the cultural and political biases against molecular crop modification, assess the safety record of GM crops, and ease the regulatory barriers to their development and deployment.

AFRICA CONFRONTS BIOTECHNOLOGY:
The Issue of Regulation

Robert Paarlberg

There is a scientific consensus, even in Europe, that the GMO foods and crops currently on the market have brought no documented new risks either to human health or to the environment. Europe has decided to stifle the use of this new technology not because of the presence of risks, but because of the absence so far of direct benefits to most Europeans. Farmers in Europe are few in number, and they are highly productive even without GMOs. In Africa, by contrast, 60 percent of all citizens are still farmers and they are not yet highly productive. For Africa, the choice to stifle new technology with European-style regulations carries a much higher cost. The future of genetically engineered foods and crops in Africa will depend heavily on choices African governments make regarding the regulation of this technology. There are essentially two different regulatory approaches available: the approach used by the European Union and the approach used by the United States. There are four key differences between these approaches:

- The regulatory approach used in Europe requires new and separate laws that are specific to genetically engineered foods and crops. In contrast, the United States regulates GMOs for food safety and for environmental safety using the laws that were already in place to govern non-GMO foods and crops.

- The European approach also requires the creation of new institutions (for example, national biosafety committees) and a separate screening and approval process for GMOs. In the United States the institutions that screen and approve GMOs (the Food and Drug Administration, the Animal and Plant Health Inspection Service, and the Environmental Protection Agency) are the same institutions that screen and approve non-GMO foods and crops.

- The European approach also differs because it can decline to approve a new technology on grounds of "uncertainty" alone, without any evidence of risk. A hypothetical risk that has not yet been tested for is sufficient reason for blockage. This is known as the precautionary approach. In the United States, if standard tests for known risks such as toxicity, allergenicity, and digestivity have been passed successfully, there is usually no regulatory barrier to commercial release.

- Finally, in Europe all products in the marketplace with some GMO content must carry identifying labels, whereas in the United States the FDA requires labels on approved GMO foods only when there is a material difference relevant to health, safety, or nutrition.

Which of these two approaches is better? In the abstract, the best regulatory approach will be one that allows new technologies to be used while preventing new risks to human health or the environment. Using this standard, the U.S. approach has done a better job because it has allowed many more useful, new technologies to be employed by farmers, without any documented new risks so far. In contrast, the European approach has blocked the planting of GMO crops in most countries in Europe, to the frustration of most European farmers who want to share in the productivity gains these crops provide.

There has not yet been any documented evidence that approved GMOs have posed new risks either to human health or the environment. This finding of "no new risks" is the official view of scientific authorities in Europe itself. European science academies took a number of years to study the impacts of GMO crops on human health and the environment following the first commercializations in 1995, but by 2001–04 a consensus had emerged that no new risks from these seeds had been documented. Among the European institutions that now endorse that consensus are the Research Directorate General of the EU,[88] the French Academy of Sciences, the French Academy of Medicine,[89] the Royal Society in the UK,[90] the British Medical Association (BMA),[91] and the Union of the German Academies of Science and Humanities.[92] Also signing on to this consensus have been the Organization for Economic Cooperation and Development (OECD) in Paris,[93] the Director-General of the World Health Organization (WHO),[94] the International Council for Science (ICSU),[95] and the United Nations Food and Agriculture Organization (FAO).[96]

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[88] Kessler, Charles, and Ioannis Economidis, eds. (2001). *EC-Sponsored Research on Safety of Genetically Modified Organisms: A Review of Results.* Luxembourg: Office for Official Publications of the European Communities. http://europa.eu.int/comm/research/quality-of-life/gmo/

[89] French Academy of Sciences (2002). "Genetically Modified Plants." Institut de France, Academie des sciences, Report on Science and technology. 13 (December). http://www.academiesciences. fr/publications/rapports/pdf/RST13_recommandations_gb.pdf; and http://www.academie-sciences.fr/publications/rapports/pdf/RST13_summary.pdf; French Academy of Medicine (2002). "OMG et sante." Recommendations (Alain Rerat). Communique adopted on 10 December. http://www.academiemedecine.fr/Upload/anciens/avis_69_fichier_lie.rtf

[90] Royal Society (2003). "Where Is the Evidence that GM Foods are Inherently Unsafe, Asks Royal Society," press release, Royal Society, 8 May; http://royalsociety.org/Submission-to-the-Governments-GM-Science-Review/; http://royalsociety.org/GM-crops-modern-agriculture-and-the-environment--- Report-of-a-Royal-Society-Discussion-Meeting-held-on-11-February-2003/

[91] British Medical Association (BMA) (2004). "Genetically Modified Foods and Health: A Second Interim Statement," British Medication Association. London. March, http://www.bma.org.uk/health_promotion_ethics/nutrition_exercise/GMFoods.jsp

[92] Heldt, H. W. (2004) "Are There Hazards for the Consumer When Eating Food from Genetically Modified Plants?" Union of the German Academies of Science and Humanities, Commission on Green Biotechnology. Gottingen: Universitat Gottingen, http://www.akademienunion.de/pressemitteilungen/2006-06/english.html

[93] OECD (Organization for Economic Co-operation and Development) (2001) "GM Food Safety: Facts, Uncertainties, and Assessment." From the OECD Edinburgh Conference on the Scientific and Health Aspects of Genetically Modified Foods, 28 February – 1 March 2000, http://www.oecd.org/document/35/0,3343,en_2649_34537_1885411_1_1_1_1,00.html

[94] Mantell, K. (2002) "WHO Urges Africa to Accept GM Food Aid," Science and Development Network, 30 August. http://www.scidev.net/en/news/who-urgesafrica-to-accept-gm-food.html

[95] ICSU, International Council for Science (2003) *New Genetics, Food and Agriculture: Scientific Discoveries –*

Skeptics who remain fearful sometimes respond that "absence of evidence is not the same thing as evidence of absence." Yet if you look for something for fifteen years and fail to find it, that must surely be accepted as *evidence* of absence. It is not *proof* that risks are absent, but proving that something is absent (proving a negative) is always logically impossible.

The explanation for Europe's highly precautionary regulatory approach toward GMOs goes beyond risks. It is a policy posture that reflects not a presence of new risks for Europeans, but instead an absence of new benefits for most Europeans. The first generation of GMO crops has provided significant benefits to some farmers, but for ordinary food consumers in rich countries there have so far been few direct benefits. The first generation of GMO crops that came to the market in 1995–96 provided benefits mostly to farmers growing cotton, maize, and soybean, in the form of lower costs for the control of insects and weeds. Yet Europe does not have many cotton, maize, and soybean farmers, so the new technology had few champions. For the 99 percent of Europeans who were not maize, cotton, or soybean farmers, the new technology offered almost no direct benefit. For consumers, the new GMO products did not taste any better, look any better, smell any better, prepare any better, or deliver any improved nutrition. Because the vast majority of Europeans saw little or no direct benefit from the technology, they felt they had nothing to lose by keeping it out of farm fields and out of their food supply. They welcomed a highly precautionary regulatory approach as one way to ensure that outcome.

To demonstrate that it was a benefit calculation rather than a risk calculation that mattered most to Europeans in this case, look at the different way Europe regulates GMOs in medicine versus GMOs in agriculture. In the case of medical drugs, Europe does not hesitate to permit the commercial sale of medicines developed with genetic engineering. By 2006, the European Medicines Agency had actually approved 87 recombinant drugs derived from genetically engineered bacteria or from the ovary cells of genetically engineered Chinese hamsters. These drugs were not free from new risks; clinical trials had shown that many actually increased risks of heart disease, malignancy, and gastric illness, but European regulators approved them just the same because of the benefits the drugs could deliver to so many Europeans. While less than 1 percent of Europeans stood to benefit directly from GMO agricultural crops, 100 percent were vulnerable to the diseases these GMO drugs could help treat, so the regulatory treatment of the GMO drugs was far less precautionary. There were both known risks from clinical trials and plenty of uncertainties surrounding long-term exposures, yet the "precautionary principle" was not allowed to block the commercial release of a technology that could bring significant benefits to Europeans.

Consider now the very different circumstances of Africa. In Africa, the percentage of the population that might benefit directly from agricultural GMOs is much higher than in Europe, because 60 percent or more of all Africans are still farmers who depend directly on agriculture

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Societal Dilemmas. http://www.icsu.org/2_resourcecentre/INIT_GMOrep_1.php4

[96] Food and Agriculture Organization (FAO) of the United Nations (2004). *The State of Food and Agriculture 2003-04: Agricultural Biotechnology: Meeting the Needs of the Poor?* Rome: FAO, http://www.fao.org/docrep/006/Y5160E/Y5160E00.HTM.

for income and subsistence. Some GMO crop traits now widely commercialized outside of Africa, such as *Bt* crops (e.g., for maize and cotton) that resist insect damage with fewer chemical sprays, could have wide benefits if planted in Africa today. Other GMO traits soon to come out of the research pipeline, including abiotic stress tolerance traits such as drought resistance, could provide even wider benefits in the future.[97]

Drought-tolerant maize is only one of the new GMO crop technologies now emerging from the research pipeline. Maize is a staple food for more than 300 million people in sub-Saharan Africa, many of whom are themselves growers of maize. These Africans remain poor and food insecure because the productivity of their labor in farming is so low. Population growth has been pushing maize production into marginal areas with little and unreliable rainfall (only 4 percent of cropland in sub-Saharan Africa is irrigated). These factors, combined with human-induced climate change, are expected to increase drought risks to maize growers in Africa in the years ahead. The development of maize varieties better able to tolerate drought is one important response to this growing challenge.

Not all drought-tolerant maize varieties will be GMOs. CIMMYT's Drought Tolerant Maize for Africa (DTMA) initiative, funded in 2007 by the Bill and Melinda Gates Foundation and the Howard G. Buffet Foundation, is designed to accelerate the breeding of non-GMO drought tolerant varieties of maize, both hybrids and open pollinated varieties (OPVs) in thirteen countries in sub-Saharan Africa. This initiative will use conventional and marker-assisted selection breeding but no transgenic techniques. Other initiatives, however, use GMO techniques. One example is the Water Efficient Maize for Africa (WEMA) project, funded in 2008 by the Bill and Melinda Gates Foundation and operated in Africa by the African Agricultural Technology Foundation (AATF).[98] CIMMYT is a partner in this project, as is the Monsanto Company. This initiative will use transgenic techniques in addition to conventional and marker-assisted selection.

Regulatory requirements in Africa for GMOs are emerging as a critical consideration here. WEMA's genetically engineered (GE) varieties of drought-tolerant (DT) maize will deliver benefits to African farmers only if African regulators first allow the technology to be tested in open field trials in Africa and then approve the technology for commercial release to farmers. The regulatory gauntlet for this technology will be long and difficult because in Africa, just as in Europe, transgenic technologies are screened using separate and much higher regulatory standards. In each separate African country, technology developers such as AATF will not be allowed to conduct research on a WEMA variety (e.g., even a confined field trial) without explicit prior approval from a national biosafety committee (NBC). Giving or selling the seed to

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[97] Robert Paarlberg, *Starved for Science: How Biotechnology is Being Kept Out of Africa,* Cambridge: Harvard University Press, 2008.

[98] Monsanto/AATF (2007). "Combining Breeding and Biotechnology to Develop Drought Tolerant Maize for Africa: A Proposal to the Bill and Melinda Gates Foundation," Monsanto Company and African Agricultural Technology Foundation, May 25, St. Louis.

farmers will not be permitted in any country until the NBC has granted a formal environmental release.

Before they grant an environmental release, NBCs typically require technology developers to compile and submit a substantial dossier of data—including the molecular characterization of the variety, the results of lab tests for food safety, and the results of confined field trials for efficacy and biosafety. Once these data are in hand, the NBC can either grant an environmental release promptly, refuse to approve, ask for more data, or do nothing at all, in which case the technology cannot undergo open performance trials in farmers' fields and cannot be legally sold or distributed to farmers.

In the hands of highly precautionary regulators, this system tends to keep new technologies out of the fields indefinitely. So far, fifteen years after GMO crops were first planted commercially in the United States, only two governments in sub-Saharan Africa have given an environmental release to any GMO crops—the Republic of South Africa (for maize, soybean, and cotton) and Burkina Faso (only for cotton). Why have so many governments in Africa chosen to follow this highly precautionary European approach toward regulating GMO foods and crops, despite the technology blockages and extended delays nearly certain to result? Five separate channels of external influence on Africa have led to this choice of Europe's regulatory approach over the approach of the United States.

Bilateral foreign assistance is the first channel of external influence on Africa. Governments in Africa are still significantly dependent on foreign assistance. On average, they are four times as aid-dependent relative to GDP as the rest of the developing world. For this reason, much that takes place in Africa today remains "donor driven." Given that Africa's official development assistance (ODA) from Europe is three times as large as ODA from the United States, the voice of European donors in Africa tends to be louder than any American voice. Governments in Europe have used their ODA to encourage African governments to draft and implement highly precautionary European-style regulatory systems for agricultural GMOs.

A second channel of external influence has been multilateral technical assistance through the UNEP/GEF Global Project for Development of National Biosafety Frameworks (NBFs). Of 23 African governments that had completed an NBF under this UNEP program by October 2006, all but the Republic of South Africa had no previous regulations in place for agricultural GMOs, so UNEP was in effect writing on a blank slate. In the end, 21 of these 23 countries embraced the strongest possible approach (the "Level One" approach), requiring regulations through binding legal instruments approved by the legislative branch of government (parliament), parallel to the European approach. Europe had greater influence than the United States over this UNEP/GEF program because European governments contribute roughly three times as much to the GEF trust fund as does the United States.

A third channel of external influence has been advocacy campaigns against GMOs from international nongovernmental organizations (INGOs), the most active of which are headquartered in Europe. Greenpeace International and Friends of the Earth International,

both based in Amsterdam, have campaigned heavily in Africa against agricultural GMOs. Zambian officials were told by Greenpeace that if GMOs were let into their country, organic produce sales to Europe would collapse. An organization named Genetic Food Alert warned Zambia in 2002 of the "unknown and unassessed implications" of eating GM foods, and a British group named Farming and Livestock Concern warned them that GM corn could form a retrovirus similar to HIV. These assertions were not backed by any evidence, but they frightened the Zambians into banning GMOs completely. A group of mostly European NGOs continued this campaign against GMOs at the 2002 Earth Summit on Sustainable Development in Johannesburg. Led by Friends of the Earth International, they coached their African partners into signing an open letter warning that GMOs might cause allergies, chronic toxic effects, and cancers, despite the absence of any scientific evidence for these hazards. At this same meeting in 2002, two Dutch organizations, HIVOS and NOVIB, joined with partner groups from Belgium, Germany, and the UK to finance a "small farmers march" on Johannesburg (led by a nonfarmer) that ended with a pronouncement that Africans "say NO to genetically modified foods."

A fourth channel of external influence has been commercial agricultural trade. Africa's farm exports to Europe are six times as large as exports to the United States, so it is European consumer tastes and European regulatory systems that Africans most often must adjust to. In 2000, private European buyers stopped importing beef from Namibia because it had been fed on GMO maize from the Republic of South Africa, and then in 2002, Zambia rejected GMO maize as food aid in part because an export company (Agriflora Ltd.) and the export-oriented national farmers union (ZNFU) were anxious that exports of organic baby corn to Europe not be compromised. The risks of export rejections from African countries that plant GMOs are actually quite small, as evidenced by the continued growth of food sales to Europe from the Republic of South Africa, yet anxieties surrounding export loss continues to play a political role.

The final channel of external influence is cultural. Most policymaking elites in Africa have much closer cultural ties to Europe than to the United States, so they are naturally inclined to view European practices as the best practices. For example, the Kenyan author of a 2004 article (published by a European-financed NGO, PELUM) that was titled "Twelve Reasons for Africa to Reject GM Crops," later explained to a newspaper reporter, "Europe has more knowledge, education. So why are they refusing [GMO foods]? That is the question everybody is asking."

Policymaking elites in Africa have often been educated in Europe. They send their children to European schools, and they travel to Europe frequently both on official and unofficial business. It is not surprising that they would be inclined to adopt European-style attitudes toward GMOs, despite the fact that Africa's needs and circumstances are so different from those of Europe. Yet political leaders in Africa pay a price for simply "doing what Europeans do." Europe imposes stifling regulations on GMO foods and crops because Europeans have relatively much less need for this new technology. European farmers are already highly productive without it and European consumers are already well fed. Indeed, like consumers in the United States Europeans are increasingly overfed. In Africa, however, where farmers are not yet productive and where so many consumers are not yet well fed, the potential gains GMO crops can provide are more costly to do without. Rather than deferring to outsiders, either Europeans or

Americans, Africans might usefully look for ways to make independent judgments of their own regarding how to regulate GMO crops. Other countries in the developing world have managed to operate relatively free from external influence—for example, the People's Republic of China. The PRC has seen a strong value in this new technology, and has invested significant public budget resources to develop the technology for Chinese use. Africa has a choice to make independent decisions regarding GMO foods and crops as well.

The tensions over the appropriate road for Africa to follow run deep. They are nicely illustrated in a comparison of two different documents: a recent CAST report and an international assessment of agricultural technology shaped heavily by European-based NGOs and sponsored by the United Nations and the World Bank. The CAST report highlights the urgency of increasing food production and farming productivity in the decades ahead, while the UN/World Bank assessment gives those tasks much less emphasis.

CAST holds to the view that applications of modern science necessarily must play a large role in making farming productive, to stay ahead of growing food demands driven by population growth and dietary enrichment. This view retains strong support from most scientists, most economists, most farmers, and most who work in the industries that provide farmers with the seeds, chemicals, and machines they need to be productive.

This first view may be mainstream among most professional agriculturalists, yet it is now strongly challenged by an increasingly influential coalition of environmentalists, social activists, food writers, and cultural elites who dislike applications of modern science to farming. These critics believe that modern farming has become excessively industrialized, capitalized, specialized, and concentrated. It is part of a corporate monstrosity they call "Food, Inc." The consensus among many NGOs now working in the developing world is that the original Green Revolution of the 1960s and 1970s, based on breakthroughs in modern crop science, was a technical failure and a social calamity. A technical failure because, they believe, it led to unsustainable water and chemical use, and a social calamity because, they claim, only rich farmers gained profit from the new seeds. Both are easily refuted charges,[99] but the refutations are ignored by those whose minds are made up. Science-based farming is seen as dangerous because it replaces small, diversified, sustainable agricultural practices based on traditional knowledge and "agroecology" with industrial scale, overly specialized, environmentally harmful "factory farming."

Which of these two camps is arguing from a stronger empirical foundation? The new CAST report is useful in answering this question because it provides such a concise manifesto for the view that productivity-enhanced, science-based farming is essential. The other side has its bible as well: a 2008 study called the International Assessment of Agricultural Knowledge, Science

[99] See, for example, Robert L. Paarlberg, *Food Politics: What Everyone Needs to Know*, New York: Oxford University Press, 2010, Chapter 6.

and Technology for Development (IAASTD).[100] In part because this report has the imprimatur of the United Nations, it is invoked as authoritative by critics of science-based farming. Which of these two dueling documents deserves greater credibility?

In the table below I compare these two documents along several interesting dimensions:

	2010 CAST Issue Paper	2008 Synthesis Report of IAASTD
Number of Authors	3	17 principal writers, 400 authors in all
Affiliation of Authors	None currently employed by industry, a government, or an advocacy NGO	Many currently working for governments or advocacy NGOs
Length	15 pages	96 pages
Estimates of Future Food Production Needs	Offers projection to 2050	Offers no projection of future production needs. Questions the view that more production will reduce hunger.
Factual Information Presented	Average page makes 28 quantitative factual assertions and mentions 24 dates.	Average page makes 1 quantitative factual assertion and mentions .83 dates
Places Faith In	Markets, public goods investments including agricultural R&D, and assistance to less-developed countries	"A fundamental shift in science and technologies, policies and institutions, as well as capacity development and investments… [that] will recognize and give increased importance to the multifunctionality of agriculture and account for the complexity of agricultural systems within diverse social and ecological contexts."

[100]International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD). Synthesis Report downloadable at http://www.agassessment.org/index.cfm?Page=IAASTD%20Reports&ItemID=2713

Within this comparison, the CAST report's greatest strength is its grounding in a quantitative projection of future food needs, powerfully justifying its call for added productivity enhancements based on science. The IAASTD report sustains its tone of suspicion toward science in part by ignoring these looming production imperatives. Rather than endorse high-productivity farming, the IAASTD report argues that productivity enhancements always lead to "unintended social and ecological consequences," many of which it claims are adverse.

On this point, the CAST report might have explained at greater length that modern high productivity farming is not the same thing as high-input, resource-intensive farming. Modern science allows farmers to produce more food with fewer inputs, and fewer environmental externalities. The CAST report makes this point indirectly in the following sentence: "Modern precision farming with GPS systems, yield monitors, weather-dependent fertilizer application rates, and other computer-assisted tools helps farmers avoid overuse of chemicals by tailoring applications to crop needs." Other modern precision farming techniques might have been referenced as well, such as drip irrigation and laser-leveled fields that help farmers avoid an overuse of water, and modern crop biotechnologies that allow farmers to control weeds and insect pests with fewer chemicals and till the land less severely, reducing the use of fuel, containing soil erosion, and sequestering carbon.

In this regard, I wish the CAST report had made reference to an important 2008 OECD study of the "environmental performance of agriculture" in the thirty most advanced industrial countries of the world, those that have mostly strongly embraced high productivity farming.[101] This study shows that between 1990 and 2004 total food production in these countries increased in volume by 5 percent from an already high level, but adverse environmental impacts were reduced along nearly every dimension. The area of land taken up by agriculture declined 4 percent. Soil erosion from both wind and water was reduced. Water use on irrigated lands declined by 9 percent. Energy use on the farm increased at only one-sixth the rate of energy use in the rest of the economy. Gross greenhouse gas emissions from farming fell by 3 percent. Herbicide and insecticide spraying declined by 5 percent. Excessive nitrogen fertilizer use declined by 17 percent. Biodiversity also improved, as increased numbers of crop varieties and livestock breeds came into use. This starts to look like a trajectory toward genuine sustainability. The same cannot be said for low productivity farming in the developing world, where chemical use is less precise, water use is more wasteful, and where cropland area continues to expand threatening forests and wildlife habitat.

When it comes to environmental sustainability, it is only through highly productive farming that the world's food needs can be met at a reduced cost to the natural environment. The best way to cut excessive input use in modern farming is not to invest less in science-based productivity enhancement, but to invest more. It may also be necessary to eliminate subsidies that distort

[101] OECD, 2008. *Environmental Performance of Agriculture in OECD Countries since 1990,* www.oecd.org/tad/env/indicators.

production incentives and employ regulatory authority where adverse externalities persist, but science-based productivity enhancement remains the key.

HOW NOT TO DO IT:
Lessons from Europe

Mark Cantley

Although the European Union approached regulation of agricultural biotech products with good and honest intent, along the way special interest groups and their targeted political interventions subverted this process, leading to suboptimal outcomes. Today, Europe's overly precautionary regulatory system denies European farmers access to productivity-enhancing biotechnology. European governments, aid agencies, and NGOs are also actively lobbying to have this system extended throughout the developing world, particularly Africa, which is already starved for agricultural innovation and technology. Europe's overly precautionary regulatory system has not made European citizens or their environment any healthier than their counterparts in the United States since biotech agricultural products were adopted there fifteen years ago. Meanwhile, the regulatory system has added new delays, costs, and uncertainties to the marketplace, discouraging innovation and investment in biotechnology, particularly for agriculture.

Europe's current position did not evolve overnight, but was rather the gradual result of savvy lobbying on the part of environmental NGOs, the inability of the scientific community to forcefully make their own case for biotechnology, and policymakers' desire to avoid negative media and please risk-averse voters. Public concern fueled by the 1990s' Mad Cow scare was used by advocacy groups to create widespread public concern about biotechnology in agriculture, despite the fact there was and is no link between biotechnology and this health concern. Currently, there is no scientifically validated evidence from Europe, the United States, or any other country that genetically modified crops pose any additional risk to human health or the environment than conventional crops. To avoid suboptimal regulatory outcomes in the future, the author suggests that regulations for biotechnology in agriculture should be: 1) *Proportional* to the chosen level of protection; 2) *Nondiscriminatory* in their application; 3) *Consistent* with similar measures already taken; 4) *Based on an examination of the potential benefits and costs* of action or lack of action (including, where appropriate and feasible, an economic cost/benefit analysis); and 5) *Subject to review,* in the light of new scientific data.

Background and Context: Institutional Innovation in Europe

The lessons offered below are the harvest of a combined twenty-seven years of work in the Research Directorate-General of the Commission of the European Communities and the Organisation for Economic Cooperation and Development (OECD). This is not, however, an official statement on behalf of the EU or the OECD, although both these worthy bodies have spent much time in developing reports, policy initiatives, legislation, and public policies for modern biotechnology. Unfortunately, in modern biotechnology the evidence and arguments of the scientific communities have not always prevailed in the policies adopted in the European Community, with results ranging from the unfortunate to the disastrous.

As an international bureaucrat, I am not a biotech specialist. My work has been much more at the interface between different views, different departments, and above all between science and policy. The same issues keep coming up—or are forced onto the agenda—in various countries and international associations around the world, year after year. Our political leaders are not often scientists—or if they are, they try to keep it secret. But they are very sensitive to issues of image, presentation, and public opinion, which in turn are dominated by a small number of eloquent "experts" and campaigning organisations. Indeed, professional campaigners have had more influence on policy for biotechnology than scientists. We were paid to try to keep our leaders well informed; however, our criticisms of European Community regulatory policies for modern biotechnology were not accepted and our unit (in the European Commission's Directorate-General for Research) was closed in 1992 at the request of DG Environment. Only in the twenty-first century, after years of argument, tight legislation, and enormous frustration for scientists and agricultural or industrial innovators, did the Commission recognise that they had allowed the EU to implement policies that thwarted the development and deployment of new biotechnologies without any measured benefit to human health or the environment.

The European Commission has a representative from each of its twenty-seven member countries. They are appointed to five-year terms, and the President of the Commission allocates each representative responsibility for one area of policy and for overseeing the work of one or two Directorates-General, or "DGs." With some 38,000 staff, the Commission is the driving motor of the EU and is much more than an executive bureaucracy. It has in principle the monopoly for the drafting of legislation. The DGs are as different as the various agencies of the U.S. federal government, or the various ministries within national administrations in Europe. In a perfect world, each commissioner would bring forward policy initiatives necessary in his domain, which would then be nodded through by his or her fellow commissioners and transmitted to the elected European Parliament and the Council of Ministers. After further debate, these officials would amend and vote on the laws, create new policies, adopt new legislation, and proclaim worthy objectives.

However, we do not live in a perfect world. Individuals and institutions pursue objectives beyond their written mandates and the areas of competence of different commissioners may overlap and conflict. Beyond the European Commission, the European Parliament has been fighting over the past several decades to expand its powers, while national administrations have been careful as to how far they are prepared to concede real powers to the new European institutions. The abstract issues addressed in various European treaties form the main agenda for international, or intra-European, debate. In theory, the Europeans are committed to such concepts as "subsidiarity," delegating all decisionmaking powers to the lowest practicable level. Current political practice, however, seems to push in the opposite direction. There are also conflicts over competence between ministries within countries and regions. Several European countries also have federal constitutions, which add another dimension of complexity to the usual business of politics. Similar conflicts of competence are common within the European Commission, as well as between the various European institutions. To highlight these

complexities, an interesting test case is the regulation of a multidisciplinary, multisectoral topic such as modern biotechnology.

It may reasonably be argued that the division of responsibilities between national administrations and EU institutions, between the different EU institutions, and between different Directorates-General within the European Commission leads to a system of checks and balances difficult for any one political group to capture. Within the Commission, the same argument may justify the division of powers between the different commissioners. And the resulting decisions have to reflect many compromises between the various national and sectoral interests in play. The absence of armed conflict within the European Union over the past sixty years may be seen as demonstrating the benefit of such a balanced system for arriving at political decisions, while gradually developing the constitutional machinery for a community of half a billion diverse peoples. But in a competitive world in which industry and agriculture engage in many unsustainable practices and in which there are many competing and technologically sophisticated contenders, prolonged debates and overcautious decisionmaking increase the risks, costs, and delays of research and investment, and penalise innovation in its competition with existing practices. Modern biotechnology has been on the agenda of the EU institutions for over thirty years. The unsatisfactory state of the regulatory policies and practices ensure that it remains high on the agenda as various interests wrestle with the problems which it poses—or which have been created to impede it.

The Early History—Epilogue, or Overture?

In their 1982 compendium, "The DNA Story: A Documentary History of Gene Cloning," Watson and Tooze[102] published a 605-page collection of key correspondence, documents, and commentary describing the scientific breakthroughs and policy debates of the preceding decade. In the final paragraph of their last chapter, "Epilogue," they conclude, "Politics and politicking preoccupied the first years of the recombinant DNA story, but that phase, fortunately, is fast becoming history. This book is our epitaph to that extraordinary episode in the story of modern biology." Sadly, that optimistic judgement has been proven wrong by subsequent decades of intense, often bitter, and increasingly global "politics and politicking" delaying and complicating the progress of research and innovation in modern biotechnology, as well as its practical applications in all sectors of the applied life sciences.

International debates started in the scientific communities in the early 1970s, as increasing numbers of molecular biologists began to switch from studying *E. coli* and its bacteriophages to working with animal cells in tissue culture and animal viruses. Apprehension increased about possible risks of research with viruses infecting the human intestinal bacterium *E. coli*, and this unease led to the organization in June 1973 of the Gordon Conference, which included an unscheduled debate and votes on biohazards. The conference co-chairs wrote to the presidents of the National Institute of Medicine and the National Academy of Sciences, which set up a

[102] James D. Watson and John Tooze, "The DNA Story: A Documentary History of Gene Cloning" (San Francisco: W.H. Freeman, 1982).

committee to consider the health implications. This committee, reported by July 1974 letters in *Science* and in *Nature*, advocated a moratorium on certain types of experiments as well as an international meeting of involved scientists to review scientific progress and to discuss how to deal with the potential hazards of recombinant DNA molecules. This meeting took place at Asilomar, California, in February 1975.

In Europe, active research had been taking place in several countries, and national reports were starting to appear before and after the Asilomar conference.[103] At European level, a proposal was put forward in 1978, drafted by DG Research, for a strict "directive" to control research and other activities concerning modern biotechnology. As the international debate progressed, the benefits of modern biotechnology began to be clearer, and the need for strict controls (additional to what already existed within the various affected sectors) became less evident. As a result, what emerged from the process was not a directive, but a recommendation (1982/412), which was much softer and did not hamper research.

Parallel work on biotechnology was going on in the US and at the OECD. The United States finalized the "Coordinated Framework" in 1986. In the same year, the OECD produced their "Blue Book," titled "Recombinant DNA Safety Considerations,"[104] including the recommendation of the council of the OECD that stated clearly that **"there is no scientific basis for specific legislation to regulate the use of recombinant DNA organisms."**

Pragmatism or Absolutism?

Through the late 1970s and early 1980s, interest in biotechnology was growing and not only in the ministries of research. Scientific communities at the national level and in the DG Research of the EC offloaded the responsibility for drafting regulations to others actors including the DG Environment, which following their regulatory "successes" on the control of chemicals was looking for new issues to influence. We learned the meaning of the French term *Chef de file* (speak when spoken to) and at committees were told to sit in the back rows. Environmental NGOs were becoming more vocal, popular, and media savvy. They targeted topics that could catch the attention of the public and appeal to popular media. Supposedly lacking an economic base, some of the leading NGOs sought and won grants from the European Commission to assist their publicity efforts. Modern biotechnology was an ideal target for such campaigning, especially as it was being driven forward not only by the enthusiasm of the scientists, but by the commercial interests and research activities of multinational firms such as Monsanto**. The combination of public and media interest, suspicion of multinational companies, and the usual reticence of scientists encouraged national environment ministries and the Environment DG in the EC to enact restrictive legislation designed to protect the public from**

[103] HMSO (1974), *Report of the Working Party on the Experimental Manipulation of the Genetic Composition of Micro-organisms* (Ashby Working Party), Cmnd. 5880, Her Majesty's Stationery Office, London; and HMSO (1976), *Report of the Working Party on the Practice of Genetic Manipulation* (Williams Working Party), CMND. 6600, Her Majesty's Stationery Office, London.

[104] OECD (1986), Recombinant DNA Safety Considerations: Safety considerations for industrial, agricultural and environmental applications of organisms derived by recombinant DNA techniques.

the spectre of profit driven biotechnology. The arguments in the European and national parliaments became noisier and more simplistic. The resulting legislation became much more stringent, often resulting in a complete ban of biotechnologies that produced no additional proven risks to human health or the environment than their conventional peers.

In 2010, there was limited celebration when the Commission authorized the planting in Europe of BASF's Amflora, a GM potato designed to have a very high level of starch suitable for industrial applications. The original application had been made in 2002. Nonetheless, this was the first such positive decision on biotechnology for agriculture in almost thirteen years. Such long and unpredictable delays and uncertain decisions inflate the costs of innovation and effectively limit the sector to the few large multinational firms able and willing to accept such risks. Thus the efforts of the environmental groups ironically serve to protect multinationals from smaller companies.

It was recognised during the debates that in some sectors existing legislation should suffice to cover the need for regulation of emerging biotechnologies. In the EC legislation adopted in 1990, a provision was made to exempt sectors from new legislation if safety aspects were already adequately addressed. This proved important in relation to public health, where there was relevant experience and a preexisting regulatory framework covering the review, approval, or rejection of new pharmaceuticals. Unlike in agriculture, there were also a large number of health-related professionals and a near universal group of patients who were anxiously seeking to accelerate such innovations. Campaigns against new products for the battle against disease were not an attractive target for NGOs seeking to enlist the support of public opinion, so health care exemptions were allowed. Some attempts were made to create a similar exemption for agricultural products, but it was less clear how "GM plants" and "GM foods" would benefit the broader public.

Special interest groups including numerous environmental NGOs further undermined this already weak popular support through disinformation campaigns that falsely suggested there was scientific proof that GM crops could damage human health and the environment. Leading international environmental NGOs seem to have perceived an opportunity to attack multinational capitalist firms, alleging that they were destroying biological diversity, undermining rural livelihoods, and providing potentially unsafe food. The combination of environmental protection, small farmers, and consumer safety was potent. When authorizations were sought for creating and launching GM products, the opposition was noisy, eloquent, and unafraid to manipulate facts. While scientists and other experts with definitive research sat silent or were locked out of key policy debates, NGOs attacked GM crops in the field and boycotted supermarkets, catching the attention of key, elected or politically appointed policy makers. For example, the first (very successful) launch in Europe of tinned GM tomatoes was later withdrawn in the face of hostile campaigning. To this day, GM tomatoes are not grown in Europe.

The Precautionary Principle, and "Zero Tolerance"

The arguments for stricter regulation were not the result of accidents or of an impartial analysis of biotechnologies' risks and benefits. Scientists, being scientists, declined to make the categorical claims that worked so well for the activists. Noting their imperfect knowledge, scientists provided a point of entry for "precautionary" legislation at national levels and in international agencies such as the United Nations. Some years after such activity had started, the Commission established an interservice group to more objectively evaluate biotechnology and suggest best practices for its regulation. After two years of work, this produced EC communication COM(2000)1 on the precautionary principle, which contained six key points:

"Where action is deemed necessary, measures based on the precautionary principle should be, *inter alia*:

- *Proportional* to the chosen level of protection,
- *Nondiscriminatory* in their application,
- *Consistent* with similar measures already taken,
- *Based on an examination of the potential benefits and costs* of action or lack of action (including, where appropriate and feasible, an economic cost/benefit analysis),
- *Subject to review,* in the light of new scientific data, and
- *Capable of assigning responsibility for producing the scientific evidence* necessary for a more comprehensive risk assessment."

If one reads this EC communication carefully, it is a recipe for balanced and pragmatic action—such as had been used in the United States when a first, limited moratorium was established in 1976. In practice, the communication was rarely read, rarely cited, and never adhered to. The legislation that has followed has ignored each of the above six points. A similar lack of interest is displayed in the speeches and papers on nanotechnology: "If there is any uncertainty, [it] virtually guarantees inaction and warns potential investors in biotechnology innovation that political risks may be more challenging than any of the economic hurdles or scientific uncertainties."

A current example is the ongoing debate about **"zero tolerance."** In the 2001 legislation, which added ever-greater stringency to the procedures for obtaining authorization to place a GMO product on the market, it was casually assumed that food retailers must not sell, and farmers must not use for planting or for animal feed, any GM product not yet explicitly authorized for such use. What tolerance level would be applied for this? The answer is zero. The protests of DG Research, concerning problems of cleaning, low-level or adventitious presence, and measurement, were ignored. DG Agriculture's concerns were similarly ignored; DG Environment was Chef de file. The result is now that if in a shipload of grain the inspector detects the presence—however miniscule the quantity—of an unauthorised product, the whole shipload is rejected and sent back to its port of origin. Importers, shippers, and insurers are unhappy. Unless a pragmatic solution can be found, a large proportion of the European livestock industry will be forced into using much more expensive feed or will be eliminated. The EU consumer will then obtain his livestock products from imported materials, as was pointed

out in a DG Agriculture publication in June 2007.[105] Meanwhile, boatloads of grain are blocked from unloading in African ports by the fear that government timidity and/or activist environmental NGOs will prevent or destroy their distribution. Prospects for the future driven by an expected surge of new GM products emerging from R&D efforts around the world are even grimmer for the EU.[106]

Conclusion

The effect of ignoring science and of allowing policy to be dictated by media publicity and campaigners' pressures will be to damage or destroy the competitiveness of substantial sections of the EU agro-food industry. These negative effects will further spill over into much of the developing world (particularly countries in Africa), which often rely on European policy advisors and depend on exports to European markets. Hope remains, however, as current EC President Barroso has moved responsibility for the authorisation of GMOs from DG Environment to DG Health and Consumer Policy—a DG with a longer tradition of attention to scientific advice and a less biased appraisal of both the risks and the benefits of new technologies.

Moving forward, key points for the Commission and others interested in biotechnology regulation include:

- The unhappy story of modern biotechnology not only negatively affects Europe, but also developing countries (particularly within Africa) that look to the EU for policy leadership and/or for export markets.

- All have suffered from delayed approval of new technologies, and from the misinformation campaigns spread by NGO and special interest groups that heighten public concerns.

- An overly precautionary regulatory approach to biotechnology in agriculture fails to take into account the continuing growth of global human population and the need for continued productivity to match if not exceed this enlarged demand.

- This is not a plea for increased charitable donations. Rather it is a plea to allow developing countries to experiment and to develop solutions to their own economic, agricultural and health problems without the threat of reduced aid or closed export markets if they embrace biotechnology.

[105] DG Agriculture and Rural Development of the European Commission, 21 June 2007: "Economic Impact of Unapproved GMOs on EU Feed Imports and Livestock Production."
[106] See, for example, Alexander J. Stein and Emilio Rodriguez-Cerezo, 2009. The Global Pipeline of New GM Crops. JRC Scientific & Technical Reports EUZR 23486-2009.

- The risks conjured up to try to justify heavier, anti-biotechnology legislation are not grounded in proven scientific fact, and instead rely on savvy advertising, popular fears, and media's preference for a sensational story.

- Rather than protecting citizens, the imposition of major regulatory burdens (i.e., delays, costs, and uncertainties) on recombinant DNA research creates greater long-term risks for mankind and for the rural environment.

CONCLUSION

Calestous Juma, Josh Drake, & L. Val Giddings

As this manuscript goes to print, there has been a second rash of global news stories highlighting rising food prices. Although we disagree with their dire predictions of actual food shortages, these stories nonetheless highlight the increasingly central role food policy and production will play in the twenty-first century. Agricultural productivity gains have peaked in the past two decades, and it will take significant new investment and innovation, particularly in biotechnology, to continue producing more food with increasingly limited natural resources. This challenge is even more important today as agriculture is also being asked to help with another environmental challenge—global climate change.

Clearly, the question of how to feed the world's growing population is as relevant today as it was nearly four decades ago during the first Green Revolution. Then, as now, what the world needs is a system capable not only of discovering new agricultural technologies but also of ensuring those technologies are properly adapted for and available in low income countries and regions. In combination with other key innovations such as improved natural resource management, new biotechnologies can make large, positive contributions to global agricultural productivity.

Discovering new biotechnologies and benefiting existing ones will require:

- Significant financial investments in agricultural research,
- Permissive regulatory and political environments, and
- Enhanced networks for knowledge and technology transfer

It is no great surprise that reinvigorating slowed agricultural productivity rates will require a new investment of time, money, and human effort. A message that is less obvious but equally important is that these investments are unlikely to take place on the global scale necessary unless they are preceded by more permissive regulatory and political environments. Highly precautionary regulatory regimes in Europe (and by extension much of Africa) are slowing the overall pace of agricultural innovation and potentially denying European and African farmers benefits enjoyed for nearly fifteen years by their peers in the United States, Brazil, and China. These harsh regulatory regimes stifle innovation by adding new delays, costs, and uncertainties to the marketplace, thereby discouraging investment in biotechnology for agriculture.

Another key point made by multiple authors in this volume is that although new scientific breakthroughs are critical, these innovations will produce limited global results unless they are complemented by parallel investments in enhanced networks for knowledge and technology transfer. The strongest illustrations of this problem come from sub-Saharan Africa where Green Revolution technologies widely adopted elsewhere in the developing decades ago remain rare. In addition to more permissive regulatory regimes, countries and multinational institutions must also work to enhance the network of research, academic, and development institutions

that customize, right size, and deploy innovations for local markets. Countries and regional institutions in the developing world, including sub-Saharan Africa, need to invest in the institutions, physical assets, and human capital that will allow them to participate in and benefit from global innovation and growth. In the medium- and long-term, these investments will also lead to more domestic innovation and growth.

Looking forward, we see challenges to food security from a growing world population, higher expectations for standards of living, increases in disposable income, growing energy demands, and climate change. But we also find ample reason to believe that the challenge to food security can be met by enhanced agricultural productivity. To achieve those productivity increases, we need greater investment in agricultural research, more innovation and investment-friendly regulatory regimes, and enhanced global and regional networks for knowledge and technology transfer. Ultimately, we are optimists about the potential of global agricultural productivity and biotechnology. We therefore hope this collection of papers will serve not as a warning of looming challenges, but rather as a call to action that will help mobilize the financial, intellectual, and political assets needed for a second Green Revolution.

AFTERWORD

Sharon Bomer-Lauritsen[107]

You've read it here in the remarks of our distinguished authors. We have what we need to feed the world. The technology and the modern farming methods exist. What the world lacks is the political will to adequately invest in these technologies and implement these methods them in the field.

The questions we should be asking are not how are we going to feed the world, but how are we going to remove the obstacles to what we know works? Thirty years ago, experts had largely written off India and China. It was believed that many of the residents of those great countries would face chronic food insecurity if not starvation. But increased crop yields saved lives, raised standards of living, and helped add two vibrant, new economies to the world.

The solutions are in our hands to replicate this success throughout the rest of the developing world. We need to use them. We look forward to continuing the conversation and joining you in taking the necessary actions.

[107] Biotechnology Industry Organization

Belfer Center for Science and International Affairs
Harvard Kennedy School
79 JFK Street
Cambridge, MA 02138
Fax: (617) 495-8963
Email: belfer_center@harvard.edu
Website: http://belfercenter.org

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