

PART IV

MODULE I—OPENING GLOBAL DIALOGUE

Introductory Remarks <i>Helen Hambly Odame</i>	27
In Search of the Right Solutions for Africa's Development <i>Kanayo Nwanze, Savitri Mohapatra and Pierre-Justin Kouka</i>	29
Agricultural Biotechnology: How Big Is It Globally? <i>Neal Van Alfen</i>	49
Ever-Green Revolution and Sustainable Food Security <i>M.S. Swaminathan</i>	63
Q&A	77

Module I—Opening Global Dialogue

Introductory Remarks

HELEN HAMBLY ODAME

University of Guelph
Guelph, ON

In preparing for this afternoon, I noted with interest a statement in the NABC 15 proceedings volume that “communication between the pro- and anti-biotech camps was problematic throughout the meeting.” Of course, we are suffering from a world of dualisms when in fact we live in a highly diverse and philosophically pluralistic global society. We should expect of our speakers and ourselves, as participants in NABC 16, a critical analysis of the case-specific nature of biotechnology. Can we not recognize its inherent contradictions because of its positivist tradition and its commercial interest? How might we approach biotechnology if indeed there is new hope for equitable and sustainable agriculture in food-insecure communities throughout the world? If we are unable to recognize and communicate the diversity of viewpoints on this important topic, we are moving away from action towards social and political lethargy, which will accept, not challenge, the global power and food security *status quo*. For me and for many others, this would be totally unacceptable.

This afternoon we will hear from three eminent speakers on agricultural biotechnology in the global context: Kanayo Nwanze, Neal Van Alfen, and M.S. Swaminathan.

In Search of the Right Solutions for Africa's Development

KANAYO F. NWANZE, SAVITRI MOHAPATRA AND PIERRE-JUSTIN KOUKA

*Africa Rice Center
Abidjan, Ivory Coast*

What are the right solutions for Africa? Put together, the United States, Europe, India, China, Argentina, and New Zealand are smaller than Africa. For a continent so diverse—in its demography, in its peoples, their cultures and traditions, and untapped resources—to suggest that one can prescribe a set of solutions, let alone find them, is presumptuous.

In examining the problems and possible solutions for Africa, we will limit our focus specifically to sub-Saharan Africa (SSA), a region of multiple natural and man-made disasters that generate horrifying statistics defying the laws of probability. Our paper attempts first to highlight the formidable challenges that face SSA, then opens a window to a thin ray of hope that is piercing the haze of despair. We will present a few examples of remarkable successes in agriculture and the potential—and concerns—regarding agricultural biotechnology.

Our examples of the signs of hope are drawn from the creation of the Africa-led New Partnership for Africa's Development (NEPAD) and the prospects of cutting-edge science. Contributions from centers supported by the Consultative Group on International Agricultural Research (CGIAR), in strong partnership with national programs in SSA, are highlighted. The reasons why highly promising Africa-specific agricultural technologies have not had the expected and much needed impact in SSA are also discussed.

The last section briefly presents the potential of biotechnology as one of the tools to address some of SSA's intractable problems. It also raises the major concerns for SSA regarding biotechnology, such as the predominant role of the private sector in biotechnology, with very little research on poor people's crops; proprietary science; the high cost of biotech research; the general lack of biosafety guidelines, policies and regulations; the absence of informed public awareness on genetically modified organisms (GMOs) in SSA; and, finally, the risk of SSA being left out of the biotechnology or gene revolution.

The concluding section draws from experiences and observations from over 30 years in agricultural research and development, and discusses the prerequisites for sustainable solutions to Africa's problems such as good governance, political commitment, better institutions, infrastructure and a favorable policy-environment that must accompany promising technologies. We call upon African leaders and all Africans for action!

MAJOR CHALLENGES

The challenges facing SSA are multiple and multi-faceted. They are usually illustrated by a number of statistics for which Africa excels. The stark figures do not reveal the underlying individual tragedies and dreadful human suffering. For the purpose of this paper, only selected major challenges and those related to agriculture are presented.

*In SSA, about 300 million people live on less than
US\$1 per day and nearly 200 million people are
chronically hungry.*

Hunger and Poverty

In SSA, about 300 million people live on less than US\$1 per day (Runge *et al.*, 2003) and nearly 200 million people are chronically hungry. In 2003, 25 million Africans required emergency food aid. In 2000, Africa had 44% of the world's hungry. If present trends continue, the number may be 73% by the year 2015 (ERS/USDA, 2000).

About 32 million African children of less than 5 years of age are underweight (Runge *et al.*, 2003). SSA is the only region where the number of malnourished children will rise over the next 20 years. The predicted increase of 6 million under current trends may prove to be an underestimate (Runge *et al.*, 2003).

SSA is also the only region of the world where poverty is increasing. The number of its poor is likely to rise from 315 million in 1999 to more than 400 million by 2015 (UNECA, 2004).

Population Growth

In the past three decades, Africa's population has grown faster than in any other region. It doubled between 1975 and 2000, from 325 to 650 million. In less than three decades it is projected to double again from the current level (Rosen and Conly, 1998). The rate of growth in the population is projected to be twice that of the growth in food production (Pinstrup-Andersen and Pandya-Lorch, 1999).

Epidemics

The epicenter of the global HIV/AIDS crisis and malarial infestation, SSA suffers the world's highest rates of deaths from HIV/AIDS (81%), malaria (90%) and tuberculosis (23%) (WHO, 2001). HIV/AIDS is ravaging the continent, changing its demography, decimating a generation, and creating the phenomenon of "AIDS orphans." Twelve million African children have lost their parents to AIDS, and this number is expected to reach 28 million by 2010 (UNAIDS, 2000). This is the only continent where polio is still a threatening disease, thereby endangering a whole generation of tomorrow's leaders.

It is estimated that the population of SSA will decrease by 84 million by 2015 as a result of the HIV/AIDS epidemic (UN Population Division, 2001). Much of this reduction is likely to come from rural areas where the incidence of the disease is highest. SSA's agricultural labor force is already devastated and will continue to be so for generations, depleting the region of its food producers, generating a spiral of acute poverty and threatening to compromise any economic, social and democratic progress in the region.

Epidemics and inadequate healthcare and social services are affecting life expectancy, which is now less than 50 years in SSA.

Over the past two decades, per-capita food production has declined significantly, partly due to neglect of the agricultural sector.

Low Agricultural Productivity

One of the biggest challenges facing SSA is how to feed its population. Over the past two decades, *per-capita* food production has declined significantly, partly due to neglect of the agricultural sector. African states and governments did not invest in economic growth and rural development, resulting in current severe food shortages and insecurity. This issue is accentuated by a number of factors, including:

- the dependence of agriculture on rainfall (making it vulnerable to droughts and low productivity),
- the lack of a significant number of sizeable agricultural businesses,
- limited use of inputs; lack of market infrastructures,
- the inadequacy of policies and regulations aimed at providing incentives to agricultural production and related businesses.

Unlike Asia, where it was possible to prevent famines thanks to Green Revolution technologies that could be applied consistently across millions of hectares of land, SSA is confronted with specific challenges—poor soils, unsuitable conditions for irrigation, and large variations in growing conditions. Green Revolution technologies, which were targeted to high-potential areas of Asia, were not suitable for SSA.

The imbalances of agricultural production are exacerbated by the lack of appropriate policies and regulations in the agriculture sector and high deficits in trade balances of African economies. While most African countries depend heavily on the export of one to two crops or of crude oil, imports meet much of their need for agricultural products to close the gap between production and consumption, making most of SSA dependent on the rest of the world. In addition, conditions imposed by international trade tariffs, anti-dumping regulations and trade barriers are not favorable to African nations.

Prescribed structural adjustment programs introduced in the 1970s aimed at eliminating government control, and subsidies and increasing guaranteed prices to the producers of tradable agricultural commodities have had a tremendous adverse impact on African economies. This situation has accentuated the non-competitiveness of SSA in the international market.

*Many experts in agriculture consider decreasing soil
fertility as the fundamental cause of declining food
security in SSA*

Environmental Challenges

Many experts in agriculture consider decreasing soil fertility as the fundamental cause of declining food security in SSA (Sanchez *et al.*, 1997). This statement remains true today as the use of fertilizer has declined in many countries with the disappearance of agricultural subsidies, poor to non-existent roads, high transportation costs, and currency devaluation which has caused fertilizer prices to rise significantly. Farmers in SSA use an average of 9 kg of fertilizer per hectare compared to 241 kg for East Asian farmers and 125 kg for those in developed countries.

Another major environmental threat in SSA is drought, which affects food production. There have been seven major droughts in the region over the last four decades. In 1972–74 and 1981–84, massive displacements and suffering resulted.

*Food security cannot be achieved in an environment
of turmoil.*

Conflicts and Instabilities

Food security cannot be achieved in an environment of turmoil. Poverty's corrosive effects often lead to social and economic instabilities in SSA, which, in turn, keep the populations impoverished and food-insecure. This is a deadly spiral, from which African nations must escape in order to begin to achieve development.

In addition to poverty, the artificial demarcation of Africa that occurred during the colonial period into relatively small political entities and the consequent disruption of existing political and social systems are some of the major causes of current conflicts. Bad and inefficient governance prevalent in many SSA countries has an exacerbating effect.

Decreasing Agricultural Aid

According to the World Bank, agricultural aid to SSA fell from US\$4 billion in 1990 to US\$2.6 billion in 1999, a loss of 35% (World Bank, 2003). Increasingly, the reduced aid is diverted to emergency relief rather than long-term development.

SIGNS OF HOPE

In spite of the bleak picture painted by the challenges described above, there is reason to believe that hope is on the agenda for Africa. Several initiatives and progress made within the region provide tangible positive signs.

New Partnership for Africa's Development

SSA stands on the verge of exciting opportunities that could place its countries—individually and collectively—on a path to sustainable growth and development. There is a heightened sense of responsibility in the international community as a whole and African leaders are increasingly taking over the reins to define where they want to take Africa.

NEPAD is an ambitious action program launched by a new generation of African leaders and embraced by the newly formed African Union (AU). Its long-term goal—to end poverty in SSA—is underpinned by peace, democracy, good governance, the development of social and physical infrastructure and the full engagement of African countries in international trade. It provides a framework for SSA's stakeholders to:

- target financial and human resources more efficiently as part of a coordinated effort for the sub-continent, and
- to measure their impacts.

NEPAD recognizes the role of agriculture in economic development and has placed agricultural growth as the cornerstone of its poverty-reduction program.

NEPAD recognizes the role of agriculture in economic development and has placed agricultural growth as the cornerstone of its poverty-reduction program. Its Comprehensive Africa Agricultural Development Program (CAADP) has identified technological interventions that can improve food security and the productivity of the region's agricultural sector.

NEPAD and the Forum for Agricultural Research in Africa (FARA)—the apex body of the sub-regional organizations in the continent—are collaborating on the large-scale Dissemination of New Agricultural Technologies in Africa (DONATA). The main objective of DONATA is to increase agricultural production and investment, and thereby reduce food insecurity and raise incomes by disseminating improved agricultural technologies such as NERICA rice (New Rice For Africa), tissue-culture banana and new cassava varieties and by institutionalizing links between major national, sub-regional and regional stakeholders in scaling up promising new technologies.

Endorsing the NEPAD action plan, the G8 countries unveiled the G8 Africa Action Plan at the historic Kananaskis Summit in Canada, 2002. Several G8 countries announced increased assistance for Africa. The Canadian government—a strong supporter of NEPAD—has pledged CAN\$500 million for SSA's development. The recent statements from the Sea Island G8 Summit are a far-reaching declaration of commitment to NEPAD and Africa as a whole. The future will assess to what extent commitments are translated into action.

Emerging or Improved Democracies

In spite of the increased number of armed conflicts in some sub-regions, a few countries provide reason to believe in the future of democracy in Africa. With the abolishment of apartheid, South Africa leads SSA on the democratic path and in good governance. Senegal, Mali and Ghana have been cited at different forums for similar significant progress. A recent addition to this list is Uganda, a country poised for major progress in this century. Good governance is high on the agenda of the AU.

Frontier Science

Advances in science and technology such as biotechnology, informatics, geographic information systems (GIS) and sophisticated simulation modeling have opened new frontiers in agricultural research and development. These advances provide hope that solutions to global challenges will also be within the reach of African people.

Today, mankind is on the brink of the golden age of plant science, when we can understand plants so precisely that it is becoming relatively easy to incorporate traits like pest resistance, durability and increased nutritional value in our crops.

Support from International Research Organizations

About 70% of Africans live in rural areas and depend, directly or indirectly, on agriculture. Therefore, agriculture must be at the heart of any effective solution to the problems of poverty, food insecurity, and environmental destruction that beset Africa. The CGIAR centers work closely with national programs to address the agricultural development gap in SSA and help to bring the benefits of modern science to the rural and urban poor.

The research outputs of the CGIAR constitute “global public goods”—freely available to all. This is particularly invaluable for SSA, during a period when a large part of agricultural research and development is moving inexorably towards the private sector.

Several research breakthroughs, including some based on basic molecular genetics, are making a difference in the lives of poor farmers and consumers.

SUCCESS STORIES

Stories from SSA often paint such a bleak picture of its sub-regions that good and positive stories often go unnoticed because they do not represent the image tagged to Africa.

Several research breakthroughs, including some based on basic molecular genetics, are making a difference in the lives of poor farmers and consumers. Two main factors have contributed to the success of several breakthroughs highlighted in this paper.

A priority-setting process and subsequent involvement of national programs in the development and a sense of ownership of new or improved technologies have provided the opportunity for creating technologies that are tailor-made for Africa. This led to major development and extension efforts that were needed to provide a boost to the up-take, out-scaling and up-scaling of research results.

Other factors are the adaptability and sustainability of new or improved technologies. A number of technologies introduced to sub-regions have suffered from lack of sustainability. Large-scale irrigation schemes provide a good example of failures over the past three decades. Projects conducted over specific life spans without consideration of the priorities of the recipient countries and little involvement of national programs in their conception were doomed to fail. Lack of funding for continuation of projects beyond the initial phase led to a proliferation of bad experiences that are often cited to make a case against any hope for Africa's development.

Biological Control of the Cassava Mealybug

Cassava, introduced from South America several centuries ago, has become one of the major food items in SSA, feeding over 200 million people. In the early 1980s however, a major pest—the cassava mealybug—caused crop losses of about 80% and threatened to completely wipe out the crop (Herren and Neuenschwander, 1991)

Researchers at the International Institute of Tropical Agriculture (IITA) in collaboration with national programs set up a mass-rearing and distribution of a predator of the cassava mealybug using data from earlier research by the International Center for Agricultural Research (CIAT) and the International Institute of Biological Control (IIBC). By 1988, the mealybug threat had been successfully controlled throughout Africa. Conservative estimates place the value of production saved at over US\$2.2 billion (Noorgard, 1988).

Banana Tissue Culture

Soil degradation and infestation/infection of orchards with pests and diseases have led to rapid declines in banana production in East Africa over the past 20 years. Applying tissue-culture technology, researchers at the Kenya Agricultural Research Institute (KARI), in collaboration with a local private biotechnology company, successfully produced *in vitro* banana plants commercially. The tissue-culture plants roughly doubled both yield and income under farmers' conditions (Qaim, 1999; Wambugu and Kiome, 2001). The technology shortened maturity time from 15 to 9 months, benefiting mainly women who tend the crop, thereby reducing the gender gap.

Banana currently accounts for more than a quarter of caloric consumption in countries such as Rwanda and Uganda, and the adoption of tissue-culture banana and its further dissemination engineered by the Africa Harvest Biotechnology Foundation International, a private non-governmental organization, is contributing to the economies of rural populations.

Soil Fertility

Leading scientists believe that replenishment of soil fertility will trigger rapid growth in African agriculture in the same way that improved germplasm ushered

in the Green Revolution in Asia (Borlaug and Doswell, 1994; Conway, 1997; Sanchez and Jama, 2000).

Joint research by the International Center for Research in Agro-Forestry (ICRAF) and national programs has found that a system involving improved 1–2 year fallow with nitrogen-fixing leguminous shrubs coupled, where available, with an application of local rock phosphate, effectively enhances soil fertility. This research result is currently being practiced by about 20,000 farmers in southern Africa with the possibility of quadrupling maize output (Sanchez and Jama, 2000)

Quality Protein Maize

Maize means survival for hundreds of millions of people in Africa. Quality protein maize (QPM) developed through traditional plant breeding by the International Maize and Wheat Improvement Center (CIMMYT) contains nearly twice as much usable protein as other types grown in the tropics, and yields 10% more grain. It can prevent malnutrition among millions of people in SSA and elsewhere. The varieties produce 70 to 100% more of the two essential amino acids, lysine and tryptophan—building blocks of proteins needed by all cells in the human body—than the most modern varieties of tropical maize.

For millions of people in West Africa, food means rice.

New Rices for Africa

For millions of people in West Africa, food means rice. Unfortunately, imported rice accounts for roughly 40% of local consumption (WARDA, 2001). The Green-Revolution successes in Asian rice proved difficult to transfer to SSA because the new varieties of rice, wheat and maize could not achieve their yield potential under African conditions. In 1991, researchers at the Africa Rice Center (WARDA) embarked on a wide-crossing exercise that led to the development of the New Rices for Africa (NERICAs): a range of varieties that combine the best traits of Asian and African species.

*NERICAs offer many advantages to farmers:
yield increases of 25 to 250% under farmers' conditions.*

The NERICAs offer many advantages to farmers: maturation in 90 to 100 days compared to 120 to 150 days for traditional varieties, less labor due to reduced weeding time, drought tolerance, and yield increases of 25 to 250% under farmers' conditions with minimum inputs.

NERICAs now occupy about 30,000 ha in Africa and are spreading rapidly to central and eastern Africa. The adoption of NERICA varieties, predicted to reach about 70% by 2006 (WARDA, 2004), is expected to save millions of dollars in rice imports and to increase farmers' incomes and overall well-being.

NEPAD has identified NERICA as one of Africa's best practices, worth scaling up and out, and has endorsed its expansion across the continent as part of its DONATA program to boost agricultural production and food security in SSA.

Absence of Large-Scale Impact of Successful Technologies

Good news is coming out of Africa. However, it is equally true that new or improved technologies that have shown great promise have not had the desired large-scale impact that would provide the necessary leap to African agriculture. The success factors mentioned above also provide some of the reasons for limited impact, one of them being lack of a proactive private sector to lead the development of large-scale farming toward an agricultural revolution.

Nonetheless, the above stories represent seeds of hope and are a good indicator of the tremendous potential of Africa's agriculture. As a vivid testimony to this potential, the leaders and researchers credited for four of these technological breakthroughs—cassava biological control, QPM, the soil fertility initiative and NERICA—were recipients of the prestigious World Food Prize in 1995, 2000, 2002 and 2004.

It is, therefore, fair to conclude that the lack of wide-scale impact of technology on Africa's agricultural development lies elsewhere, that science and technology are on the right track and the onus is on our political leaders and policymakers to provide conducive and favorable policies, a stable environment and the political will to sustain the adoption and dissemination of high-impact technologies.

AGRICULTURAL BIOTECHNOLOGY: POTENTIAL AND CONCERNS

Potential

Biotechnology is a powerful ally in agricultural research. It provides a variety of tools that are more precise, faster and allow scientists to improve plants and animal breeds in ways that conventional breeding can not. These include:

- tissue culture for improved and more rapidly available planting material,
- embryo rescue for crossing distant relatives that would not normally produce a viable offspring,
- anther culture that enables breeders to develop a complete plant from a single male cell,
- molecular markers to better understand genetic diversity in crops, livestock and their pests.

Thanks to markers, initial breeding can be done in a laboratory, saving the time and money required to grow several generations in the field.

For SSA, agricultural biotechnology can be especially valuable because it helps develop crops that need fewer expensive or otherwise unavailable inputs such as pesticides and fertilizers and vaccines for livestock. An important feature of this technology is that it is packaged in a convenient form: the seed. This is especially useful for resource-poor farmers. It means providing solutions for difficult problems.

Agricultural biotechnology can help boost crop productivity and enhance the nutritional content of staple foods. The latter is especially important in SSA, where more than half of the population suffers from micronutrient deficiencies, e.g. of vitamin A and iron. In short, food and nutritional security can be improved using biotechnology.

CONCERNS

Unfortunately, biotechnology has become synonymous with GMOs or transgenics, although these are only one aspect. For SSA, as in other parts of the developing world, economic, health and environmental issues are among the main concerns with respect to the use of agricultural biotechnology.

Very little research in transgenics is being conducted on subsistence crops of relevance to farmers in SSA.

Socioeconomic

The current focus of biotechnology research is on crops and diseases that are of economic relevance to developed rather than developing countries. Very little research in transgenics is being conducted on subsistence crops of relevance to farmers in SSA.

Most private-sector research focuses on solving problems faced by farmers in industrialized nations because that is how research costs can be recovered. SSA farmers need more drought tolerance in varieties of cassava, maize, sorghum, millet, and rice that are high-yielding and resistant to common pests and diseases.

Once such improved crop varieties are created, they must be within the purchasing power of the small farmer who has evolved complex, cheap and effective systems to save, exchange and use seeds from one harvest to the next. In such an environment, patented GM seeds are completely unsuitable, especially if they cannot be saved for replanting.

Patented GM genotypes, therefore, threaten to restrict the ability of small farmers to conserve, use and sell seeds, which would seriously impact their means of survival and increase their dependence on private monopolized agricultural resources.

Health

The second major concern regarding the use of biotechnology is that most SSA countries are not equipped to address any potential risks to human and animal health.

In 2002, Zambia rejected the GM maize that was offered by the United States as food aid to help an estimated 2.4 million people. Zambian experts cited the absence of conclusive evidence on the food's long-term effects on several factors, including human health, the country's long-term food-production capacity and impact on the environment and trade.

The health concerns in SSA echo those in other parts of the world. For example, in 2004, Monsanto suspended plans to introduce the world's first biotech wheat, bowing to protests from around the world. However, discussing environmental or ethical issues is hard with destitute people who have lost dignity and hope because they have nothing to eat.

Other Concerns

SSA lacks several key factors that are necessary for the region to fully harness biotechnology for its agriculture: appropriately trained scientists, good research facilities, proper biosafety regulations and efficient protocols for transformation and genomics. The high cost of biotechnology is also a serious constraint. At the same time, many leaders are concerned that Africa cannot afford to miss the biotechnology revolution.

ADDRESSING MAJOR CONCERNS AND CONSTRAINTS

Socioeconomic Concerns

It is true that the private sector dominates biotechnology research and needs intellectual property rights (IPR) and equity with respect to its products. But at the same time, it is in the private sector's interest to ensure that farmers in the developing world can afford their products. Novel partnerships are being formed between the private sector, donors and non-profit organizations to find common and acceptable grounds.

The African Agricultural Technology Foundation's mission is to acquire technologies through royalty-free licenses along with associated materials and know-how for use on behalf of SSA's resource-poor farmers.

For example, the Rockefeller Foundation, the United States Agency for International Development (USAID) and the Department for International Development (DFID), are providing ways for North-South partnerships to open up African markets in a mutually beneficial and sustainable manner by facilitating the African Agricultural Technology Foundation (AATF), launched in 2003. AATF's mission is to acquire technologies through royalty-free licenses along with associated materials and know-how for use on behalf of SSA's resource-poor farmers, while complying with all laws associated with the use of these technologies. Four major biotechnology and agrochemical companies have agreed to freely share their technologies with African agricultural scientists through the AATF.

Specific technical challenges—improved nutrient uptake and rooting, biological nitrogen fixation, responses to carbon dioxide, tolerance to key environmental stresses, *etc.*—are difficult to handle through traditional breeding or simple biotechnology. Transgenics offer great possibilities, for example in addressing deficiencies in protein, vitamins and iron. Unfortunately, resistance to complex environmental stresses is governed by multiple genes, making it difficult to achieve even via genetic engineering. It will probably be a long time before farmers and consumers benefit from such research. Most of the short-term successes in biotechnology would be derived from marker-assisted breeding and diagnostics rather than from transgenic crops.

Contributions from the CGIAR Centers

The following are examples of biotechnology research projects by the CGIAR and SSA national agricultural research systems (NARSs) for smallholder farmers:

- HarvestPlus is a major global Challenge Program initiated by the CGIAR for addressing malnourishment using both conventional methods and biotechnology. The International Rice Research Institute (IRRI) is developing improved rice varieties enhanced in beta-carotene, iron and zinc, which would greatly benefit millions of people who depend mostly on rice.
- Researchers at WARDA where NERICA rice was developed are using anther culture and molecular-marker technology in collaboration with their partners to evaluate hundreds of varieties to exploit the genetic diversity present in indigenous rice, and transfer desirable genes from cultivated and related wild species into suitable varieties.
- Rosette virus disease is a scourge of groundnuts in Africa and no effective control has been found. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has developed transgenic groundnuts with a viral coat-protein gene; it is ready for testing in SSA.
- Similarly, the discovery of *Bt* toxins highly effective against the African sweet potato weevil—by the researchers of the International Potato Center (CIP) and their partners—will open the way to the development and deployment of transgenic sweet potato varieties in SSA.

- CIMMYT and its partners have been trying to develop varieties tolerant of *Striga*, a major parasitic weed of maize in SSA. A gene identified from maize itself offers the most exciting possibility.
- Grass pea is an important source of dietary protein for the poor in Ethiopia. Able to grow in harsh conditions and during drought, it is the only hope for the poor. However, it contains a neurotoxin that induces “lathyrism” or paralysis of the legs. Plant regeneration protocols have been used at the International Center for Agricultural Research in the Dry Areas (ICARDA) to obtain plants with low concentration of the neurotoxin through somaclonal variation.

Health and Environmental Concerns

Several African countries are signatories to the Cartagena Protocol on Biosafety, which deals with the conservation of biological diversity and the equitable sharing of benefits from the use of genetic resources.

The Protocol seeks to protect biological diversity from potential environmental risks posed by living modified organisms (LMOs) and GMOs resulting from modern biotechnology, taking into account risks to human health and focusing on trans-boundary movement of LMOs. It establishes an advanced informed agreement (AIA) procedure for ensuring that countries are provided with the information necessary to make informed decisions before agreeing to the importation of such organisms.

The Program for Biosafety Systems (PBS) is another important initiative that has been established to assist national governments in studying the policies and procedures necessary to evaluate and manage potential harmful effects of modern biotechnology on the environment and human health. Awarded about \$15 million by USAID, the program’s unique approach addresses biosafety as part of a sustainable development strategy, anchored by agriculture-led economic growth, trade, and environment objectives.

Awareness remains the key to narrowing the gap between the public’s understanding and this rapidly advancing field of science. More transparency on the part of the organizations conducting biotechnology research or testing its products would reassure the public and other stakeholders.

Increasing Biotechnology Research Capacity in SSA

NEPAD has proposed a continent-wide network of Centers of Excellence in biosciences with four hubs: one in each of four sub-regions to develop the capacity of African scientists to conduct their own cutting-edge bioscience research and develop programs addressing high-priority problems. In 2003, the Biosciences Facility, hosted by the International Livestock Research Institute (ILRI) in Nairobi, Kenya, on behalf of NEPAD, was launched for East and Central Africa with CAN\$30 million funding from Canada. The core scientific competencies of the Biosciences Facility will be genomics, bio-informatics and their functional applications.

Technological innovation is just one piece in a large and complex mosaic.

CONCLUSIONS

From the foregoing, it is clear that technological options, both conventional and non-conventional, are available in Africa and to Africans for ensuring food and nutrition security while sustaining the environment. But the right solutions for the region require more than just technology. Science and technology alone will work no magic in SSA, nor will technology provide a “quick fix” to result in increased and sustained agricultural growth. Technological innovation is just one piece in a large and complex mosaic.

There are two essential pieces in that complex mosaic: The right leadership and a favourable external environment but with one common thread: a shift in paradigm.

New Forms of Partnerships

Africa features prominently on the G8 agenda. Sea Island was the third G8 summit in succession to which African leaders were invited for what is described as “dialogue”: a euphemism in this context for exchanging pious declarations and empty promises. The G8 has endorsed NEPAD and is on record that they would spend 0.7% of national income on development assistance. Yet aid to Africa has dropped on a *per-capita* basis from \$33 in the 1990s to \$20 today. At the G8 summit in Kananaskis, Canada, South African President Thabo Mbeki’s challenge for a Marshall Plan for Africa was met with deafening silence.

In response to Africa’s worsening food and political crisis, the United Kingdom recently created the International Commission on Africa to heal the scar of Africa’s poverty. The United States has embarked on a series of initiatives to fight hunger in Africa. Kofi Annan’s Water, Energy, Health, Agriculture and Biodiversity (WEHAB) initiative, the UN Millennium Development Goals (MDGs), their various task forces and a host of others run parallel to NEPAD’s development agenda that each is supposedly committed to support. So far, only Ottawa has provided funds to NEPAD. Where is the coordination?

Beyond immediate humanitarian aid, Africa needs long-term development assistance embedded within the framework of NEPAD. This type of assistance has helped Uganda to turn the corner on AIDS, has put more than a million Kenyan children in school and has helped sustain growth in Tanzania and Mozambique. This is where a definite shift in paradigm must occur, on how the North relates to the South.

Africa's solutions are in Africa.

African leaders should cease trooping to Washington, Tokyo, Ottawa, London, Paris, Bonn, Brussels, the Hague, *etc.*, to be lectured on how Africa's problems can be solved only to return home with empty promises. Africa's solutions are in Africa. If they must wine and dine with the G8, then they should aggressively negotiate with countries in the Organization for Economic Cooperation and Development (OECD) who spend close to \$1 billion/day on farm subsidies and impose trade barriers that cost SSA \$20 billion a year in exports and prevent Africa's poor farmers from participating in simple market economies in their own sub-regions.

Good Governance and Wise Policies

At independence, the new leaders of emerging African nation-states embraced the new form of western democracy modeled after their colonial masters in London, Paris, Brussels and Lisbon. They then proceeded to invest in building modern state capitals and administrative structures at the expense of rural development. That was the first mistake we made. Copying and imitation is not development. Development is a natural and intrinsic process, generated from within, phenotypically manifesting itself in the beauty of forms and cultures. It is homegrown, reflecting cultural values and our heritage. But we strove to become modern overnight, forgetting that the West had gone through centuries of development. Agriculture—once the backbone of our economies—was relegated to the background, if not altogether forgotten. Africa's food crisis was predictable 40 years ago. It is a simple but sad truth: at independence, Africa did not invest in agriculture and rural development!

The right solutions for SSA call for fundamental changes in the mindset both of leaders and followers: good governance, accountability, wise policies, improved infrastructure and the spirit of self-reliance. Billions of dollars of development assistance or a plethora of successful technologies cannot revive SSA's agriculture as long as there is widespread corruption, inefficient governance and lack of leadership and vision. Africa will benefit from technologies when agricultural policies are favorable and consistent, when there is political support at the highest level, and the technologies are nurtured and shepherded by the producers of the technologies.

Our governments have committed to spending at least 10% of their budgets on agriculture. It is a laudable step. Effective extension services and public-awareness campaigns must spread the word about improved technologies. "Farm lobbies"

*Our governments have committed to spending at least
10% of their budgets on agriculture.*

are urgently required for the region so that farmers can put political pressure on governments to support agricultural technologies, to institute policies that guarantee prices, create access to credits, inputs and markets, and establish equitable land-tenure systems and safety nets and subsidies to support vulnerable groups.

Rural Development

In the same vein, emphasis should shift to rural development, investment in rural infrastructure, including reliable power supply, good roads linking farmers to markets, and adequate communication facilities. Local agro-industries should be encouraged particularly in terms of post-harvest processing and the transformation of local produce into value-added products. These must not be done by governments, but should be devolved to the private sector. Only when domestic markets are viable and vibrant will competitive regional markets emerge and farmers will aspire beyond existing boundaries.

Women produce up to 80% of basic foodstuffs in Africa.

Governments continue to undermine the role of women in the agricultural sector. Women produce up to 80% of basic foodstuffs in Africa, yet our policies continue to marginalize them. Studies have clearly shown that when female farmers have access to resources such as land, credit, technology, training and marketing, they are more productive than their male counterparts. They invest in child health, nutrition and education and are better heads of single households than are men.

Investment in Human and Institutional Capacity Development

Africa's economic renewal and sustainable development will not be achieved without effective investment in science and technology. But Africa must also have its own capacity to generate these technologies. SSA should not remain just a client of technology. It must take an active part in it, both as an innovator and as a user as part of a holistic strategy for SSA's resurgence, so that the sub-continent can achieve the MDGs and usher in the "Doubly Green Revolution" called for by Gordon Conway (Conway, 1997).

We must, therefore, engage in massive investment in human capital and create institutions that will provide a conducive environment for our scientists. Human-capacity development without parallel favorable and conducive institutional environments have undermined our development efforts, and continue to encourage the steady erosion of our brain power into the diaspora, with thousands of frustrated skilled professionals migrating westwards and northwards for opportunities in the developed world. This loss in human capital has been estimated at 70,000 scholars annually while the region spends \$4 billion annually to recruit, educate and train 100,000 expatriate replacements (Ofori-Sarpong, 2003).

Self-Reliance

African people have a rare capacity for resilience and optimism. Centuries of oppression have not dimmed this extraordinary source of strength. And we have proof that when provided adequate resources, with the right leadership, with commitment and conviction, Africans are capable of remarkable achievements. But prophets are never recognized by their own people, which is why our leaders continue to look beyond their boundaries for advice and for development strategies hatched elsewhere and delivered by so-called experts.

We know of no country, no people, whose economic and political development was not an indigenous and intrinsic process, engraved in its own culture and adapted to the soil, climate and race.

We strongly believe that Africa's problems cannot be solved by its partners. The onus is on Africans themselves. For we know of no country, no people, whose economic and political development was not an indigenous and intrinsic process, engraved in its own culture and adapted to the soil, climate and race. Africans should decide for themselves what is best for them. A meaningful partnership begins only when we know what we want for ourselves. Only then would help from others add value to our efforts. We should select the most useful technologies, whether conventional or novel, push the frontiers of science and technology, harness the best of biotechnology and evolve the right policies for our needs so that we can benefit from the powerful economic forces of market liberalization and globalization.

The paradox of our times is to live in a world of plenty, with spectacular technological advances, yet witness millions trapped in tragic poverty. If African leaders continue to treat hunger, disease, and malnourishment as second priorities to building sports facilities and monuments, they should be brought before the International Court of Justice for crimes against humanity, crimes they have committed against their peoples over the past four decades.

ACKNOWLEDGMENTS

Information contained in this paper on the success stories and contributions of the CGIAR Centers to African agricultural research and development was provided by the centers. A draft of this paper was reviewed by Shellemiah O. Keya and Samuel Bruce-Oliver who also contributed to its finalization.

Views expressed in this paper are those of the authors and not of the CGIAR nor of the Africa Rice Center (WARDA)

REFERENCES

- Borlaug N Doswell CR (1994) Feeding a human population that increasingly crowds a fragile planet. In: Supplement to Transactions 15th World Congress of Soil Science. Chapingo: International Society of Soil Science.
- Conway G (1997) *The Doubly Green Revolution: Food For All in the 21st Century*. London: Penguin Books Ltd.
- Economic Research Service of the United States Department of Agriculture (ERS/USDA) (2000) Food Security Assessment Project, December 2000. Washington, DC: United States Department of Agriculture.
- Herren HR Neuenschwander P (1991) Biological control of cassava pests in Africa. *Annual Review of Entomology* 36 257–283.
- Noorgard RB (1988) The biological control of cassava mealybug in Africa. *American Journal of Agricultural Economics* 70 366–371.
- Ofori-Sarpong E (2003) Effects of Brain Drain in National Development. Accra: Ghanaian Chronicle.
- Pinstrup-Andersen P Pandya-Lorch R (1999) Securing and sustaining adequate world food production for the third millennium. In: NABC Report 11: World Food Security and Sustainability: The Impact of Biotechnology and Industrial Consolidation (Weeks D *et al.* Eds). Ithaca: National Agricultural Biotechnology Council.
- Qaim M (1999) A socioeconomic outlook on tissue culture technology in Kenyan banana production. *Biotechnology and Development Monitor* 40 18–22.
- Rosen JE Conly SR (1998) Africa's population challenge. Washington, DC: Population Action International.
- Runge CF *et al.* (2003) *Ending Hunger In Our Lifetime: Food Security and Globalization*. Baltimore: The Johns Hopkins University Press.
- Sanchez PA Jama BA (2000) Soil fertility replenishment takes off in east and southern Africa. International Symposium on Balanced Nutrient Management Systems for the Moist Savanna and Humid Forest Zones of Africa, Cotonou, Benin, October 2000.
- Sanchez PA *et al.* (1997) Soil fertility replenishment in Africa: an investment in natural resource capital. In: *Replenishing Soil Fertility in Africa* (Buresh RJ *et al.* Eds.). Madison: Soil Science Society of America and American Society of Agronomy.
- Joint United Nations Program on HIV/AIDS (UNAIDS) (2000) Report on the Global HIV/AIDS Epidemic. Geneva: World Health Organization.
- United Nations Economic Commission for Africa (UNECA) (2004) Press Release No. 12/2004. Addis Ababa: UNECA.
- UN Population Division (2001) *World Population Projections. The 2000 Revision: Highlights*. New York: United Nations.
- Wambugu F Kiome R (2001) The Benefits of Biotechnology for Small-Scale Banana Farmers in Kenya. ISAAA Briefs No. 22. New York: ISAAA.

WARDA (2001) *Bintu and Her New Rice for Africa: Breaking the Shackles of Slash-and-Burn Farming in the World's Poorest Region*. Bouake: WARDA.

WARDA (2004) *Annual Report 2002–2003*. Bouake: WARDA.

World Health Organization (WHO) (2001) *World Health Report 2001, Mental Health: New Understanding, New Hope*. Geneva: WHO.

World Bank (2002) *Africa Database 2002*. Washington DC: World Bank.

World Bank (2003) *African Development Indicators (ADI) 2003*. Washington DC: World Bank.



KANAYO F. NWANZE has served as director general of the West Africa Rice Development Association—now known as the Africa Rice Center—since December 1996. The Africa Rice Center is an autonomous intergovernmental agricultural research association of African member states and one of fifteen international agricultural research centers supported by the Consultative Group on International Agricultural Research (CGIAR). Dr. Nwanze has 30 years experience in international

agricultural research, research management, and development work in sub-Saharan Africa (anglophone and francophone countries) and Asia, at CGIAR Centers in Niger, Nigeria, Congo (DRC), Burkina Faso, and India.

He has published extensively and is a member of several scientific associations and a board member of several Africa-based institutions. In 2001, he was conferred with the title of “Commander of the National Order of Merit of Côte d’Ivoire” in recognition of his outstanding leadership of the Africa Rice Center and service to the West African sub-region.

He is the current chair of the Center Directors Committee that groups the directors general of the fifteen centers supported by the CGIAR. Nwanze holds a BSc in Agricultural Biology from the University of Ibadan, Nigeria, and MS and PhD degrees in entomology from Kansas State University.

Agricultural Biotechnology: How Big is it Globally?

NEAL K. VAN ALFEN
*University of California
Davis, CA*

Transgenic crops were first grown commercially on a large scale in 1996 when 1.7 million hectares (Mha) were planted. During the intervening years, the area in transgenic crops grew to 67.7 Mha in 2003. This rate of adoption of a new technology is remarkable, but similar to rapid adoption of other breakthrough technologies of the past (James, 2003). While many different types of transgenic plants have been grown experimentally, relatively few have been grown commercially, and only soybean, maize, cotton and canola are grown on a large scale. The limited number of transgenic crops grown, and their concentration in just a few countries, is a reflection of the resistance shown by consumers in some parts of the world to this new technology (Alston, 2004).

Each year since transgenic crops were first planted, it has been anticipated by some that the adoption of this technology will plateau and eventually decline because of consumer resistance and governmental barriers in some regions of the world. This does not seem to be happening and an analysis of recent trends suggests that widespread adoption will continue to expand beyond the United States. The United States remains the largest producer of transgenic crops, with more than half of the world-wide area in 2003. Rates of adoption of transgenic crops in some developing countries, however, have been rapid. Argentina was one of the early adopters of herbicide-tolerant soybean. In 1996–1997, 1% of the crop was genetically modified (GM), but by 2001–2002 more than 90% of the crop was transgenic. An even more-rapid adoption of transgenic maize has occurred in Argentina (Trigo and Cap, 2003). Approval for planting of transgenic soybean in Brazil was given in 2003, and it was conservatively estimated that more than 3 Mha would be planted in 2003–2004 (James, 2003).

Farmers in China planted transgenic cotton for the first time in 1998 and by 2001 approximately 31% of that crop was of GM cultivars. However, these figures do not necessarily reflect how rapidly growers have adopted this technology. The commercial production of transgenic cotton began in a few provinces in the Yellow River cotton region. Within three years it represented 97% of the crop in Hebei Province and 80% in Shandong Province. Introduction of transgenic cotton occurred later in other regions. Cotton farms in China are small; it is estimated that *Bt* cotton had been adopted on more than 3.5 million by 2001 (Pray *et al.*, 2002).

Transgenic crops are slowly being introduced in other countries. In 2003, five countries each had more than 1 Mha of transgenic crops (United States, Argentina, Canada, Brazil and China) and another five had between 50,000 and a million ha (South Africa, Australia, India, Romania and Uruguay). Small plantings of transgenic crops have occurred in another eight countries, most of which are not likely to join the group of major producing countries soon (James, 2003).

*Where farmers have been given the opportunity to
make a choice, adoption has been rapid.*

Resistance in some parts of the world to transgenic food products is slowing the spread of both the type of transgenic crops produced and the locations in which they are grown (Alston, 2004). There has been much public discussion concerning the relative costs and benefits of the technology, but unless consumers are confident that benefits substantially outweigh the costs, spread to other crops and countries will be slow. Where farmers have been given the opportunity to make a choice, however, adoption has been rapid. This is true for both large-farm producers in the United States and smallholders in China and South Africa. A number of studies have indicated that the rapid adoption of this technology is primarily driven by economic advantage. Economic incentive is the most important driver of non-mandated change, so it is not surprising that this has occurred.

ECONOMIC ADVANTAGES OF GM CROPS

The type of economic advantage provided by the technology has varied from region to region. A survey of literature-source data obtained from US growers regarding farm-level advantages of *Bt* cotton and maize and herbicide-resistant soybean indicated that, in most cases, the growers used less pesticide and had higher profits than they did using comparable conventional technology (Marra *et al.*, 2002). It was reported that there was a profit advantage for the farmer of from \$16 to \$173/acre, including the technology fee, for growing *Bt* cotton. A reduction in pesticide sprays of from 1.3 to 3.4 spray events per season was a major reason for this economic advantage.

A more comprehensive survey in China over a three-year period demonstrated the same trend among smallholder farmers (Huang *et al.*, 2002a; Pray *et al.*, 2002). This study documented the reduction in pesticide use by farmers who adopted *Bt* cotton to be 24–63 kg/ha. To put these savings in perspective, it was reported that in 2001, adoption of *Bt* cotton in China resulted in a reduction of 78,000 tons of formulated pesticide, the equivalent of about 25% of the total pesticide use on all crops in China in the mid-1990s (Pray *et al.*, 2002). The net economic advantage to Chinese growers of *Bt* cotton was estimated at approximately \$500/ha compared with the growing of non-*Bt* cotton. A similar economic advantage—due to reduction of pesticides and increased yields—was reported for farmers with smallholdings in South Africa (Ismael *et al.*, 2002).

The economic advantage of adoption of herbicide-resistant soybean in Argentina appears to be primarily the result of energy savings from switching to no-till cultivation methods, which facilitated double-cropping soybeans with wheat (Trigo and Cap, 2003). In addition, the patent protection for Roundup has expired resulting in competitive pricing of this herbicide; it is estimated that the price in 2001 was less than 30% of the price paid when Monsanto held the patent. The authors of this study indicated that the cost advantage of transgenic soybean to growers was about US\$20/ha, primarily due to energy-cost savings from the more effective weed-management strategy.

These various examples from different parts of the world demonstrate that economic advantage to the farmer resulted in rapid adoption of the technology. The particular nature of the economic advantage varied from country to country, but generally was associated with a reduction in the use of pesticides or cost savings that resulted from changing pesticide-use practices.

Within the past fifty years there has been a significant increase in agricultural research by the private sector relative to that funded by the public sector.

RESEARCH INVESTMENTS

Investments in research represent confidence in economic returns. This is particularly true for investments in the applied sciences, such as agriculture. Agricultural research was the first publicly supported research endeavor probably because it was widely recognized in the agrarian world of the time that providing the funds for that research would have immediate, important paybacks. During the past century, the development of agricultural machinery, processed foods and beverages, synthetic fertilizers, hybrid seed, and pesticides opened the doors for agricultural research investments by for-profit companies. Within the past fifty

years there has been a significant increase in agricultural research by the private sector relative to that funded by the public sector. Private-sector agricultural research in the United States more than tripled in constant-value dollars between 1960 and 1995 (Shoemaker, 2001).

The first major shift in agricultural research from the public to private sector occurred with the development of pesticides. While pesticides were originally a product of public research, today, essentially all pesticide-development research occurs in private laboratories. Shifts are also occurring in traditional plant-breeding programs: in 1980, 70% of the soybeans planted in the United States were public-sector varieties whereas in 1997 it was estimated that only 10–30% of the soybeans were public-sector varieties. Public-sector cotton seed declined from 37% in 1975 to 1979 to about 7% in 1997. Maize-seed sales in the United States in 1997 were dominated by four private companies, with a combined market share of 69% (Shoemaker, 2001). All major US commercial transgenic crops were developed by private seed companies. This shift to private-sector agricultural research has certainly accelerated with the advent of agricultural biotechnology, and because of the rapid change in the relative roles of public- and private-sector agricultural research, unresolved stresses are occurring. It is not surprising that a recurring theme in discussions about agricultural biotechnology relates to social/economic issues associated with for-profit companies seeking payback on their research investments.

Public institutions continue to actively invest in agricultural biotechnology research, which contrasts with their withdrawal from pesticide research and development. Although private investment in agricultural biotechnology exceeds that of public-sector investment (55%:45%), public-sector investment is growing throughout the world (Huang *et al.*, 2002b). Even in countries such as Japan, where consumers are opposed to transgenic foods, significant investments are being made in agricultural biotechnology research. European scientists play major roles in the research that enables agricultural biotechnology product development and they continue to field-test transgenic crops in a public environment hostile to the technology. China's investment in agricultural biotechnology has increased rapidly, and if proposed increases in spending come to fruition, it will account for about one-third of the public-sector investment worldwide. The payback in China for investment of public funds in transgenic cotton was repaid in social benefits by only the second year of commercial production (Huang *et al.*, 2002b). The anticipation of this type of economic return on investment is what appears to be driving the increasing investment in agricultural biotechnology by public entities, even in those countries that do not permit commercial production of GM crops.

Although many have suggested that the public resistance to agricultural biotechnology is similar to the resistance that resulted in the cessation of expansion of nuclear power in the United States, such comparisons are superficial at best. The growth in research and academic program investments in agricultural bio-

technology is not typical of those of an industry in the throes of death. Unlike the nuclear-power industry, which had only a single product to offer, there are unlimited possible uses of transgenic technology in agriculture. Some of these are clearly not suitable for field release or food use, but there are many that will meet strict regulatory standards and provide significant economic and social benefits.

*. . . no clear evidence of negative health effects associated
with those GM crops that have been adopted.*

HUMAN HEALTH ISSUES

One of the early questions raised about methods used to create transgenic crops was whether there would be increased health risks for consumers, unique to the technology. This is a much-researched topic that has yielded no clear evidence of negative health effects associated with those GM crops that have been adopted. Therefore, little of value can be added here except to point out that most reviewers of the topic have concluded that the methods *per se* do not create a risk (Kaeppeler, 2000). It is clear, however, that each new product should be assessed for its risks and benefits, as should be true for any new food product.

Another way to look at the health effects of currently grown GM crops is to examine if any positive, rather than negative, health benefits have resulted from their adoption. One of the most obvious considerations is that related to the shift in pesticide use associated with *Bt* and herbicide-resistant crops. The concern about the toxicity of pesticides has been a major driver in the growth of the organic food industry; it is obviously a topic of great public interest and because of the possible toxicity associated with the consumption of most pesticides, their residues in food are carefully regulated.

Pesticide-Associated Illnesses

In China, more pesticides per hectare are used on cotton than on any other crop (Huang *et al.*, 2002c). Significant reductions in use of pesticides have occurred in that country as a result of the adoption of *Bt* cotton (Pray *et al.*, 2002), with concomitant reductions in occurrence of farmer illness from pesticide exposure. Over the three-year period of 1999 to 2001, between 12% and 29% of the farmers who grew non-*Bt* cotton reported becoming ill because of exposure to pesticides. In contrast, during the same period, only 5% to 8% of farmers growing *Bt* cotton reported becoming ill due to pesticides (Huang *et al.*, 2002a). Clearly, reduced exposure to pesticides resulted in dramatic health benefits for the estimated 3.5 million farmers with smallholdings in China who had adopted *Bt* cotton by 2001 (Pray *et al.*, 2002).

Pesticides in Drinking Water

This reduction of insecticide use, and the replacement of more-toxic, persistent herbicides by a less toxic, easily degraded alternative, should result in public-health benefits. Pesticides are common contaminants of public water supplies. The US national primary drinking water standards lists thirty-three items to be regulated for their presence in drinking water; twenty-three of these are pesticides or their breakdown products (OTA, 1995). The herbicide atrazine is one of the more common and toxic contaminants of drinking water in agricultural regions where it is used (Barbash *et al.*, 2001). Replacement with less-toxic, readily degraded glyphosate should result in fewer problems of public water-supply contamination by atrazine (Barbash *et al.*, 2001). Likewise, reductions in the use of organophosphate insecticides where *Bt* crops are grown should also reduce the danger of contamination of drinking water.

Mycotoxins in Food

There is growing evidence that *Bt* maize has reduced amounts of mycotoxins in the grain than has non-*Bt* maize. Fungi capable of producing toxins are ubiquitous on crops. Many are weak pathogens and grow on plant surfaces or in wounds. Once established in wounds, they are able to penetrate adjacent living plant tissue. Fungi produce a wide array of secondary metabolites, some of which are toxic and/or carcinogenic to humans and animals. Among the most potent is a closely related group of secondary metabolites known as aflatoxins (Payne and Brown, 1998). These and other mycotoxins, such as the fumonisins—formed in plant tissues including grain—are important health threats and stringently enforced regulations limit their presence in food. In many parts of the world, particularly in Africa, these mycotoxins are responsible for serious health problems since much of the food consumed is not inspected for mycotoxins (Bankole and Adebajo, 2003; Fandohan *et al.*, 2003).

Bt maize contains less of the fumonisins than does non-GM maize probably because there is less predation by insects (Munkvold, 2003). Fumonisin, produced by *Fusarium* spp., cause a variety of health problems in animals, including humans (Bankole and Adebajo, 2003). The extent of the reduction of fumonisins in *Bt* maize compared with non-GM maize surprised researchers (Munkvold, 2003). It appears that the reduction is the consequence of fewer fungi growing in grain damaged by insects, particularly the European corn borer. Bakan *et al.* (2002) reported that experiments in Spain and France showed that grain of *Bt* maize had 4- to 10-fold less overall fungal presence than did non-GM varieties, as determined by the relative amounts of ergosterol, a fungal membrane component, in the grain. In these studies the amount of fumonisin B1 was significantly reduced in *Bt* maize. In summarizing the results of thirteen studies where fumonisin content of *Bt* and near isogenic non-*Bt* maize were compared, Munkvold (2003) reported that in eleven of these studies, significant reductions of fumonisin content were reported in *Bt* maize. Magg *et al.* (2002) found only slight reductions in

the amount of fumonisins in *Bt* maize grown in central Europe and suggested that *Bt* maize may not be effective in reducing fumonisins under these growing conditions. Munkvold (2003) indicated, however, that fumonisin content is generally negligible in maize grown in higher latitudes; the most common maize-ear disease of that region—gibberella ear rot—is not associated with insect damage. Similar consistent reductions of aflatoxins in *Bt* maize have not been reported, probably because heat and water stress are more important factors in the development of the fungi responsible for aflatoxin contamination than is insect damage (Munkvold, 2003).

Developed countries have strict standards for the amounts of mycotoxins allowable in food. Foods that contain mycotoxins, such as maize, peanut and other nuts, and dried fruits generally do not represent a large portion of the diet of consumers in developed countries, so the benefits of *Bt* maize, and future transgenes that reduce mycotoxins in food, will not be as important as they are to developing countries where these foods represent a much larger part of the diet, and where there are less-developed regulatory and inspection programs (Bankole and Adebajo, 2003). It is ironic that the narrow interpretation of the precautionary principle with the intention to protect the health of consumers in some developed countries has created an atmosphere whereby solutions to serious health and economic problems in developing countries are stymied (Otsuki *et al.*, 2001).

The issues related to environmental impacts of agricultural biotechnology thus can be considered as a subset of the issues related to all invasive species, i.e. will this technology create new or unique problems that may cause environmental or economic challenges?

ENVIRONMENTAL ISSUES

A variety of concerns have been expressed regarding the impact of transgenic crops on the environment. Primary among these is that unwanted genes may become fixed into populations of wild species. This is not a new problem since many of our crops have the potential to breed with related wild species, but we obviously do not want to continue to spread plants and animals around the world in ways that may disrupt local ecosystems. Most of the plants and animals that our ancestors domesticated and that we use to feed the world did not evolve where they are grown today; not surprisingly, some of these have become weedy. The issues related to environmental impacts of agricultural biotechnology thus can be considered as a subset of the issues related to all invasive species, *i.e.* will this technology create new or unique problems that may cause environmental or economic challenges?

The primary question regarding agricultural biotechnology is not whether GM crops can have negative impacts on the environment, but whether or not there is something unique about the technology that creates a need for them to be separately regulated. The Ecological Society of America has considered this issue and concluded that the technology does not create unique risks, but that there are potential risks from products of the technology that must individually be evaluated (Snow *et al.*, 2004).

Risk is associated with any change.

Our traditional genetic manipulation technologies, *i.e.* selective breeding and induced mutation methods, create products that have potential risks. The southern corn leaf blight of maize was a consequence of the widespread use of a rare mutation in maize, the cytoplasmic Texas male sterile trait. This useful trait for the breeding of hybrid maize unintentionally created plants that were uniformly susceptible to a previously unknown fungal disease (Bekele and Sumner, 1983). In essence, the use of this naturally occurring gene in traditional breeding programs created a new plant-disease problem. It is impossible to foresee such consequences, and they are clearly not unique to a particular technology. Other examples similar to the southern corn leaf blight incident are known, and they collectively reinforce the reality that risk is associated with any change.

The key question is whether or not the benefits associated with widespread adoption a new product are worth possible unknown risks. Experience to date would suggest that the environmental risk associated with the current generation of GM crops has been minimal and that positive environmental benefits have come from their adoption.

Decreased use of insecticides and the switch to less-toxic herbicides have been significant benefits from the adoption of the first generation of GM crops. These are important not only for human health but also for the environment. Agricultural chemical use is widely considered to be detrimental to the environment, and reduction in use of these chemicals or change to less-toxic or less-persistent chemicals is a public-policy issue in many countries (NRC, 2000). The data documenting pesticide-use changes illustrate the impact that GM crops have had in meeting these public-policy goals. In Argentina there has been an 83% reduction in the use of herbicides of toxicity class II and a total elimination of the use of those of toxicity class III. While there was an increase in the amount of herbicide used, the increase was in the lowest toxicity class. Associated with this change in herbicide use was the adoption of no-till practices on over 9 Mha of double-cropped soybean and wheat. The net benefits from adoption of GM soybean in Argentina were thus decreased energy use, less soil erosion by adoption of no-till practices, and a shift to a less toxic and rapidly degraded herbicide (Trigo and Cap, 2003).

A careful study of pesticide-use changes in China after adoption of *Bt* cotton showed similar positive environmental benefits. Huang *et al.* (2002a, c) concluded that pesticide use with *Bt* cotton decreased sharply compared with non-*Bt* cotton cultivation, in some regions by 70% to 80%. This reduction is an important accomplishment since it has been suggested that farmers in China overuse pesticides to optimize yield and reduce labor inputs on their small-farm plots (Widawsky *et al.*, 1998). Host-plant resistance as a means to control insects and disease is recognized as a much more environmentally friendly approach, and needs to be encouraged where such resistance is available (NRC, 1996).

The trends in pesticide use reported above suggest that there is hope for further significant changes in amounts and types of pesticides used as more GM crops are adopted. In the United States, it has been public policy to encourage alternatives to pesticide use in agriculture. California, which accounts for 22% of the national pesticide use, has led this effort, in part by requiring adoption of the world's most comprehensive reporting system for pesticide use. Yet despite significant efforts to reduce California's pesticide use with non-biotech methods, an examination of the data showed no change between 1993 and 2000; the same was true for pesticide use in the rest of the country (Epstein and Bassein, 2003). The impact of adoption of GM crops would not likely be noticed on this scale of reporting since herbicides account for the greatest proportion of pesticides used (68%), and the amount of herbicides used is not expected to drop with adoption of GM crops; a shift to lower-toxicity herbicides is the expected outcome. Also, the greatest use of pesticides in the United States is on high-value crops with which no GM alternatives are commercially available.

Pesticide use is not uniform around the world; the highest relative amounts applied per hectare are in Japan and the European Community (Parris and Melanie, 1993). It is unfortunate that the regions of the world that apply the most pesticides have taken the leadership in opposing adoption of agricultural biotechnology and thus have slowed the adoption of a technology that has the potential to substantially reduce the amounts of toxic, persistent pesticides used in the world. Parris and Melanie (1993) suggested that high use of agricultural chemicals in these regions is the result of the relative political power of farmers who have successfully blocked the adoption of stringent environmental policies that would limit the use of agricultural chemicals. There is ample evidence for the adverse human-health and environmental costs associated with the use of pesticides (Low *et al.*, 2004). A proven technology to reduce toxic pesticide use is available and would likely be adopted if the precautionary principle were used with a broader perspective in policy decisions (Levidow, 2003).

CONCLUSION

The first large-scale planting of GM crops was in 1996. Since then, the rate of adoption of the relatively few types of GM crops available has been dramatic, increasing to almost 70 Mha planted in 2003. Although the largest proportion of

GM crops is grown in the United States, many other countries of the world plant them. The very rapid adoption of available GM crops in developing countries such as Argentina and China attest to the economic advantages to farmers. The particular economic driver of adoption varies between countries, but they are clearly not limited to large farms; more than 3.5 million farmers in China grow Bt cotton on small holdings (Pray et al., 2002).

One of the first concerns expressed was that GM technology would create genetic changes that could pose health risks to consumers. Considerable investigation of this issue, and years of experience with the technology, have revealed no evidence for such risks (Kaeppler, 2000). Each product of the technology, however, needs to be assessed for potential health risks, particularly possible allergenicity (Taylor and Hefle, 2001). This scrutiny should not be limited to foods created by transgenic means. There is strong evidence that adoption of currently available GM crops will have positive health benefits, such as reducing pesticide poisoning of farm workers and reducing the exposure of consumers to highly toxic and carcinogenic mycotoxins (Munkvold, 2003) particularly in the developing world.

Although environmental risks are associated with some of the possible uses of the transgenic technology, it is the product, not the technology, that presents the potential risk.

Although environmental risks are associated with some of the possible uses of the transgenic technology, it is the product, not the technology, that presents the potential risk (Snow *et al.*, 2004). Again, each product must, therefore, be carefully studied for its potential risk before it is widely adopted. This is similar in principle to the assessment of any risk to the environment that must be conducted prior to an action, such as the movement of plants and animals into a new area. On the other hand, adoption of some GM crops has resulted in a positive impact on the environment. Pesticide use in some areas has decreased as a consequence of the adoption of Bt varieties; toxic, persistent herbicides have been replaced by less toxic easily degraded alternatives, and soil and energy have been conserved by taking advantage of the GM technology to adopt no-till cultivation methods.

Although the adoption of GM crops has been very rapid in countries that have approved them, there has been resistance in many other countries, particularly in Japan and the European Community. The complexity of the social issues driving this resistance is illustrated by the fact that the countries most resistant to adoption of the technology are also by far the largest users per hectare of pesticides

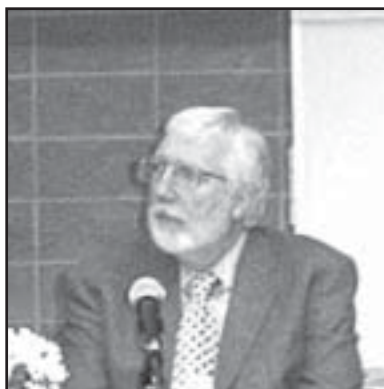
(Parris and Melanie, 1993), which are known to cause health and environmental problems. A systems-level approach to evaluation of the relative value and risk of GM technology would entail studies of how this technology might reduce pesticide use in intensively managed crops, conserve soil by adoption of reduced tillage methods, or reduce human health risks associated with use of pesticides and consumption of mycotoxin-contaminated foods in developing countries. These analyses could be done using the currently available GM crops without even considering all of the other possible benefits that can be derived from adoption of new products of this technology. These comments are not meant to suggest that there does not need to be close oversight and evaluation of new products of GM technology, only to suggest that we need to do just that, *i.e.* allow the evaluation and adoption of products derived from biotechnology.

REFERENCES

- Alston JM (2004) Horticultural biotechnology faces significant economic and market barriers. *California Agriculture* 58 80–88.
- Bakan B *et al.* (2002) Fungal growth and Fusarium mycotoxin content in isogenic traditional maize and genetically modified maize grown in France and Spain. *Journal of Agriculture and Food Chemistry* 50 728–731.
- Bankole SA Adebajo A (2003) Mycotoxins in food in West Africa: current situation and possibilities of controlling it. *African Journal of Biotechnology* 2 254–263.
- Barbash JE *et al.* (2001) Major herbicides in ground water: results from the National Water-Quality Assessment. *Journal of Environmental Quality* 30 831–845.
- Bekele E Sumner DR (1983) Epidemiology of Southern corn leaf blight in continuous corn *Zea mays* culture. *Plant Disease* 67 738–742.
- Epstein L Bassein S (2003) Patterns of pesticide use in California and the implications for strategies for reduction of pesticides. *Annual Review of Phytopathology* 41 351–375.
- Fandohan P *et al.* (2003) Infection of maize by Fusarium species and contamination with fumonisin in Africa. *African Journal of Biotechnology* 2 570–579.
- Huang J *et al.* (2002a) Bt cotton benefits, costs, and impacts in China. *AgBioForum* 5 153–166.
- Huang J *et al.* (2002b) Plant biotechnology in China. *Science* 295 674–677.
- Huang J *et al.* (2002c) Transgenic varieties and productivity of smallholder cotton farmers in China. *Australian Journal of Agricultural and Resource Economics* 46 367–387.
- Ismael Y *et al.* (2002) Benefits from Bt cotton use by smallholder farmers in South Africa. *AgBioForum* 5 1–5.
- James C (2003) Global Status of Commercialized Transgenic Crops: 2003. ISAAA Briefs No. 30. Ithaca: ISAAA.
- Kaeppler HF (2000) Food safety assessment of genetically modified crops. *Agronomy Journal* 92 793–797.

- Levidow L (2003) Precautionary risk assessment of Bt maize: what uncertainties? *Journal of Invertebrate Pathology* 83 113–117.
- Low F *et al.* (2004) Ranking the risk of pesticide dietary intake. *Pest Management Science* 60 842–848.
- Magg T *et al.* (2002) Relationship between European corn borer resistance and concentration of mycotoxins produced by *Fusarium* spp. In: *Grains of Transgenic Bt Maize Hybrids, their Isogenic Counterparts, and Commercial Varieties*. *Plant Breeding* 121 146–154.
- Marra MC *et al.* (2002) The payoffs to transgenic field crops: an assessment of the evidence. *AgBioForum* 5 43–50.
- Munkvold GP (2003) Cultural and genetic approaches to managing mycotoxins in maize. *Annual Review of Phytopathology* 41 99–116.
- National Research Council (NRC) (1996) *Ecologically Based Pest Management, New Solutions for a New Century*. Washington, DC: National Academy Press.
- National Research Council (NRC) (2000) *The Future Role of Pesticides in U.S. Agriculture*. Washington, DC: National Academy Press.
- Otsuki T *et al.* (2001) Saving two in a billion: quantifying the trade effect of European food safety standards on African exports. *Food Policy* 26 495–514.
- Parris K Melanie J (1993) Japan's agriculture and environmental policies: time to change. *Agriculture and Resources Quarterly* 5 386–399.
- Payne GA Brown MP (1998) Genetics and physiology of aflatoxin biosynthesis. *Annual Review of Phytopathology* 36 329–362.
- Pray CE *et al.* (2002) Five years of Bt cotton in China—the benefits continue. *The Plant Journal* 31 423–430.
- Shoemaker R (Ed) (2001) *Economic Issues in Agricultural Biotechnology*. Economics Research Service, USDA. Information Bulletin No. 762. Washington, DC: USDA.
- Snow AA *et al.* (2004) Genetically engineered organisms and the environment: current status and recommendations. Ecological Society of America Position Paper. http://www.esa.org/pao/esaPositions/Papers/geo_position.htm
- Taylor SL Hefle SL (2001) Will genetically modified foods be allergenic? *Current Reviews of Allergy and Clinical Immunology* 107 765–771.
- Trigo EJ Cap EJ 2003. The impact of the introduction of transgenic crops in Argentinean agriculture. *AgBioForum* 6 87–94.
- United States Congress Office of Technological Assessment (OTA) (1995) *Agriculture, Trade, and Environment: Achieving Complementary Policies*. OTA-ENV-617. Washington, DC: US Government Printing Office.
- Widawsky D *et al.* (1998) Pesticide productivity, host-plant resistance and productivity in China. *Agricultural Economics* 19 203–217.

NEAL VAN ALFEN was raised in Modesto, California, and received a BS in chemistry in 1968 and MS in botany in 1969 from Brigham Young University. He received a PhD in plant pathology from the University of California, Davis, in 1972.



Dr. Van Alfen started his professional career as a plant pathology research scientist at the Connecticut Agricultural Experiment Station in New Haven studying tree diseases. In 1975 he moved to Utah State University to be a cooperative extension plant pathology specialist and a member of the faculty of the Department of Biology. In 1990 he moved to Texas A&M University, College Station, to serve as head of the Department of Plant Pathology and Microbiology. In 1999, he returned to UC Davis to become dean of the College of Agricultural and Environmental Sciences.

Van Alfen's research interests have focused on controlling plant disease using low-input, sustainable methods. He also has extensive experience as a consultant on effects of air pollution on environmental health.

He has served on numerous national committees and boards, including a number of National Research Council studies on biological control. He recently served as president of the American Phytopathological Society, and currently is editor of the *Annual Review of Phytopathology*.

Ever-Green Revolution and Sustainable Food Security

M.S. SWAMINATHAN

M.S. Swaminathan Research Foundation
Chennai, India

The “green revolution,” a term coined by William Gaud in October, 1968, is a process that leads to improved agricultural productivity. In January, 1968, in a lecture at the Indian Science Congress, I emphasized the need to improve productivity in perpetuity without associated ecological and/or social harm (Swaminathan, 1993):

Exploitive agriculture offers great dangers if carried out with only an immediate profit or production motive. The emerging exploitive farming community in India should become aware of this. Intensive cultivation of land without conservation of soil fertility and soil structure would lead, ultimately, to the springing up of deserts. Irrigation without arrangements for drainage would result in soils getting alkaline or saline. Indiscriminate use of pesticides, fungicides and herbicides could cause adverse changes in biological balance as well as lead to an increase in the incidence of cancer and other diseases, through the toxic residues present in the grains or other edible parts. Unscientific tapping of underground water will lead to the rapid exhaustion of this wonderful capital resource left to us through ages of natural farming. The rapid replacement of numerous locally adapted varieties with one or two high-yielding strains in large contiguous areas would result in the spread of serious diseases capable of wiping out entire crops, as happened prior to the Irish potato famine of 1854 and the Bengal rice famine in 1942. Therefore the initiation of exploitive agriculture without a proper understanding of the various consequences of every one of the changes introduced into traditional agriculture, and without first building up a proper scientific and training base to sustain it, may only lead us, in the long run, into an era of agricultural disaster rather than one of agricultural prosperity.”

Later, I coined the term “ever-green revolution” to highlight the pathway of increasing production and productivity in a manner such that short- and long-term goals of food production are not mutually antagonistic. In his recent book, *The Future of Life* (Vintage Books, 2002), Edward O. Wilson referred to my concept of ever-green revolution:

The problem before us is how to feed billions of new mouths over the next several decades and save the rest of life at the same time, without being trapped in a Faustian bargain that threatens freedom and security. No one knows the exact solution to this dilemma. The benefit must come from an evergreen revolution. The aim of this new thrust is to lift food production well above the level obtained by the green revolution of the 1960s, using technology and regulatory policies more advanced and even safer than those now in existence.

How do we achieve this ever-green revolution, i.e. a balance between human numbers and human capacity to produce food of adequate quantity, quality and variety?

How do we achieve this ever-green revolution, i.e. a balance between human numbers and human capacity to produce food of adequate quantity, quality and variety? The growing damage to the ecological foundations essential for sustainable food security—land, water, biodiversity, forests and the atmosphere—is leading to stagnation in yields in green-revolution areas. Climate change may compound such problems with adverse effects on temperature, precipitation, sea level and ultra-violet B radiation.

An analysis of food insecurity indicators in rural India carried out by the M.S. Swaminathan Research Foundation (MSSRF) with support from the World Food Programme (WFP), indicates that the Punjab-Haryana region—India’s food basket—may become food-insecure in another 20 years. Indicators used in measuring sustainability of food security are: land degradation and salinization, extent of forest cover, groundwater depletion and the nature of crop rotation. In all of these parameters, Punjab and Haryana occupy low positions. The common rice-wheat rotation has led to displacement of grain and fodder legumes capable of improving soil fertility. The current trend is towards non-sustainable farming resulting from land and water mining.

Forewarned is forearmed. What can we do to launch global agriculture on the pathway to an ever-green revolution, where advances in crop and farm-animal productivity are not accompanied by either ecological or social harm? The following suggestions are aimed at converting the vast know-how now available into field-level *do-how*.

INTEGRATED ATTENTION TO THE COMPONENTS OF FOOD SECURITY

Food security has three major dimensions:

- availability of food—a function of production,
- access to food—a function of purchasing power/access to sustainable livelihoods, and
- absorption of food in the body—determined by access to safe drinking water and non-food factors such as environmental hygiene, primary health care and primary education.

Capacity to support even the existing human and animal populations has been exceeded in many parts of the developing world. Hence, the future of food security depends upon population stabilization, the conservation and care of arable land through attention to soil health and replenishment of fertility, and the conservation and careful management of all water sources so that more crop can be produced per drop of water.

OWNERSHIP AND SUSTAINABLE USE

Much of the degraded and desertified land belongs either to resource-poor families or constitutes over-used and over-grazed common property. Ownership patterns of land and water determine the feasibility of introducing integrated and sustainable land- and water-management systems. Even where land is individually owned, locally acceptable systems of social management may have to be introduced through legislation, education and social mobilization. Women's access to land is also important. Water, particularly groundwater, should be a social resource and not private property. Creating an economic stake in conservation is vital for ensuring the sustainable use of natural resources.

ENVIRONMENTAL REFUGEES

Degradation and erosion of arable land and the depletion and pollution of water resources result in the loss of rural livelihoods. This triggers unplanned migration of the rural poor to towns and cities, with proliferation of urban slums. The rise in the numbers of such environmental refugees threatens peace and security. Norman Myers has chronicled the seriousness of the situation. There should be a monitoring mechanism for avoiding loss of rural livelihoods. Development programs should strengthen linkages between ecological and livelihood security.

There are now unique opportunities for launching a food-for-sustainable-development initiative, in the form of a “grain for green” movement.

GRAIN MOUNTAINS AND HUNGRY MILLIONS: THE GROWING PARADOX

There are now unique opportunities for launching a food-for-sustainable-development initiative, in the form of a “grain for green” movement. Such a program could accord priority to:

- restoration of hydrological and biodiversity “hot spots,” particularly in mountain ecosystems,
- coastal agro-aqua farms (planting of salicornia, mangroves, casuarina, palms, *etc.* along with coastal agriculture and aquaculture),
- water harvesting, watershed development, wasteland reclamation, and anti-desertification measures,
- recycling of solid and liquid wastes and composting, and
- agro-forestry and other sustainable land-use systems in the fields of resource-poor farmers.

A Global Food for Sustainable Development and Hunger Elimination Initiative could be launched by the International Alliance Against Hunger, proposed by FAO. About 25 million tonnes of grains would provide nearly 100 million person-years of work designed to eliminate poverty-induced endemic hunger and at the same time restore and enhance environmental capital stocks.

Such food-for-ecodevelopment initiatives could be managed at the local level by community food banks (CFBs) operated by women’s self-help groups. Such CFBs can be designed to address concurrent issues relating to chronic, hidden and transient hunger. The merit of CFBs will be low transaction cost and transparency. They can also help to widen the food-security basket, thereby saving what could become “lost” crops. Where animal husbandry, including poultry farming, is important to provide additional income and nutrition to families living in poverty, CFBs could also operate feed and fodder banks.

It is the fundamental duty of the state as well as of the well-to-do sections of the population to confer on those who go to bed undernourished the right to food and thereby to opportunities to lead productive and healthy lives. Thanks both to the spread of democratic systems of governance at the grass-roots level and to technological advances, we now have a unique opportunity to foster a community-centered and controlled-nutrition security system. Such decentralized community management will help to improve delivery of entitlements, reduce transaction and transport costs, eliminate corruption and cater to the twin needs of introducing a life-cycle approach to nutrition security and meeting the challenge of seasonal fluctuation in nutritional status. If such CFBs are operated by women, this will help to bridge the gender divide in the area of nutrition.

NEW GENETICS

The elucidation of the double-helical structure of the deoxyribonucleic acid (DNA) molecule in 1953 by James Watson, Francis Crick, Maurice Wilkins and Rosalind

Franklin marked the beginning of what is now known as the “new genetics.” Research during the past 51 years in the fields of molecular genetics and recombinant DNA technology has opened up new opportunities in agriculture, medicine, industry and environmental protection. The ability to move genes across species barriers has led to heightened interest in the conservation and sustainable and equitable use of biodiversity, since biodiversity is the feedstock for plant, animal and microbial breeding enterprises.

Considerable advances have been made in the past 25 years, taking advantage of the new genetics, in medical research, production of vaccines, sero-diagnostics and pharmaceuticals for human and farm-animal healthcare. The production of novel bioremediation agents—for example, the new *Pseudomonas* strain for clearing oil spills in oceans, rivers and lakes developed by Anand Chakraborty—is also receiving priority attention because of increasing environmental pollution.

There has also been substantial progress in agriculture, particularly in crop improvement through molecular-marker-assisted breeding, functional genomics, and recombinant DNA technology. A wide range of crop varieties containing novel genetic combinations are now being cultivated in the United States, Canada, China, Argentina and several other countries. A cotton variety containing the *Bacillus thuringiensis* gene (*Bt* cotton), resistant to the bollworm, is now under cultivation in India resulting from official and unofficial (illegal) releases.

There is little doubt that the new genetics has opened up uncommon opportunities for enhancing the productivity, profitability, sustainability and stability of major cropping systems. It has also created scope for developing crop varieties tolerant/resistant to biotic and abiotic stresses through an appropriate blend of Mendelian and molecular breeding techniques. It has led to the possibility of undertaking anticipatory breeding to meet potential changes in temperature, precipitation and sea level as a result of global warming. There are new opportunities for fostering pre-breeding and farmer-participatory breeding methods in order to combine genetic efficiency with genetic diversity.

While the benefits are clear, there are also many risks when entering unknown and unexplored territory. Such risks relate to potential harm to the environment and to human and animal health. There are also equity and ownership issues in relation to biotechnological processes and products. The following are major questions and areas of concern to the public and to the policymaker.

- What is inherently wrong with the technology? Is the science itself safe, an example being the use of selectable marker genes conferring antibiotic or herbicide resistance?
- Who controls the technology? If the technology is largely in the hands of the private sector, the overriding motive behind the choice of research problems will be profit and not necessarily public good. If this happens, “orphans will remain orphans” with reference to choice of research priorities. Crops being cultivated in rainfed, marginal and fragile environments—which are crying out for scientific attention—may remain neglected.

- Who will have access to the products? If the products arising from recombinant DNA technology are all covered by intellectual property rights (IPR), it will result in social exclusion and will lead to further enlargement of the rich-poor divide in villages.
 - What are the major biosafety issues? There are serious concerns about the short- and long-term effects of genetically engineered organisms on the environment, biodiversity and on human and animal health.
-

There is need for transparent and truthful risk-benefit analyses in relation to genetically engineered organisms, on a case-by-case basis.

Thus, there is need for transparent and truthful risk-benefit analyses in relation to genetically engineered organisms, on a case-by-case basis. In the coming decades, Indian farm women and men will have to produce more food and other agricultural commodities to meet home needs and to take advantage of export opportunities, under conditions of diminishing *per capita* availability of arable land and irrigation water and expanding abiotic and biotic stresses. Enlargement of the gene-pool with which breeders work will be necessary to meet these challenges. Recombinant DNA technology provides breeders with a powerful tool for enlarging the genetic base of crop varieties and for “pyramiding” genes for a wide range of economically important traits. The safe and responsible use of biotechnology will enlarge our capacity to meet the challenges ahead, including those caused by climate change. At the international level, the Cartagena Protocol on Biosafety provides a framework for risk assessment and aversion. At the national level, there is need for regulatory mechanisms that inspire public, political and professional confidence.

SCIENCE AND ORGANIC SEED

To ensure that organic farming leads to higher productivity per unit of land and water used, it is essential that research in the following areas is intensified.

Soil-Health Management

The earlier methods of soil-fertility management, like shifting cultivation, are no longer relevant today due to population pressure on land. Cereal-legume rotations and intercropping are important for replenishing soil fertility. Efficient green-manure plants like the stem-nodulating *Sesbania rostrata* and bio-fertilizers comprising efficient microorganisms (Higa, 1998) have to be packaged in an integrated nutrient-supply system, which includes the application of compost, organic manures and plant residues. Inputs are needed to ensure outputs. For example, a ton of rice needs at least 20 kg of nitrogen along with appropriate quantities of

phosphorus, potassium and micronutrients. Research on soil-health management, in order to ensure adequate soil fertility for high productivity, should receive high priority. The efficient-microorganism (EM) methodology of Dr. Higa needs greater emphasis.

All organic farmers should be provided with soil health cards to monitor regularly the physics, chemistry, microbiology and erodability of their soils. Care of soil health is fundamental to productive agriculture.

Sustainable organic farming will also need bioremediation agents that can help to improve soil health through the sequestration of salt, heavy metals and other yield-reducing constraints. A consortium of microorganisms each capable of performing an important function like nitrogen fixation, phosphorus solubilization, and/or sequestration of salts and pollutants will be needed for each major agro-climatic and agro-ecological farming system.

The other area of research that is essential for sustained high productivity is integrated pest management involving concurrent attention to pests, diseases and weeds. For this purpose, there is need for a biosecurity compact that will help to manage not only pests, diseases and weeds, but also invasive alien species and mycotoxins in food. Sanitary and phytosanitary measures and Codex Alimentarius standards of food safety need to be integrated in organic production protocols.

*There will be need for productive genotypes of crop plants
that can perform well under conditions of soil salinity,
alkalinity and acidity.*

As population pressure on land and water increases, there will be need for productive genotypes of crop plants that can perform well under conditions of soil salinity, alkalinity and acidity. Special genetic gardens will have to be established for halophytes and drought-tolerant genotypes. Also, suitable donors for tolerance of salinity and drought will have to be used in anticipatory breeding for adaptation to climate change and sea-level rise. Scientists at MSSRF have developed sea-water tolerant genotypes of rice, mustard and legumes using the mangrove species *Avicennia marina* as donor. Similarly, *Prosopis juliflora* is being used as a donor of genes for drought tolerance. Such pre-breeding work needs to be integrated with participatory breeding with farm women and men so that location-specific varieties can be developed. Genetic diversity is essential to avoid vulnerability to pests and diseases. Therefore, gene-deployment strategies will have to be developed jointly by scientists and farm families for each agro-ecological region. Successful organic agriculture will need a paradigm shift from purely experiment-station-based research to participatory research in farmers' fields.

Teruo Higa's complex culture of naturally occurring beneficial microorganisms—photosynthetic bacteria, lactic acid bacteria, yeasts, fermentative fungi and

actinomycetes—has multiple uses. It can be used to purify water and sewage, solve sanitary problems, and improve the environment. There is need for more research on such consortia of microorganisms.

Recent research at MSSRF by Loganathan and Nair has led to the isolation of a bacterial strain capable of fixing nitrogen and solubilizing phosphate. *Swaminathania salitolerans* gen. nov., sp. nov. was isolated from the rhizosphere, roots and stems of salt-tolerant wild rice associated with mangrove species. Field trials in rice using this microorganism are now in progress.

It is important to harness all the tools that traditional wisdom and contemporary science can offer in order to usher in an era of bio-happiness. The first requirement for bio-happiness is nutrition and water security for all and forever.

Sustainable organic agriculture will need more science, not less. Artificial barriers should not be created between scientific methods. It is important to harness all the tools that traditional wisdom and contemporary science can offer in order to usher in an era of bio-happiness. The first requirement for bio-happiness is nutrition and water security for all and forever. This is the challenge before all involved in organic farming and the seed industry.

The seed industry has a particularly vital role to play in ensuring genetic diversity in crop plants and in providing organic farmers with genotypes based on a pyramiding of genes for tolerance to major biotic and abiotic stresses. There is also need for greater attention to under-utilized or orphan crops, many of which are not only nutritious but also capable of performing well under fragile and rainfed environments.

In order to change the mindset relating to nutritious millets, the Food and Agriculture Organization (FAO) should change the terminology from “coarse cereals” to “nutritious cereals.” There is need to reverse the narrowing of global food crops by including in the diet a wider range of cereals, millets, grain legumes, vegetables and tubers. In the past, human communities depended upon several hundred species of plants for their nutrition and health security. Diversified farming systems and good dietary habits are essential to confer benefits both to the producer and to the consumer of organic farming products.

Production agriculture and forestry are the major solar-energy harvesting enterprises of the world. An ever-green revolution will help to optimize the production of farm commodities through a symbiotic interaction between solar and cultural energy. This is the pathway to sustainable food security and bio-happiness.

The rich-poor divide is widening and jobless economic growth—better described as joyless growth—is spreading. Although skin-color-based apartheid has ended, technological and economic apartheid are appearing.

FINDING COMMON INTERNATIONAL GOALS:

PATENTS AND UN MILLENNIUM DEVELOPMENT GOALS

From the beginning of time, science and technology have been key elements in the growth and development of societies. Entire eras have been named for the levels of their technological sophistication: the stone age, the bronze age, the iron age, the age of sail, the age of steam, the jet age, the computer age and the age of genomics and proteomics. We are now on the threshold of the nano-age. Unfortunately, the scientific revolution is taking place at a faster pace than our social evolution. As a result, demographic, digital, gender, genetic, technological and economic divides are growing. The rich-poor divide is widening and jobless economic growth—better described as joyless growth—is spreading. Although skin-color-based apartheid has ended, technological and economic apartheid are appearing.

Since its inception, the United Nations University (UNU) has been a center for both humanistic science and scientific humanism. It has, therefore, a moral responsibility for showing how we can bridge these various divides and foster unity wherever discord prevails. The UNU should instill pride in performance and excellence. The UNU Institute for New Technologies (INTECH) should promote a global ecotechnology movement based on a blend of frontier science and traditional ecological prudence.

The world is facing a trilemma—a triple dilemma. Over 3 billion women and men, struggling to survive with an income of less than US\$2 *per capita* per day, are crying for peace and equitable economic development. Countries in southern Africa, and Ethiopia, Afghanistan and North Korea are in the midst of serious famines. In India, the severe debt burden of small farmers sometime results in suicides. Two thousand years ago, the Roman philosopher Seneca said, “A hungry person listens neither to reason nor religion, nor is bent by any prayer.” Thus, one aspect of the trilemma is the craving for peace and development which is equitable in social and gender terms. On another side, there is a growing violence in the human heart. Terms like ethnic cleansing and biological and biochemical terrorism are widely used in the media. The revival of small pox is becoming a possibility. The nuclear peril has again raised its head. Over 30,000 nuclear weapons are stored in the arsenals of major and minor powers. The availability of large

quantities of highly enriched uranium increases opportunities for nuclear adventurism.

The third side of the trilemma is the spectacular progress of science and technology, resulting in an increasing technological divide between industrialized and developing countries. Helping to bridge this divide can be an important contribution of advanced educational and research institutions like the University of Guelph.

In the 1994 report of the International Commission on Peace and Food, which I chaired, we anticipated a substantial peace dividend following the collapse of the Berlin wall and the end of the Cold War. No peace dividend has materialized, instead expenditure on military hardware and internal security is increasing day by day, particularly so as a result of the tragic events of September 11, 2001, in the United States and similar events elsewhere.

Contemporary developmental challenges, particularly those relating to poverty, gender injustice and environmental degradation are indeed formidable. However, remarkable advances in information and communication technology, space and nuclear technologies, biotechnology, agricultural and medical sciences, and renewable energy and clean-energy technologies provide hope for a better common present and future. Genomics, proteomics, the Internet, space and solar technologies and nanotechnology are opening uncommon opportunities for converting the goals of food, health, literacy and work for all into reality. It is however clear that such uncommon opportunities can be realized only if the technology push is matched by an ethical pull. This is essential for working towards a world in which unsustainable life styles and unacceptable poverty become features of the past.

There is a growing mismatch between the rate of progress in science, particularly in molecular biology and genetic engineering, and the public understanding of their short- and long-term implications.

Also, there is a growing mismatch between the rate of progress in science, particularly in molecular biology and genetic engineering, and the public understanding of their short- and long-term implications. There is an urgent need for institutional structures that inspire public confidence that risks and benefits are being measured in an objective and transparent manner. Scientists and technologists have a particularly vital role to play in launching an ethical revolution. The Pugwash movement, which I now have the privilege to head, is an expression of the social and moral duties of scientists to promote the beneficial applications

of their work and prevent their misuse, to anticipate and evaluate possible unintended consequences of scientific and technological development, and to promote debate and reflection on the ethical obligations of scientists in taking responsibility for their work. Rabelais said, "Science is but the conscience of the soul." It is the enduring task of our universities, which are the breeding grounds of leaders who will shape our future, to ensure that science and technology are employed for the benefit of humankind, and not its destruction.

We now have a Global Convention on Biological Diversity to help in the conservation and sustainable and equitable use of biodiversity. We need urgently a similar Convention on Human Diversity. While a convention alone will not halt the growing intolerance of diversity—particularly with reference to religion and political belief—it will help foster a mindset that regards diversity as a blessing and not a curse. Both biodiversity and human diversity are essential for a sustainable future. The human genome map shows that over 99.9% of the genomic constitution is the same in all members of the human family. Universities should do more to spread genetic literacy.

It is also necessary to reflect on methods of giving meaning and content to the ethical obligations of scientists in relation to society. The 1999 World Conference on Science in Budapest called for a new social contract between scientists and society. With a rapidly expanding IPR atmosphere in scientific laboratories, the products of scientific inventions may become increasingly exclusive in relation to their availability, with access limited to those who can afford to pay. The rich-poor divide will then increase, since orphans will remain orphans with reference to scientific attention and investment. How can we develop a knowledge-management system that will ensure that inventions and innovations of importance to human health, food, livelihood and ecological security benefit every child, woman and man, and not just the wealthy? UNESCO could organize a Global Patents Bank for UN Millennium Development Goals. Scientists and technologists from all universities and public research institutions should be encouraged to assign their patents to such a bank, so that the fruits of scientific discoveries are available for the public good. Such a Patents Bank for UN Millennium Development Goals would stimulate scientists to consider themselves as trustees of their intellectual property, sharing their inventions with the poor in whose lives they may make a significant difference for the better. Over two centuries ago, the French mathematician the Marquis de Condorcet, a contemporary of Thomas Malthus, said that the human population will stabilize if children are born for happiness and not just existence. The Government of Bhutan has taken the lead in developing a Gross National Happiness Index, based on the economics of human dignity, love of art and culture and commitment to spiritual values. Making all well-to-do members of the human family regard themselves as trustees of their financial and intellectual property will be essential for fostering a human happiness movement. The twenty-first century holds great promise for advancing the human condition provided there is an appropriate blend of technology and public action.

RUSSELL AND EINSTEIN

I will end with an appeal issued by Bertrand Russell, Albert Einstein and colleagues contained in the Russell-Einstein Manifesto (Born *et al.*, 1955):

We appeal, as human beings, to human beings. Remember your humanity and forget the rest. If you can do so, the way is open to a new paradise; if you cannot, there lies before you the risk of universal death.

The year 2005 marks the sixtieth anniversary of the use of atom bombs on Hiroshima and Nagasaki and the fiftieth anniversary of the Russell-Einstein manifesto. Can we use this opportunity to rid humankind of the nuclear peril and concentrate on harnessing science and technology for achieving the goals of food, water, health and work for all and forever?

REFERENCES

- Born N *et al.* (1955) The Russell-Einstein Manifesto. <http://www.pugwash.org/about/manifesto.htm>.
- Higa T (1998) An Earth Saving Revolution II. Tokyo: Sunmark Publishing Inc.
- Swaminathan MS (Ed.) (1993) Wheat Revolution : A Dialogue. Madras: Macmillan India Ltd.



M.S. SWAMINATHAN has been acclaimed by *Time* magazine as one of the twenty most influential Asians of the twentieth century and one of only three from India, the others being Mahatma Gandhi and Rabindranath Tagore. He was described by the United Nations Environment Programme as “the father of economic ecology” and by Javier Perez de Cuellar, Secretary General of the United Nations, as “a living legend who will go into the annals of history as a world scientist of rare distinction.”

A plant geneticist by training, Professor Swaminathan’s contributions to the agricultural renaissance of India have led to his being widely referred to as the scientific leader of the green revolution movement. His advocacy of sustainable agriculture leading to an ever-green revolution makes him an acknowledged world leader in the field of sustainable food security.

Swaminathan is a fellow of many of the leading scientific academies of India and the world, including the Royal Society of London and the US National Academy of Sciences. He has received forty-five honorary doctorate degrees from universities around the world. He currently holds the UNESCO Chair in Ecotechnology at the MS Swaminathan Research Foundation in Chennai (Madras), India, and is chairman of the Pugwash Conferences on Science and World Affairs.

Module I—Opening Global Dialogue

Q&A

MODERATOR: HELEN HAMBLY ODAME

*University of Guelph
Guelph, ON*

Alan Wildeman (University of Guelph, Guelph, ON): The comment was made about major corporations now making intellectual property freely available to Africa and I was wondering if you could expand upon what the word “free” actually means. I’ve followed the discussion around some of the drugs for HIV, for example, and when you dig into it a little bit more deeply you find out that free is not necessarily free. Do you have any comment on the technology around agriculture?

Kanayo Nwanze: When the African Agriculture Technology Foundation (AATF) was being established, I was a member of the Design Advisory Committee until early 2002. My recollection: I will not mention the four major multinationals that are providing technologies to the AATF, but the AATF is basically serving as an honest broker. For instance, if one of those companies gives a construct to the AATF, the AATF will take on responsibility for any risks. This is quite a complicated setup, but it guarantees that companies that provide their technologies, in whatever form to AATF, are absolved from liability. And I also know that one of the clauses in the agreement in the setup of AATF that some of these technologies would not be made available outside of Africa.

Ron Herring (Cornell University, Ithaca, NY): There is one thing that everybody in this debate agrees about: there is going to be an enormous increase in social surveillance of agriculture, and I’m curious how you come down on the type-1, type-2 errors that we might make. That is, not knowing risk particularly of gene flow through agro-ecologies; we don’t know what these risks are. So far, they don’t seem to be very great. But, not knowing, what kind of biosafety regulations ought to be in place? The experience in Brazil, in Rio Grande do Sul, and in Gujarat of Bt

cotton movement of uncertified, unofficial seeds—both of these indicate to me that it's unlikely that traditional institutions are going to be able to become effective seed-police. I just don't see it happening. So the question is, how much ought to be invested in biosafety institutions and bioregulation? The type-1 and type-2 error is that if we make a very, very tight regime when it's not necessary we've wasted resources. If we make a very loose regime and there is some very serious threat out there of gene flow, then we have a potential catastrophe. Or we could have very, very tight regulation and we don't need it, or very loose regulation and we do need it, or very loose regulation and we don't need it. I wonder how you come down on this. Everyone wants the scientist to tell the rest of society what level of regulation and what kind of regulation is necessary. We're dealing not with risk, which has a probability distribution attached, we're dealing with uncertainty.

That is our strength as a species. We are very adaptive.

Neal Van Alfen: We have to look with an historical perspective at what we have done, and continue to do, to our planet. Clearly, our environmental standards are changing, and that's one of the realities that we face. Historically, we made a mess of things. Every place that we've moved to, we've carried our favorite foods with us and, inadvertently, our pests. So, rats are everywhere and disrupting ecosystems. Through our movement about the planet, we have created and continue to create environmental problems. Agriculture is part of this, and certainly we have to take responsibility for what we do, but as we do things we learn from our mistakes and we try to adapt. So, I would say that we continue to do the best job we can, recognizing that our standards are constantly changing; more is expected all the time and we ought to be trying to meet those expectations, those standards. Now, can we ever achieve perfection in that regard? I don't see that we will—there will always be things that we don't foresee—but I hope that we will continue to learn from our mistakes. That is our strength as a species. We are very adaptive.

Ron Cox (Science and Technology Committee of the Ontario Federation of Agriculture, Toronto, ON): I guess the previous person started into the idea of gene flow and from my limited reading I understand that research has been done mostly in Australia and New Zealand. I'm not aware of whether more research has been done in your own particular countries, but it seems that people don't seem to be concerned. Is enough being done with isolation strips and other mandated precautions? A lot of research is being done in greenhouses to prevent pollen escape. Do you feel that you are ready to expand further in your own particular countries?

Van Alfen: Is your question in terms of how great of a threat is the release of an undesirable trait into the environment through our experimentations?

Cox: Yes. I have seen roughly 1 to 2% and in many areas it would meet the European standard as well.

Van Alfen: Let me give you an example in terms of rice and red rice. There is a clear danger of putting traits into rice that can move to a weed, which is a very big problem in agriculture. Clearly, studies done on gene flow from domesticated rice to red rice have shown that it is modest. But gene flow occurs and so precautions are necessary. Sorghum to Johnson grass is one in which gene flow could occur very rapidly. On the other hand, there are examples of attempts to establish genetically modified organisms in the environment for pollution remediation and for biological control. The first example in the United States was the release of a microorganism to compete with naturally occurring ice-nucleating microbes. This was an attempt to establish a microbe in the environment for a positive affect. And essentially it failed. Another example is the attempt to establish a transgenic fungus in the environment that has a virus incorporated into its genome as a biological control agent for a disease of trees. Again, this has not been successful. So we cannot make uniform predictions about the escape of transgenes into the environment; some will be easily fixed into natural populations while others will be very difficult to establish, even if we want them to become established in a natural population. Unfortunately a mistake could be made; therefore, each should be evaluated on a case-by-case basis, just as we do when we introduce new biological control agents into a region.

Our infrastructure for looking at the problem in its many dimensions is still lacking.

M.S. Swaminathan: I fully support what you said. The major problem now in many developing countries—even in my own land—although we've made some progress, our infrastructure for looking at the problem in its many dimensions is still lacking. We have to build functional capacity and look at each case by case; it is very difficult to generalize at the moment. Maybe 10 years from now, as science progresses, we'll know how to handle it. But at the moment it is better to be cautious, take it case by case. It will involve a lot of money to understand gene flow, how far pollen travels and so on. And, in the context of India, farm animals are also important. Human health, animal health, the environmental health, all of them have to be examined. Take cotton for example, *Bt* cotton: cottonseed cake is used as animal feed then it goes into the human food chain. So, the number of tests you have to make is very considerable. There is insufficient infrastructure,

research infrastructure, scientific infrastructure. If this science is to do a lot of good without controversy, we will have to develop public confidence to reach agreements on mechanisms. There seems to be more public confidence in the regulatory mechanism in the United States. In my country, it remains far from satisfactory. People don't have full confidence. There has to be transparency in the whole mechanism of testing. It's complex. We have to learn from each other—how to do it right. Medical biotechnology—particularly vaccines—does not have the problems we see in the food-biotechnology area. There is much wider acceptance of biotechnological products in pharmaceuticals and medicine.