A 2020 Vision for Food, Agriculture, and the Environment
2020 VISION

FOCUS 7

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APPROPRIATE TECHNOLOGY FOR SUSTAINABLE FOOD SECURITY

EDITED BY PER PINSTRUP-ANDERSEN

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A 2020 Vision for Food, Agriculture, and the Environment

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Appropriate Technology for Sustainable Food Security

Overview

Per Pinstrup-Andersen

Focus 7 • Policy Brief 1 of 9 • August 2001

Modern science and technology offer tremendous opportunities for improving the well-being of current and future generations and the environment. However, they also embody risks. Science and technology must be guided toward outcomes desired by society. Guiding science and technology to benefit the poor and food insecure in developing countries is the focus of this set of policy briefs.

Some people argue that modern science and technology have little to offer the poor. To paraphrase Bill Gates: The poor do not need computers; they need food, clean water, and health care. Yes, but they also need education, jobs, and—if they are among the millions of the world's poor and malnourished who live in rural areas—opportunities to produce enough food at a reasonable cost and without degrading the natural resources needed by their children and grandchildren. Is modern information and communication technology (ICT) irrelevant to these needs? Ask the poor women in hundreds of Bangladeshi villages who have escaped poverty by renting cell phone time to their neighbors, who in turn got higher prices for their handicrafts and agricultural products because they received timely market information.

Some people oppose the idea that modern biotechnology be applied to help the poor farmers and consumers solve their food and agriculture problems. Many low-income Chinese farmers who produce more cotton with less pesticides because they have access to genetically modified Bt seed are lucky that the opposition did not get to the seed before they did. Some people are also opposed to developing improved technology for small farmers through traditional research methods, such as those used in the Green Revolution. They argue that the indigenous knowledge generated by farmers over centuries is most appropriate for poor farmers. Ask the millions of Asian farmers who escaped food insecurity and poverty thanks to the Green Revolution—and for the first time were able to send their children to school or build a good house—if they shouldn't have taken advantage of new technologies.

Some people are opposed to poor farmers' using purchased inputs, such as improved seed, inorganic fertilizers, and chemical pesticides. There are better solutions, they argue; poor farmers become dependent on the market and on private suppliers of such inputs. However, how can those of us who have been fortunate enough to escape poverty, food insecurity, and malnutrition by integrating into the exchange economy ethically argue that the poor should stay isolated from that economy because they may become dependent? The poor will escape poverty and food insecurity only if they take the risk of integrating with the rest of the economy.

Modern science and technology is only one of many factors that will determine whether and to what extent the poor will benefit or lose from integrating into the exchange economy. Existing institutions and policies as well as the technology itself may be biased against the poor. Competitive markets for the goods and services produced by the poor may be absent. Government regulations on ICT may be such that the poor cannot benefit. Public or private monopolies may exploit the poor who try to participate. Technology suppliers' owning patents or other intellectual property rights, as well as uneven distribution of market power between the poor and the suppliers, may facilitate exploitation of the poor. In such cases the dependency argument may be valid.

For these reasons, efforts to guide modern science and technology to solve poor people's food and nutrition problems are likely to be successful only if supported by appropriate policies and institutions. Modern technology should be viewed as part of a broader effort to help the poor solve their problems and not as a silver bullet applied in isolation.

Recent dramatic changes in scientific methods and the resulting technologies have been accompanied by heated debate about these technologies and others on the horizon. What are the potential benefits and risks? What new policies and institutions are needed to achieve benefits without incurring unacceptable risks? What should be the roles of the private and the public sectors? Does new science infringe on societies' and individuals' values and ethical standards? Are the traditional approaches not better? Most of the debate takes place in rich countries among well-fed individuals. The most important question—how can modern science and technology help poor people escape poverty, hunger, and malnutrition—does not take a front seat in these debates. Neither do poor people. The best way to find out what poor and food insecure people want is to give them real choices.

This set of briefs does not pretend to speak for the poor and food insecure. Instead, it presents relevant evidence regarding actual and potential benefits and risks associated with a number of technology areas and contains suggestions for how the benefits can be enhanced and the risks reduced.

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It also includes the authors' opinions about the extent to which the technologies discussed could help poor people solve their food and nutrition problems in a sustainable manner.

The first four briefs discuss alternative technologies for helping poor farmers enhance their well-being through higher agricultural productivity and lower production risks. Jules Pretty presents evidence that agroecological approaches in a large number of projects not only increase productivity but also contribute to more efficient water use, improved soil quality, and pest and weed control with little or no chemical pesticides. He concludes that such approaches lead to sustainable agricultural development, reduced rural poverty, and improved rural livelihoods. He suggests that a larger share of the research budget should be spent on further advancing these approaches.

Prabhu Pingali refers to the success of the conventional research approach underlying the Green Revolution in enhancing food supplies, food security, and poverty reduction. While this approach has led to ecological stress in some cases, he concludes that, when it is focused on marginal areas, it pays off in higher farm yields. He argues that such research will continue to play a major role in efforts to ensure food security and that biotechnology can play an important complementary role.

This sentiment is echoed by Calestous Juma, who concludes that genetic engineering can significantly help poor farmers and consumers. He discusses why perspectives on the use of genetic engineering for food and agriculture are likely to vary between rich and poor countries and notes that almost all genetic engineering has been focused on agriculture in the rich countries. New incentives for the private sector and expanded public investment are needed to develop technology needed by the poor. He suggests that the rich be more sensitive to the needs of the poor when making decisions on trade, property rights, and foreign assistance.

Jennifer Thomson discusses the potential utility of modern biotechnology for Africa and concludes that the region's farmers should be given access to appropriate technology developed through molecular biology–based research.

These briefs indicate that the three technological approaches should be considered complementary rather than alternatives. Give farmers the choice, and each is likely to combine elements from the three approaches in a way that will be optimal for his or her situation.

The next two briefs deal with ICT. Nuimuddin Chowdhury explores how ICT can improve the economic welfare of the rural poor. He stresses the opportunities offered by Internet connectivity and cell phones and argues that filling the existing strong latent demand for more information in rural areas could greatly benefit the poor. He calls on policymakers to create policies and institutions that will foster rapid spread of ICT infrastructure in rural areas.

Uwe Deichmann and Stanley Wood focus on whether geographical information technologies, such as global positioning systems, are appropriate tools for the poor in developing countries. They find that information generated by these technologies is used widely in developing countries to track land use and land degradation, human settlement, and many other uses. However, the benefits for the rural poor have been mostly indirect, through better information. The authors conclude that geographical information technology offers great opportunities for improving rural livelihood through better information.

Recent technological advances have also affected the availability and costs of energy from alternative sources, such as solar panels, biogas, and windmills. R. K. Pachauri and Pooja Mehrotra review the energy problems in rural areas of developing countries, assess the opportunities offered by alternative sources, and compare them with more traditional sources. They identify a number of potential benefits for the rural poor and for the environment from alternative energy sources and suggest policy measures needed to promote them, including the elimination of subsidies on traditional sources.

The major cause of illness and death among children in developing countries is diarrheal diseases, most of which are caused by contaminated food. Morton Satin discusses the potential benefits and risks associated with the use of food irradiation to address food-borne diseases. He suggests that food irradiation be used to complement best practices to avoid contamination. He argues that fear of the unknown is the main reason why many consumers do not demand irradiated food.

The collection of briefs provides a snapshot of some of the most important technologies available for improving the food security of the poor in developing countries. Most of these technologies have been developed to serve people in rich countries. Some are immediately applicable to poor people's food and nutrition problems. Others will serve the poor only if existing policies and institutions are changed. The interaction between technology and policies is critically important. To be truly effective in helping the poor solve their food problems, modern science must focus on developing the technology and knowledge that most appropriately address these problems. With access to the results, poor people should then be empowered to design and implement their own solutions. ■

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Appropriate Technology for Sustainable Food Security

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Farmer-Based Agroecological Technology

Jules Pretty

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A more sustainable agriculture seeks to make the best use of nature's goods and services as functional inputs. It does this by integrating regenerative processes (such as nutrient cycling, nitrogen fixation, soil regeneration, and natural enemies of pests) into food production processes. It minimizes the use of inputs that damage the environment or harm human health. It builds on farmers' knowledge and skills and seeks to make productive use of social capital, namely people's capacities for collective action for pest, watershed, irrigation, and forest management.

The success of modern agriculture in recent decades has often masked significant externalities that affect ecosystem services and human health, as well as agriculture itself. Sustainable agriculture relies more on agroecological and organic approaches to food production. While any farmer or agricultural system with access to sufficient inputs, knowledge, and skills can produce large amounts of food, most farmers in developing countries are not in such a position. The central issue today is to what extent farmers can improve food production with cheap, low-cost, locally available technologies and inputs without causing environmental damage.

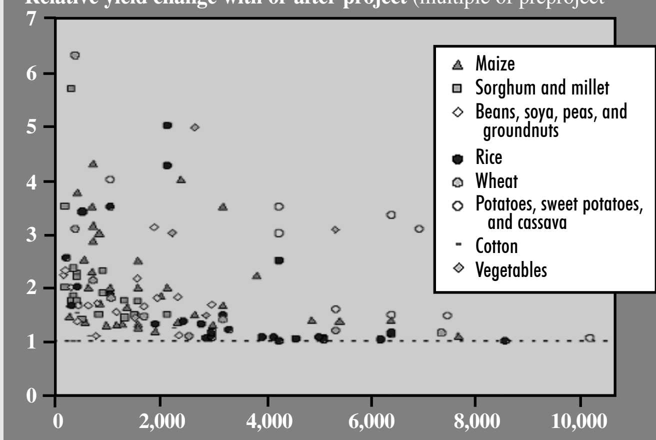
RECENT EVIDENCE

The University of Essex recently completed an audit of progress toward sustainable agriculture in 52 developing countries. This audit indicated that improvements in food production are occurring through one or more of four mechanisms:

- Intensification of a single component of the farm system—such as home-garden intensification with vegetables and trees;
- Addition of a new productive element to a farm system—such as fish in paddy rice—that boosts the farm's total food production, income, or both but that does not necessarily affect cereal productivity;
- Better use of natural capital to increase total farm production, especially water (by water harvesting and irrigation scheduling) and land (by reclamation of degraded land), enabling growth of additional new dryland crops, increased supply of water for irrigated crops, or both; and
- Improvements in per-hectare yields of staples through introduction of new regenerative elements into farm systems (for example, integrated pest management) or locally appropriate crop varieties and animal breeds.

The dataset contains details of 89 projects (139 entries of crop-project combinations) with reliable data on per hectare yield changes with the introduction of new regenerative elements (see figure). These data illustrate that sustainable agriculture has led to an average 93 percent increase in per-hectare food production.

Changes in Relative Crop Yields with Sustainable Agriculture Projects



Source: J. Pretty and R. Hine, Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence, final report from the SAFE-World Research Project, University of Essex, Colchester, U.K., 2001.

SOCIAL LEARNING FOR SUSTAINABILITY

Farmers require timely information on pest-predator relationships, moisture and plants, soil health, and the chemical and physical relationships between plants and animals. Farmers who understand that they can manipulate these agricultural elements, and who are confident about experimentation, are better innovators. Social learning is a vital part of the process of adjustment in sustainable agriculture projects, as participatory and interactive processes help people learn about agroecology and how better to manage it. The empirical evidence indicates that social learning leads to greater innovation, together with increased likelihood that social processes producing these technologies are likely to persist.

AGROECOLOGICAL IMPROVEMENTS

Four types of agroecological improvements have played substantial roles in the food production increases found in the audit: more efficient water use, improvements to soil quality, pest and weed control with minimum or zero pesticide or herbicide use, and redesigns of whole systems.

When better harvested and conserved, water improves productivity. Such water harvesting can lead to extra crops in irrigated lands—particularly important in dryland Asia, where

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small patches of irrigated rice now produce two crops per year rather than one. In rainfed environments, better water harvesting and conservation improves productivity by enabling new lands to be brought under farming and by increasing cropping intensity on existing lands.

To be sustainable, agriculture must also reduce soil erosion and make improvements to soil organic-matter content, water-holding capacity, and nutrient availability. The adoption of zero-tillage methods and diversification within crops and rotations of crops have been particularly successful approaches to soil improvement. The use of zero-tillage—combined with the use of green manures, herbicides, or both—has spread to 20 million hectares in southern Brazil and Argentina.

In Bangladesh, 80 percent of the 150,000 farmers using integrated pest management now no longer use any pesticides. A positive side-effect of using low-pesticide systems is the incorporation of fish, shrimp, and crabs into rice fields, which increase protein production. Novel research in dryland East Africa has found that the chemical cues (semiochemicals) produced by maize when fed upon by the stalk-borer pest, and which cause increased foraging and attack by parasitic wasps, are also released by a variety of grasses. In western Kenya, 2,000 farmers have adopted new "push-pull" pest-management systems (pushing the pests and pulling in the predators), resulting in 60–70 percent increases in maize yields.

The last area of innovation involves simultaneous changes to many farm variables, resulting in synergistic effects. In Madagascar, the system of rice intensification involves 6-day rather than 40-day transplanting, wide spacing, and regular weeding to encourage root growth, and water stressing during the vegetative growth period. With increased tiller numbers and grains per tiller, yield increases from 2 to 10 metric tons per hectare are now common. The system is now being replicated in Asia and elsewhere in Africa, despite initial scientific scepticism.

TRADE-OFFS OF SUSTAINABLE AGRICULTURE

In most contexts, critical trade-offs and contradictions will emerge from sustainable agriculture. For example, building a road to improve marketing near a forest can aid timber extraction. Closing grazing land to rehabilitate it could force people with no other source of food for their livestock to sell them. An increase in cropping intensity or the amount of land cultivated could increase the household workload, with the burden most likely falling on women and the profits going to men, who are less likely to invest in children and the household.

New winners and losers will emerge with the widespread adoption of sustainable agriculture. Producers of current agrochemical products are likely to suffer market losses from a more limited role for their products. The increase in assets that could come from sustainable livelihoods based on sustainable agriculture may simply increase the incentives for more powerful interests to take over.

POLICIES FOR SUSTAINABILITY

Several things are now clear about sustainable agriculture:

- The technologies and social processes for local-level agroecological improvements are well tested and established.
- The social and institutional conditions for the spread of sustainable agriculture are less well known but have been established in several contexts.
- The political conditions for the emergence of supportive policies are the least established, with only a few examples of real progress.

Most of the sustainable agriculture improvements seen in the past decade have arisen despite existing national policies. Although global recognition of the need for policies to support sustainable agriculture is increasing and almost every country would now say it supports sustainable agriculture, the evidence points toward only patchy reforms.

Some countries have seen state-level support for zero-tillage, watershed and soil management, and participatory irrigation management. A much larger number of countries have reformed elements of agricultural policies through new regulations, incentives and environmental taxes, and administrative mechanisms, and these are having considerable though partial effect. Only Cuba and Switzerland have given explicit national support for sustainable agriculture, putting it at the center of agricultural development policy and integrating policies accordingly.

CONCLUSION

Research indicates that sustainable agriculture is making a significant contribution to reducing poverty and improving rural livelihoods and could do more. As it is management and knowledge intensive, sustainable agriculture requires building the capacity of farmers and their communities to learn about the complex ecological and biophysical complexity in their fields and farms and so change their actions. It tends to succeed when organizations operate together, and so work should progress from the local to the national and international levels and links should be fostered between government, non-governmental organizations, and the private sector.

Sustainable agriculture needs enabling policy frameworks that deliberately encourage its spread. Policies framed to deliver increased food production must change if they are to help deliver environmental and social benefits, too. In addition, rural development policies and institutions focusing on exogenous solutions to the economic and social problems of rural communities must change to match the needs of community-based and participatory development. Finally, a larger proportion of research and science budgets needs to be directed toward agroecological technologies and better linkages between scientists and farmers. ■

For further information, see J. Pretty and R. Hine, *Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence*. Final Report from the SAFE-World Research Project (Colchester, U.K.: University of Essex, 2001), <www2.essex.ac.uk/ces>; J. N. Pretty, "Can Sustainable Agriculture Feed Africa?" *Environ. Dev. and Sustainability* 1, no. 3/4 (1999): 253–274; and J. N. Pretty and R. Hine, "The Promising Spread of Sustainable Agriculture in Asia," *Natural Resources Forum* 24, no. 2 (2000): 107–126.

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Appropriate Technology for Sustainable Food Security

Conventional Research-Based Technology

Prabhu L. Pingali

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The enormous success of the Green Revolution in enhancing food supplies and food security in the developing world is well known. The development and promotion of modern, high-yielding varieties was the most important factor contributing to this success. While new tools, technologies, and products will come from rapid advances in molecular biology and genetic engineering, the science that made the Green Revolution possible remains important today and will continue to play a crucial role in the future. Modern biotechnology tools will complement conventional breeding approaches rather than substituting for them. Crop improvement requires more than genetic manipulation using conventional breeding or molecular techniques; genetic-resource management, agronomy, and crop-management research will continue to play a crucial role in enhancing and sustaining crop productivity.

GAINS FROM CONVENTIONAL TECHNOLOGIES

Productivity gains achievable from conventional technologies have not been fully exploited. The yield gap between what is possible and what is actually achieved on farmers' fields is quite large, especially in the more marginal environments. The best farmers in high-potential environments achieve yields that are at par with experiment-station yields, but the majority lag far behind—by as much as 2 to 3 metric tons per hectare for the major cereal crops. Farmers in the high-potential environments have excellent access to modern farming inputs but often lack the agronomic and crop-management technologies and knowledge that are crucial for bridging the yield gap. For example, the yield achieved on farmers' fields depends not only on the amount of fertilizer applied but also on when and how it is applied. Research on and promotion of improved crop-management technologies lags behind that on improved varieties. Even where such information is available, farmer adoption has been limited, because knowledge about crop husbandry tends to be highly location-specific and requires a significant amount of farmer time for experimentation and decisionmaking.

In the less-favorable production environments, the yield gap is substantially larger, often more than 4 metric tons per hectare. Here access to inputs is indeed a problem, but so are knowledge and adoption of improved crop- and resource-management technologies. General knowledge about growth in sustainable crop productivity in the marginal environments rarely translates to farmer practice at the local level. Substantial opportunities exist for applying what is already known to increase and stabilize food supplies in the marginal environments.

In addition to the persistent yield gap, the geographic areas in which the Green Revolution occurred are showing signs of a slowdown in the rate of growth in cereal yields on farmers' fields—despite a steady growth in yield potential on experiment stations. Declining productivity trends are a direct consequence of the environmental and ecological stress imposed by intensive cereal-crop systems on the agricultural resource base. The stress manifests itself in several ways, including buildup of salinity and waterlogging, declining soil-nutrient status, increased soil toxicities, and increased pest buildup. More judicious use of inputs can go a long way toward sustaining crop productivity. Improved crop- and resource-management technologies that are already on the shelf and a policy environment that creates incentives for their adoption could help reverse the degradation trends.

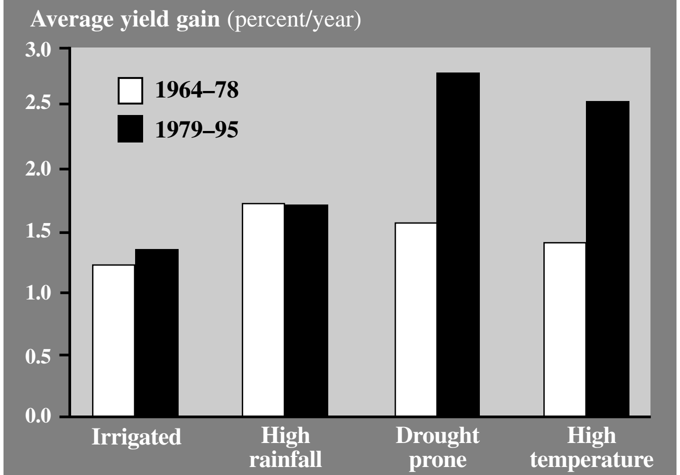
THE CONTINUING VALUE OF CONVENTIONAL RESEARCH

The conventional research pipeline continues to provide a steady stream of significant products for enhancing cereal-crop productivity. Products continue to emerge in the areas of seed, crop-management, and resource-management technologies.

Yield potential for the major cereals has continued to grow at a steady rate since the initial jump that kick-started the Green Revolution. For example, yield potential in irrigated wheat has been rising at the rate of 1 percent per year over the past three decades, an increase of around 100 kilograms per hectare per year. For both rice and wheat, a more dramatic shift in yield potential is anticipated over the next decade with the development of super-high-yielding varieties that are already in the research pipeline at the International Rice Research Institute and the International Maize and Wheat Improvement Center. These varieties are the result of a deliberate change in plant architecture introduced to increase the ratio of grain-to-plant biomass and are expected to increase yields by 15–20 percent. These super-high-yielding varieties have been developed using only conventional breeding techniques.

Starting in the early 1980s, the more marginal production environments began to experience the benefits of the Green Revolution, especially for wheat, rice, and maize. In the case of wheat, the rate of growth in yield potential in drought-prone environments was around 2.5 percent per year during the 1980s and 1990s (see figure). Interestingly, the source of this growth in yield potential has changed through time. Initially the growth in yield potential for the marginal environments came from technological spillovers as varieties bred for the high-potential environments were adapted to the marginal environments.

Rate of Yield Gains in Favorable and Marginal Wheat Environments, 1964–1995



Source: M. Lantican and P. Pingali, Growth in Wheat Yield Potential in Marginal Environments, proceedings of the Warren E. Kronstad Memorial Symposium, 17–17 March 2001, Cuidad Obregón, Mexico (El Batán, Mexico: International Maize and Wheat Improvement Center, forthcoming).

During the 1990s, however, further gains in yield potential came from breeding efforts targeted specifically at the marginal environments. In both environments, the dramatic shifts in yield potential have come from conventional breeding methods.

In addition to their work on shifting the yield frontier of cereal crops, plant breeders continue to have successes in the less glamorous areas of maintenance research. These include plants with durable resistance to a wide spectrum of insects and diseases, plants that are better able to tolerate a variety of physical stresses, crops that require significantly lower number of days of cultivation, and cereal grain with enhanced taste and nutritional qualities.

In addition to plant breeding, research on crop and resource management plays an important role in sustaining improvement of crop productivity. The best varieties often fail to express their potential on farmers' fields because of inadequate investment in the development and dissemination of complementary crop management technologies. Moreover, as discussed earlier, improved land and crop management practices can reduce environmental stress caused by intensive farming. With the current and anticipated future decline in cereal-crop prices, crop management innovations—given their ability to save on input use and thereby reduce unit production costs—will be increasingly crucial for sustaining the competitiveness of cereal-crop production. Farmers will eagerly seek technologies that improve the efficiency of input use in the quest to sustain farm profits in a world with increasingly integrated food markets. The rapid spread of zero-tillage in the rice-wheat zone of South Asia is a case in point. Farmers there achieve cost savings from reducing power, water, and labor use and at the same time help reduce environmental stress.

THE MARRIAGE BETWEEN CONVENTIONAL AND NOVEL APPROACHES

Biotechnology knowledge and tools are extremely complementary to those of conventional plant breeders, and a marriage of the two would have significant social benefits. Indeed, breeders and molecular biologists have been working together for some time now, especially in the areas of genetic fingerprinting, molecular marker-aided selection techniques, and tissue culture. Genetic engineering and genomics are areas in which future collaboration can be anticipated.

Molecular marker-aided selection methods have resulted in significant improvements in breeding efficiency by reducing the trial-and-error aspect of the breeding process and by allowing for time and sometimes cost savings. Genetic fingerprinting has made it easier for breeders to identify economically useful traits in genetic resource collections and to bring them into the breeding pools. Genes from wild species of rice, wheat, and maize have been brought into the breeding pools with the help of tissue culture. Genetic engineering could widely extend the breeder's impact by bringing genes from other species into the breeding pools for cereal crops.

CONCLUSIONS

While exciting new developments in biotechnology are grabbing many of the headlines, the conventional research pipeline has not run dry. Conventional research methods will continue to be an important source of technology supply for crop improvement and management. Advances in biotechnology can play an important complementary role by strengthening the breeder's toolkit and extending the reach of conventional methods. At the same time, increased understanding and acceptance of research tools that draw on farmers' participation could help target research outputs to particular environmental and socioeconomic niches. Agricultural scientists have at their disposal a wide spectrum of complementary tools, from molecular biology to social sciences. Choosing not be inclusive and integrative can be counterproductive to the goal of sustainable food security for the poor in the developing world. ■

For further information see P. L. Pingali, M. Hossain, and R. V. Gerpacio, *Asian Rice Bowls: The Returning Crisis?* (Wallingford, U.K.: CAB International, 1997); P. L. Pingali and P. W. Heisey, "Cereal-Crop Productivity in Developing Countries: Past Trends and Future Prospects," in J. M. Alston, P. G. Pardey, and M. Taylor, eds., *Agricultural Science Policy* (Baltimore, Md.: Johns Hopkins University

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Appropriate Technology for Sustainable Food Security

Modern Biotechnology

Calestous Juma

Focus 7 • Policy Brief 4 of 9 • August 2001

The emergence of modern biotechnology has invoked a major global controversy over the future of world agriculture. The debates surrounding this controversy have often reflected the interests of developed countries and paid little attention to the needs of developing countries, especially those needs related to food requirements of low-income populations. This brief argues that biotechnology—especially genetic modification—represents an important technology option for meeting the long-term food needs of developing countries. However, this technology must be used within a policy framework that recognizes the importance of managing the health, environmental, and socioeconomic risks associated with it.

DIVERGENT NEEDS

Developed-country consumers continue to express skepticism toward transgenic foods. This is partly because they have a wide range of affordable foods from which to choose. They therefore question the need to use new technologies to make incremental changes in their foods without offering tangible benefits. In response, industry in the developed countries is looking into ways of producing foods that are relevant to the consumers. The success of such investments is still in doubt, but the concerns in developed countries evidently stem from the view that meeting food-security needs is no longer the concern of consumers. Much of the consumer interest is shifting to the quality of the food they consume and its contributions to improved health.

The situation in many developing countries—especially in Africa—is different. Low-income families in these countries are faced with a wide range of challenges, including malnutrition, hunger, and related illnesses. Addressing these challenges requires the deployment of available technological options. The poor often rely on a limited range of food sources, and as ecological degradation continues, their capacity to meet their needs diminishes. Raising agricultural productivity while promoting sustainable land use is key. Indeed, in many poor regions of the world agricultural production is done by women who also have other critical household responsibilities.

Responding to these challenges requires investing in technologies that are appropriate to the needs of low-income communities, which lie in diverse ecological zones often far from major markets. Agricultural production in these areas will need to be equally diverse and to reflect local needs and preferences. Genetic modification and the emerging techniques of genomics offer the possibility of designing farming systems that are responsive to local needs and reflect sustainability requirements. In other words, genetic modification and genomics make it possible to design farming systems that are decentralized and more productive than existing methods.

CURRENT TECHNOLOGICAL TRENDS

In 2000, transgenic crops covered an estimated 44.2 million hectares, a 25-fold increase over the 1996 figure. This rapid expansion occurred mainly in the United States, Canada, Argentina, and China, which account for 99 percent of the coverage of transgenic crops. The bulk of this coverage was in the United States (68 percent), with Argentina accounting for 23 percent; Canada, 7 percent; and China, 1 percent. Most of this coverage is in large farms where genetic modification has been used to introduce incremental changes in existing crops. These incremental changes explain why the distribution of transgenic crops is limited to geographical areas with similar ecological conditions.

Transgenic applications are currently limited to soybeans, corn, canola, and cotton. Transgenic soybeans covered 25.8 million hectares in 2000; corn, 10.3 million hectares; cotton, 5.3 million hectares; and canola, 2.8 million hectares. The bulk of the crops express herbicide tolerance and disease resistance.

These trends show that the early diffusion of transgenic crops has been largely in the temperate regions and has been limited to a few major commercial crops. The promise of biotechnology in meeting the needs of low-income families in the developing world still remains a distant dream.

The promise of transgenic applications has not been realized for two main reasons. First, crop development for low-income families, such as the Green Revolution, has traditionally been carried out by the public sector. However, the biotechnology has emerged from the private sector, which lacks the incentives to invest in crops for low-income families. Second, agricultural research in the public sector has been declining, and therefore little investment has gone into developing crops for low-income families. The situation is not likely to change without a redirection of existing research priorities in private enterprises, stemming from appropriate incentives as well as significantly increased public sector funding for agricultural research. In addition, institutional arrangements will have to be created to facilitate closer cooperation between private and public sector institutions.

REDIRECTION OF EXISTING TECHNOLOGICAL EFFORTS

Efforts to redirect biotechnology to address the needs of low-income families in developing countries should be placed in a large policy framework that addresses other social issues. More important, such strategies should be part of policies designed to use science and technology to achieve sustainable development goals that embody ecological, social, and economic requirements. In addition, biotechnology should be considered one tool in a larger portfolio of technological options, to be applied where it is needed and where it offers the best available option for solving specific problems.

The choice of technology should be driven by the determination of local needs. Many developing countries have already indicated priorities that could be addressed using genetic modification in their agricultural development strategies. Many African countries, for example, lie in regions where drought tolerance, disease resistance, and crop-yield increases are priorities. Crops such as cassava, millet, yams, millet, and sorghum are prime candidates for genetic modification. Modification that seeks to prolong the shelf life of foods could help reduce postharvest losses significantly. The use of herbicide tolerance in low-till agriculture is another high priority, especially in helping to lessen farm labor and providing farm workers—most of whom are women—with opportunities to engage in other activities.

Another potential area for biotechnology application is the development of livestock that is tolerant to many tropical diseases. Modern methods, such as genomics, could be applied in this area without requiring transgenesis. Also related to agricultural production is the significance of revegetation in marginal areas. Investment in fast-growing plants could help facilitate ecological restoration in many denuded regions of the world. Such research could also add to the fodder available in these countries.

Redirecting global research and development efforts to focus on these challenges will entail considerable international cooperation, increases in public sector funding, and incentives for private enterprises. It will also require tolerance for using science and technology for sustainable development in the developed and developing countries.

TECHNOLOGY MANAGEMENT

Three categories of risk need to be addressed in considering the role of biotechnology for low-income families: health, environment, and socioeconomic considerations. The advent of biotechnology demands that all countries put in place measures that ensure safety to human health and the environment. Such measures involve the judicious use of strategies for assessing, managing, and communicating risk. In addition, equity considerations also call for social policies that address the impact of new technologies on rural populations. Such policies should include ways of creating alternative livelihoods for farm workers displaced by new technological practices.

Many developing countries are currently reluctant to engage in biotechnology development because they fear some developed countries would erect barriers against their products. These concerns are real and have created an atmosphere of distrust that is likely to undermine not only the global trading system, but also the ability of developing countries to meet their basic needs.

A final area of concern is the impact of intellectual property protection on the ability of the developing countries to use biotechnology. This point has two dimensions. First, international agricultural research institutions are increasingly dealing with intellectual property issues. Ways must be found to enable these institutions to have access to technologies needed to meet the needs of low-income families. Second, national research institutes in developing countries face similar challenges. Some biotechnology firms, including Monsanto, have made public pledges to share technologies with developing countries. Realizing such pledges will require considerable institutional innovation to provide the required comfort among the providers and users of technology.

THE WAY FORWARD

Promoting the responsible use of biotechnology to meet the needs of low-income countries will require fundamental policy adjustments in the developing and developed countries. Developing countries need to formulate policies that recognize the importance of science and technology in overall economic development and in agricultural production in particular. They must reexamine existing agricultural policies to accommodate the imperatives of emerging technologies, changing markets, shifting public perceptions about safety, and rising environmental concerns.

Developed countries could play a key role by exhibiting greater sensitivity to the needs of developing countries. In addition, they need to play a leading role in exploring how scientific and technological advances in general, and biotechnology in particular, could help solve the problems of low-income families. This role will entail increased public sector funding, greater scientific and technical cooperation, and creation of incentives that allow private enterprises to work on developing-country challenges. Holders of intellectual property rights will need to demonstrate greater creativity in ensuring that those who work on meeting the needs of low-income families have the freedom to operate. ■

For further information, see C. James, *Global Trends in the Commercialization of Transgenic Crops*, (Ithaca, N.Y., U.S.A.: International Service for the Acquisition of Agribiotech Applications, 2001); C. Juma, "The New Genetic Divide: Biotechnology in a Globalizing World," *International Journal of Biotechnology* 4 (forthcoming); and M. Qaim, A. F. Krattiger, and J. von Braun, *Agricultural Biotechnology in Developing Countries: Towards Optimizing the Benefits for the Poor* (Dordrecht,

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A 2020 Vision for Food, Agriculture, and the Environment

2020 VISION

Appropriate Technology for Sustainable Food Security

Modern Technology for African Agriculture

Jennifer Thomson

Focus 7 • Policy Brief 5 of 9 • August 2001

By the year 2025 Sub-Saharan Africa will experience a grain shortfall of nearly 90 million tons. That estimate is based on the assumption that farmers can maintain current cereal yields. In fact yields have been decreasing over the past 40 years. Reasons for this include the fact that the subcontinent probably has the poorest soil in the world. It is prone to erosion, highly acidic, and chronically short of water. To reduce the anticipated shortfall, farmers in Africa will have to produce higher yields. One way to achieve this goal is by using modern biotechnology, namely the planting of genetically modified crops.

In his book *The Doubly Green Revolution*, Gordon Conway, president of the Rockefeller Foundation, argues that the only way to improve crop production in the 21st century is to combine conservation of the environment with productivity. He calls for scientists and farmers to forge genuine partnerships to design better crops. He also urges them to develop and rediscover alternatives to inorganic fertilizers and pesticides, to improve soil and water management, and to enhance the earning opportunities for the poor, especially women. To quote him:

> Genetic engineering has a special value for agricultural production in developing countries. It has the potential [of] creating new plant varieties that not only deliver higher yields but contain the internal solutions to biotic and abiotic challenges, reducing the need for chemical inputs such as fungicides and pesticides, and increasing tolerance to drought, salinity, chemical toxicity and other adverse circumstances. Most important, genetic engineering is likely to be as valuable a tool for the lower-potential lands as for the high-potential. It can be aimed not only at increasing productivity but at achieving higher levels of stability and sustainability.

PRODUCING TRANSGENIC CROPS FOR THE DEVELOPING WORLD

Most transgenic crops currently available are produced by the private sector for farmers in the developed world. However, partners linking the private and public sectors are making a concerted effort to address the needs of the developing world. Of interest to Africa is the encouraging research into the production of virus-resistant sweet potatoes, cassava, and maize; improved productivity of bananas; and crops that tolerate salt and desiccation. Research carried out in South Africa has shown that soil acidity and drought stress account for 80 percent of yield losses, while diseases and pests account for the remaining 20 percent.

Why highlight these crops? Many people in eastern and southern Africa eat sweet potatoes as a subsistence crop. Scientists from Kenya, South Africa, Uganda, and the United States have succeeded in improving the protein content of sweet potatoes by a factor of four using tissue culture. This improvement could have a significant effect on the lives of many people in Africa. And with the help of genetic engineering, scientists are making good progress in developing a virus-resistant sweet potato.

Cassava, known to western societies as a source of tapioca, is a staple food in much of Africa. The leaves and starchy roots of this plant make up the world's third-largest source of calories after rice and maize. In some years cassava mosaic virus has almost wiped out the entire crop in certain African countries. Another problem with the crop is that it contains high levels of cyanide and requires three to five days of labor-intensive preparation that involves soaking the cassava in water and scrubbing it to remove the cyanide. Both of these problems could be solved by genetic engineering.

Many Africans eat maize three times a day. The crop is, however, sensitive to the maize streak virus, which plagues both commercial and subsistence farmers. Research using genetic engineering carried out in South Africa shows great promise for the development of a maize variety resistant to maize streak virus. This research has been funded by collaboration between the public and private sectors.

In the western world, bananas and their close relatives, plantains, are a snack and a dessert, but in western and central Africa they provide more than one-quarter of all food calories. The United Nations Food and Agriculture Organization ranks bananas as fourth among the world's most important food crops. Scientists in Kenya, using modern tissue-culture techniques, have succeeded in dramatically improving the yield of bananas.

One genetically modified crop having an impact on African countries, including South Africa, is insect-resistant cotton. In 1997 four small-scale farmers agreed to participate in field trials in the KwaZulu Natal province. The results were so impressive that the next year 75 farmers planted the genetically modified seed, and by the year 2001 644 farmers were involved. Although this crop will not solve Sub-Saharan Africa's grain shortage, cash crops are extremely valuable in economically uplifting rural areas.

Another way in which transgenic crops could be invaluable to Africa is in the production of vaccines. The process of combining pharmaceuticals and farming (called "pharming") can produce vaccines cheaply and free of possible contaminating animal viruses that could become harmful to humans. The most expensive aspects of a vaccination program are cold storage and needles. If vaccines can be produced in transgenic tomatoes or bananas, the need for cold storage and needles will be circumvented. Scientists are making impressive strides in this area. In addition, research is being carried out in South Africa to use tobacco, an extremely hardy and drought-tolerant crop, to produce vaccines against the African variety of HIV and other African-specific viruses.

RESPONDING TO THE OUTCRY AGAINST TRANSGENIC CROPS

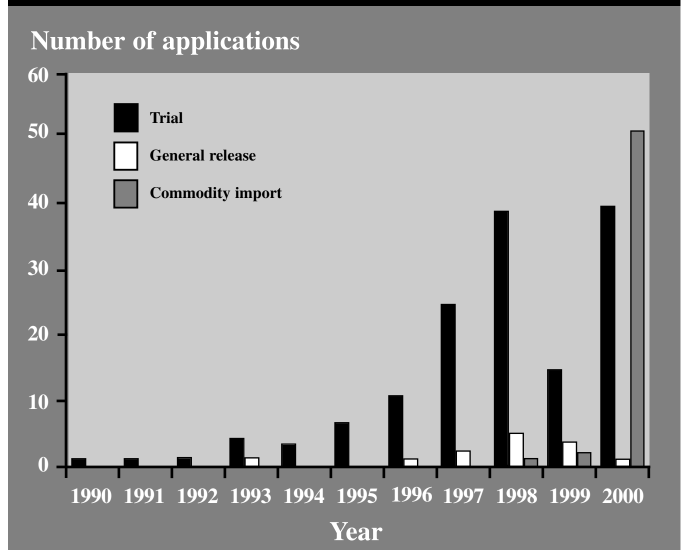
In light of these obvious needs and the advantages of using genetically modified crops to meet those needs, how should Africa respond to the current outcry in Europe against such crops? Unlike Europeans, rural African farmers must be able to feed themselves, their families, and possibly their communities without depending on shop-bought food. Meeting this goal is important for sustaining the environment as well as for feeding people. As Kenyan anthropologist Richard Leakey said, a person must have at least one square meal a day to be a conservationist or an environmentalist.

Although African scientists applaud the use of biotechnology to improve crop and food production in Africa, some journalists disagree. They contend that the United States finds a ready market in Africa for genetically modified food and imply a conspiracy between the U.S. government and the United Nations World Food Programme to dump unsafe, genetically modified crops in Africa as emergency aid for the world's starving and displaced. However, the only food that has been delivered as food aid has been declared safe by U.S. regulatory agencies. Moreover, the World Food Programme only accepts food donations that comply with the safety standards in the donor country.

As for growing genetically modified crops in Africa, no U.S. company will consider field trials in a country, let alone commercial releases of such crops, until the country has a biosafety management system in place. Unfortunately, such a system is generally lacking in Africa, and the process of implementing them takes time. South Africa, leading the way, published the regulations for its Genetically Modified Organisms Act in 1997 but is only now implementing them.

The figure below shows the number of applications received between 1990 and 2000 for permits to test, grow, and import genetically modified crops in South Africa. The drop in the number of trial and general releases in the first half of 1999 is largely attributable to the takeover of the previous nongovernmental regulatory authority by the National Department of Agriculture.

NUMBER OF PERMIT APPLICATIONS TO USE GENETICALLY MODIFIED CROPS IN SOUTH AFRICA, 1990–2000



Source: Department of Agriculture, South Africa.

In conclusion, countries in Africa need genetically modified crops as one way to increase yields and decrease Africa's chronic food shortages. If Europe does not want or need these crops, that is for it to decide. We Africans, however, have no intention of allowing any nation dictate to us what is, or is not, in our best interest. ■

For further information, see G. Conway, *The Doubly Green Revolution: Food for All in the Twenty-First Century* (Ithaca, N.Y., USA: Cornell University Press, 1998); T. Dyson, "World Food Trends and Prospects for 2025," *Proceedings of the National Academy of Sciences* 96, no. 11 (1999): 5929–5936; and F. Wambugu, "Why Africa Needs Agricultural Biotech," *Nature* 400, no. 6739 (1999): 15–16.

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A 2020 Vision for Food, Agriculture, and the Environment
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APPROPRIATE TECHNOLOGY FOR SUSTAINABLE FOOD SECURITY

INFORMATION AND COMMUNICATIONS TECHNOLOGIES

NUIMUDDIN CHOWDHURY

FOCUS 7 • POLICY BRIEF 6 OF 9 • AUGUST 2001

Information and communication technologies (ICTs) capture, store, process, share, display, protect, and manage information. Together, they compose a globally oriented strategic industry that, thanks to cost competitiveness, is becoming pervasive. The world has never before seen such a dramatic transformation of space and time due to technology as it has in the last five years. Fluency in ICT skills has become a code for competitiveness in the new, information-based economy.

Computer and Internet use is increasing at a breakneck speed, particularly in Asia. The World Wide Web has become a huge library, laboratory, and bazaar all rolled into one. In several large developing countries, ICTs represent the fastest-growing industries and are assuming growing macroeconomic importance. Wireless phone use is expanding across geographic, sectoral, and class boundaries. Countries, companies, and citizens that have the infrastructure, skills, and institutions that complement ICTs are hooked to a veritable technological and competitive juggernaut.

Do these new technologies offer any means of improving the economic welfare of smallholder agriculturalists in developing countries? And how can these technologies, especially those surrounding the World Wide Web, be brought within reach of these smallholder farmers?

HOW ICTs HELP ALLEVIATE RURAL POVERTY

The first nexus between ICTs and rural poverty is economic growth itself. Countries with vigorous growth rates overall are associated with lower poverty, and rapid diffusion of ICTs is increasingly seen as essential to accelerating growth. Thus rapid diffusion of ICTs that can spur productivity growth should be a high priority for developing countries.

Relative lack of literacy and numeracy typically characterize the poor, as does lack of access to accurate price, technical, and other information relevant to the profitability of their business decisions and their integration with markets. Illiteracy and lack of education breed social and cultural isolation, and the poor, who are often in remote areas, are further handicapped by limited availability of public information that the nonpoor take for granted (for instance, information about health and sanitation hazards; public transportation schedules; rights to public, gravity-flow irrigation systems; and natural disasters). Today, more than ever before, having access to relevant, timely, adequate, and accurate information is critical if the poor are to make viable business, health, and safety decisions that can enable them to escape poverty.

HOW ICTs HELP SMALLHOLDER PRODUCERS COMPETE IN THE GLOBAL MARKETPLACE

The information needs of the rural poor depend, among other things, on geography and the stage of agricultural transformation at which a country finds itself. Asia, for example, is clearly much further along than Africa in terms of the shift from monocropping to a diversified agriculture. As agriculture diversifies, production changes from monoculture staples to mainly irrigated, high-value horticulture, aquaculture, animal husbandry and poultry production, and floriculture. The marketing cycles of these products are shorter than those for traditional crops from the standpoint of smallholder producers and need tighter coordination with buyers. This situation puts a significant premium on accurate, real-time information. As producers undertake these activities on a wider scale and as a nationwide distribution system begins to come of age, ICTs can play a greater role in the business processes that create and mobilize robust supply chains. Appropriate policies will be required to ameliorate the significant market failures that are bound to hobble the market integration of smallholders in such technology-rich efforts. Without these policies a new kind of "urban bias" would arise, generating inequality and instability in developing countries.

Even smallholder agriculturalists must participate in an increasingly integrated global economy characterized by greater use of ICTs. Globalization will be accompanied by more intense competition and redefined business processes with an accent on much greater use of ICTs. ICT powerhouses will harness high-end computing in their efforts to develop designer crops and achieve "just-in-time" marketing and storage of farm crops. Agents in smallholder agriculture have no option but to try to find "hooks" with which to take advantage of the ICT-led transformation.

ICTs can help the smallholder agriculturalists compete in this global, information-driven marketplace by

- Giving policymakers access to real-time market information and best-practice insights and providing smallholder farmers with the latest information about public interventions in food and agricultural markets;
- Improving the profitability of business decisions and the associated returns to labor of small fishermen and farmers, traders, and other small producers by providing adequate, up-to-date information, for example, on grain prices, possible supply shocks, and new or improved production techniques;

- Reducing private and public search and transaction costs;
- Fostering diversification of the rural economy;
- Saving lives by mounting early-warning information systems and introducing Internet-based healthcare solutions and diagnostics;
- Using the Web to improve the education, training, and income-earning potential of the poor in developing countries.

Smallholder agriculturalists often have strong latent demand for production and marketing information and may not be able to reach their economic potential without that information. The poor who do have access to ICTs are using them to develop highly customized marketing strategies. This is especially true with wireless phones and the Internet. For example, in the rural phones program run by GrameenPhone in Bangladesh, the poor typically use cell-phone access as a production input (for example, to keep in touch with market developments relating to perishable goods). Such access has a considerable effect on the poor's production surpluses. This kind of use is not confined to South Asia. In Laos, while cell phone purchases were motivated mainly by social needs (getting in touch with loved ones), economic uses (such as keeping abreast of the latest output and input prices and exchange rates) were important too. In both Ghana and India, coastal fishermen, while still at sea, have used cell phones for the latest information about markets with the best prices for a particular catch. Also in south India, in villages where fishermen in the past depended on astrologers to avoid being lost at sea in inclement weather, they now depend on broadcast advisories gleaned from the Web.

India's Tamil Nadu University of Veterinary and Animal Sciences, in collaboration with Cornell University, is setting up a rural email network. Compared with a brick-and-mortar extension system, the advantages of this emerging online version are speed, a potentially much vaster reach, a much lower cost of providing service, and wider interactivity. In this region, raising fast-growing broiler chickens is common, thus making access to emailed extension advice an important priority.

In northeast Bangladesh, rural wireless broadband has been installed using wireless local loop (WLL). WLL delivers bandwidths broad enough to support applications such as the downloading of graphics-rich Web pages replete with price and product data. WLL is much cheaper than the global system for mobile communications (GSM), which currently dominates the digital cellular market, and thus appears destined to become the ultimate platform of choice of rural telephony services. With rural wireless broadband providing the basic models of telephony and Internet connectivity, it will be possible to discover where and how agriculture, rural development, and communications technology intersect.

HOW TO BRING ICTs WITHIN REACH OF SMALLHOLDER AGRICULTURALISTS

How to bring this new crop of technologies within affordable reach of smallholders in developing countries is among the most actively debated issues in the international development community. The lack of bare essentials—literacy, social and physical capital, electrical power, and physical infrastructure—in poor regions is a significant challenge in mainstreaming ICTs in the service of smallholder agriculture. However, this challenge needs to be met. Leaving the poor out of the technology loop can leave them irretrievably, and unnecessarily, behind.

These technologies have a community interface as well as an individual interface. If governments provide necessary information infrastructure as a matter of policy, communities can and undoubtedly will invest in circumventing the limitations of poor individuals. Those communities would of course need public leadership in the development of policies and institutions.

The following policies have the potential to bring the benefits of ICTs to smallholder agriculturalists:

- Create a congenial climate for high rates of investment, including by private enterprise, in telecommunications and information infrastructure that provides rural public call offices and ICT-enabled communications centers on the broadest basis;
- Invest in telecommunications companies and Internet connectivity to the point of making them economically viable commodities;
- Wire farmers into connectivity, archive indigenous knowledge related to farm extension, convert it into local vernacular, and populate an email network with farmers interested in receiving farm extension online;
- Host regular updates of prices of benchmark farm commodities for key terminal markets on government Web sites, and make them available for downloading;
- Provide smallholder farmers with leading-edge computer hardware, enabling applications that improve the productivity of the smallholder agriculturalists and promote farm-friendly Web content; and
- Wire rural schools into the Internet, exposing children to computerization to demystify technology; and make computer labs in such schools into community learning hubs where children learn computing during regular hours and parents learn computing after-hours as continuing education students.

Without ICTs the poor will find it all the more difficult to integrate themselves with unfolding economic processes and global markets, making their escape from the vicious cycle of poverty even more uncertain. But their loss would also translate into national and global economic loss. Investment in and widespread diffusion of ICTs therefore should be a high priority for developing countries. ■

For further reading see N. Chowdhury, U. Mohan, and K. von Grebmer, "Information and Communication Technologies, Poverty, and Food Security in the New Century," Communications Division Discussion Paper 1 (Washington, D.C.: International Food Policy Research Institute, 2001, forthcoming).

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A 2020 Vision for Food, Agriculture, and the Environment

2020 VISION

Appropriate Technology for Sustainable Food Security

GIS, GPS, and Remote Sensing

Uwe Deichmann and Stanley Wood

Focus 7 • Policy Brief 7 of 9 • August 2001

The role of information and communication technology (ICT) in accelerating development is drawing increasing attention. ICT promises to help isolated and disenfranchised communities transform themselves into development participants who are better informed and integrated. However, this promise is tempered by concerns that the control and application of ICT could reinforce—or simply reconfigure—existing forms of inequity and marginalization and might be unsustainable in more remote rural areas.

INFORMATION AND COMMUNICATION TECHNOLOGY TOOLS

Low-income rural residents have adopted some information technologies with considerable success. The best known is the mobile phone, which, for example, helps reduce the information gap between farmers and traders. Mobile phones are inexpensive, require no special training, and serve social functions beyond their use in rural trade. They are also easily shared or rented out, providing nonfarm income opportunities for enterprising rural households.

Another group of more specialized ICT tools helps manage and interpret data about an area's resources and infrastructure, such as digital maps or images of a village, watershed, or entire country. Researchers, planners, and other technical specialists are making greater and greater use of this information. The tools include systems to store, manage, and analyze geographically referenced data (geographic information systems, or GIS); devices that measure geographic location (global positioning system, or GPS, receivers); and airborne data collection systems that provide periodic land use, land cover, and other thematic information (aerial photos and satellite remote sensing).

While obstacles exist—particularly in developing countries—geographically referenced data is providing new insights into global issues such as the patterns and processes of human settlement, natural resource use and degradation, agricultural performance, disease, and conflict. Agriculture, unlike most other forms of economic activity that benefit from geographic concentration, is tied to a natural resource base that is spatially dispersed and highly variable. Physical, social, and economic geography thus play a crucial role in determining the scale and scope of agriculture at a given location.

GIS technology provides tools for visualizing, integrating, and analyzing spatial data and a unique capacity to merge information from many sources. By using a common spatial framework, GIS enables users to analyze how physical, social, and economic factors interact. Constraints to widespread use of GIS have been its high cost and complexity and the difficulty of obtaining geographically referenced (georeferenced) data. However, as the technology has become cheaper and less complex, it has become more accessible to nonspecialists.

GPS and remote-sensing techniques have also reduced the problem of obtaining georeferenced information. For instance, most field surveys now use GPS to capture the location of sample points, such as plots or households, enabling easy visualization of survey results and integration with other geographic data. GPS receivers range from the handheld models that are inexpensive, easy to use, and provide coordinate accuracy of about 10 meters to differential receivers that yield accuracy in centimeters.

Great advances have also been made in remote sensing and aerial photography. Image-processing techniques generate digital maps from aerial photos or satellite data that combine the accuracy of a topographic map with the rich contextual information of a photograph. Despite these advances and the falling prices of some satellite data, however, their direct use is likely to remain the domain of specialized users.

HOW SPATIAL TECHNOLOGIES BENEFIT THE POOR

Spatial technologies have benefited the rural poor mostly indirectly, by generating improved information for research, policy analysis, planning, and monitoring. Precision farming techniques are used in high-intensity commercial agriculture, where detailed location information determines, for example, the level of fertilizer applied to each portion of a field. However, the capital, maintenance, and training requirements are well beyond the means of most farmers in developing countries, particularly smallholders whose small field sizes make these technologies uneconomic.

One of the most direct applications of GIS in developing countries is participatory mapping, where, for example, specialists interact with farming communities to create spatial inventories of natural resources, property status, land-use rights, and perceived problems. Such inventories feed into a consultative process aimed at building consensus on more equitable and sustainable resource-management arrangements. Experience has shown that villagers can quickly relate to geographic representations of their surroundings. Community mapping can also help foster the process of transferring greater decisionmaking power and fiscal responsibility to local levels of government.

GIS is increasingly being used widely in parcel mapping. Without proper land registration, formal land markets are less efficient and the incentives to invest in land conservation might be limited. Also, without land titles, farmers often have difficulty accessing credit. In many instances, however, land ownership, access, and use rights may be complex—especially where resources are communal. Land-titling systems tend to assume that a given piece of land is uniquely assigned to an owner, while in reality it may be subject to a complex web of overlapping, shared uses based on informal, mutually beneficial agreements. Formalizing and administering such complex patterns in the fairly rigid language of digital cartography is difficult and in some cases impossible.

PUBLIC PARTICIPATION GIS

Questions do arise about the political economy and sustainability of GIS approaches applied at the community level, and research on those issues has given rise to a literature on Public Participation GIS, or PPGIS. PPGIS research primarily addresses concerns about GIS as an invasive technology that benefits some people and institutions while marginalizing others. While this work has often focused on developed-country experiences, its concerns are even more pertinent to poor communities in developing countries. PPGIS issues include

- Changes in local politics and power relationships resulting from the use of GIS in spatial decisionmaking;
- The effects of differential access to GIS hardware, software, data, and expertise;
- The educational, social, political, and economic reasons for lack of access and exemplary ways in which communities have overcome these barriers;
- The ways in which socially differentiated communities and their local knowledge might best be represented within GIS;
- GIS as local surveillance; and
- Identifying public data policies that positively or negatively influence small-scale local businesses.

Two important PPGIS research thrusts have emerged. The first focuses on the design of truly participatory GIS-based processes for conflict resolution and decisionmaking with regard to community resources. The second aims at advancing the ability of nongovernmental organizations, agents, and other representatives of indigenous and local communities to use GIS to advocate for inclusion, participation, and recognition.

SUCCESSFUL PRO-POOR APPLICATIONS OF SPATIAL TECHNOLOGIES

Many successful pro-poor applications of spatial technologies exist at the more aggregate levels of agricultural planning and research. Detailed information about agroecological and socioeconomic conditions, for instance, enables better targeting of agricultural technology. Geographic information also assists in planning rural infrastructure, such as prioritizing national investments in rural roads, electricity, health, and education. The preparation of welfare or poverty maps can greatly improve targeting interventions to the poorest communities. Geographic targeting at the level of small communities reduces the chance that the intended recipients are missed or that resources leak to the nonpoor. Other successful GIS applications in rural areas include emergency planning and response.

The key to successful GIS applications is the availability of detailed spatial data. While remotely sensed information and GPS-based field surveys help plug some data gaps, much information is still difficult to obtain at a geographic scale that is relevant for operational impact. This is particularly true for socioeconomic data, which cannot be captured remotely or interpolated from sparse observational information. The main sources of such information—censuses and surveys—do not address all information needs. The former are carried out infrequently and provide only the most basic information, while the latter can provide detailed information but usually not at aggregation levels that are suitable for operational work. Strengthening of formal and informal capabilities for spatial-data collection at local levels is thus one of the priority needs.

FUTURE BENEFITS OF SPATIAL TECHNOLOGIES

Geographic information technologies will continue to provide considerable indirect benefits through better-informed policymaking, research, planning, and development support by both government and nongovernment agents. As national spatial-data infrastructures continue to develop, baseline geographic data should be easier to obtain. This improvement will enable more practitioners to make use of digital mapping and analysis, particularly if parallel enhancements are taking place in Internet accessibility. Through an Internet map server, geographic information can be made accessible to nonspecialized users through standard browsing tools. Combined with other initiatives to bridge the digital divide, such as wireless technologies, Internet mapping could help disseminate critical geographic information to local cooperatives or farming communities. Examples are weather maps based on up-to-date satellite images or regional commodity-price information.

The future might also bring cheaper and easier-to-use tools that enable farming communities to generate or access information about individual and shared resources without external facilitators. With better information about land management status and options and the effectiveness of farming technologies and resource-management practices, communities may avoid resource-related conflicts as they build consensus on uses and rights. However, the cost-effectiveness of introducing GIS technologies into poor communities and the potentially harmful social consequences will continue to require close scrutiny by researchers and policymakers alike. ■

For further reading see Committee on the Human Dimensions of Global Change, *People and Pixels: Linking Remote Sensing and Social Science* (Washington, D.C.: National Research Council, 1998); Nancy J. Obermeyer, "PPGIS: The Evolution of Public Participation GIS," <www.ucgis.org/oregon/ppgis.pdf>; and John O'Looney, *Beyond Maps: GIS and Decision Making in Local Government* (Redlands, Calif.: ESRI Press, 2000).

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A 2020 Vision for Food, Agriculture, and the Environment
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Appropriate Technology for Sustainable Food Security

Alternative Energy Sources

R. K. Pachauri and Pooja Mehrotra

Focus 7 • Policy Brief 8 of 9 • August 2001

Food security for a growing population cannot be attained without the elimination of rural poverty. Solving the energy problem of the rural areas can be a major component of poverty alleviation and requires understanding the nature of energy use, the available technology choices, and fuel mix for these areas. Rural areas of most developing countries rely predominantly on biofuels, mainly fuelwood, for their fuel needs. Biomass fuels—fuelwood, crop residues, and animal dung—provide 85–90 percent of domestic energy in rural areas and 75 percent of all rural energy. In the rural economy of India, for example, the domestic household sector is the most prominent energy consumer, followed by the agricultural sector.

Inefficient biomass use in traditional devices has serious environmental effects, locally and globally. The burning of biomass fuels leads to high levels of indoor air pollution that especially affect women and children. Deforestation and a rapidly declining resource base make provision of alternative energy to rural areas for ecological sustainability a crucial prerequisite for food security.

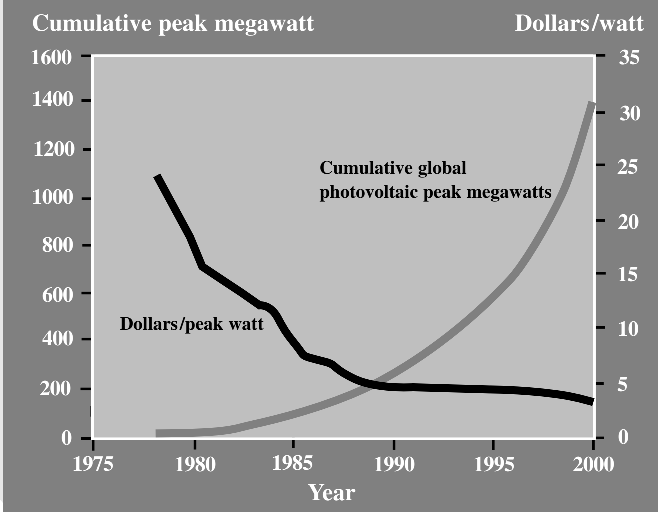
ALTERNATIVE ENERGY OPTIONS

Many rural communities consume little electricity, and extending electricity grids to meet their energy needs may prove more costly and take longer than harnessing new and renewable sources of energy already available in these communities—wind, solar, and biomass—through renewable energy technologies (RETs). The attractiveness of these sources lies primarily in their abundance and ready access. The RETs for exploiting these sources include biogas plants, solar lanterns, solar home lighting systems, improved cookstoves, improved kerosene lanterns, solar water pumping systems, solar water heating systems, and water mills.

Programs already in place show the viability of using RETs. The Ministry of Non-conventional Energy Sources (MNES) of India has been promoting the use of photovoltaic technology for energizing unelectrified villages and homes for nearly 15 years. Despite the high initial cost of photovoltaic systems, for certain decentralized applications involving relatively low-load and low-capacity use of conventional power equipment, photovoltaic systems are cost-effective on the basis of life-cycle cost. The life-cycle cost calculations of photovoltaic applications—home lighting systems, water pumping systems, and power plants—show that small-capacity photovoltaic systems are generally competitive with grid extension in locations that are 3–5 kilometers away from the gridline.

Technological and commercial innovations have brought the photovoltaic market within the reach of low-income users. Globally, for example, the cost per watt (peak) of photovoltaic energy fell from about US$25 in 1980 to around US$3.50–4.00 in 2000 (see figure). In Kenya, more than 2.5 megawatts of photovoltaic electricity has been sold, mostly to households in rural areas. In India, the total installed capacity of photovoltaic systems was 47 megawatts as of December 2000; additionally 18 megawatts have been exported.

Trends in Global Photovoltaics



Source: S. Kaufman, *Rural Electrification with Solar Energy as a Climate Protection strategy*. Research report No. 9 (Washington, D.C.: Renewable Energy Policy Project, 2000).

Wind power has also proved to be a viable energy alternative. In India, more than 1.3 gigawatts of wind energy capacity has been added over the past six years exclusively in the private sector, which either sells electricity to the electric utilities or wheels it over the utility grid for self-consumption.

Studies indicate that cooking with biogas (a highly combustible fuel comprising methane, carbon dioxide, nitrogen, hydrogen, and hydrogen sulphide, produced through anaerobic fermentation of organic matter) can be cheaper than cooking with any commercial fuel. In 2000, for instance, using kerosene in a cooking system (Nutan stove) yielded energy and levelized annual costs of Rs 1.60 and 1.65 per kilowatt-hour, respectively, compared with Rs 0.61 and 0.33 per kilowatt-hour, respectively, for a cooking system using biogas (controlled pressure).

The Tata Energy Research Institute (TERI) has installed or disseminated renewable and energy-efficient technologies in about a hundred villages in different parts of India (see table) by setting up demonstration projects involving and enhancing the capacities of local people to plan, install, and manage these interventions. The key features of these technology-transfer projects were the close involvement of the communities and their contributions of cash and labor to the efforts. These interventions have functioned well, and the community-based institutional arrangements put in place take care of operation and maintenance problems encountered in the long term.

FUEL SAVINGS EFFECTED BY THE INITIATIVES IN DIFFERENT RURAL AREAS BY TERI

Installations/ dissemination	Number installed in 99 villages	Type of fuel saved	Fuel saving per year
Biogas plants	132	Fuelwood	211 tons
Solar lanterns	467	Kerosene	9,736 liters
Solar home lighting systems	11	Kerosene	764 liters
Improved cookstoves	1,060	Fuelwood	424 tons
Improved kerosene lanterns	2,325	Kerosene	13,950 liters
Solar water heating systems	7	Fuelwood	73 tons

Note: Solar water pumping systems (3) and water mills (50) are the other devices installed by TERI.

BENEFITS OF ALTERNATIVE ENERGY OPTIONS

Alternative energy options enable local institutions to manage their own energy needs and thus provide rural development opportunities. This situation encourages decentralized decisionmaking, which has far-reaching implications for the governance of a community. In addition, dissemination and popularization of energy-efficient devices and alternatives to conventional fuels can do the following:

- *Provide better lighting.* Better lighting enables the poor to stretch their period of economic activity; their children can help them in daily chores and then study in the evenings.
- *Help the environment.* Efficient use of conventional sources of energy or use of renewable energy helps save the environment from further degradation and gives it an opportunity to regenerate (see table).
- *Provide sustainable fuel systems.* Afforestation and agroforestry, combined with the introduction of energy-efficient devices, can help create a sustainable fuel-use system within the rural community and sustain the ecological balance of a region.
- *Benefit women.* Lowered dependency on fuelwood and other household fuel sources reduces the drudgery of women by shortening or eliminating the distances they travel for fuel collection. The improved cookstove, for example, has been associated with an average net annual saving of seven person-days of labor a year in India.
- *Benefit human health.* Use of improved cookstoves and biogas plants, for example, helps reduce or eliminate health problems associated with using conventional cookstoves, including respiratory diseases and eye problems.
- *Enhance income.* Alternative energy sources can provide local employment opportunities through direct use of energy in small-scale industry and agriculture, through construction, repair, and maintenance of energy devices, or through the sale of energy to local utilities. In India, for example, biomass gasification systems are used to dry horticulture produce (such as large cardamom and ginger). Another example is the use of solar water-heating systems to meet the hot-water demand of hotels and hospitals.

ALTERNATIVE ENERGY OPTIONS: PRIORITIES AND POLICIES FOR PROMOTION

Much of the innovation in RETs, such as photovoltaic cells and wind energy equipment, has emanated from the developed world. In many poor rural areas of the developing world, however, innovations in use of biomass resources may have greater relevance. Even in the case of wind power, large generators have been developed essentially for feeding power into the grid while applications for using wind power in groundwater irrigation have received inadequate attention. National governments, multilateral organizations, and the corporate sector need to involve the rural poor in defining priorities for renewable energy development. Biomass gasifiers, for example, if properly developed and used, could generate decentralized power at prices lower than that from photovoltaic systems.

Therefore, in addition to reorienting research and development priorities, public policy must aim at disseminating RETs in the developing world to reduce costs. Already several technologies—solar water heating, biomethanation, and biomass gasification—are viable alternatives in most rural situations. Removing subsidies on polluting fuels and grid-based power is essential, however, as these make RETs less attractive economically as alternatives. Apart from fiscal policies and measures, the development and large-scale use of RETs would require major interventions at the grassroots level, including the provision of microfinancing arrangements.

In summary, a sustainable approach for poverty alleviation employing energy-technology interventions would essentially need to address the following:

- Adapting technology to the specific needs of the communities;
- Building the capability of rural communities to maintain RETs for continued use;
- Ensuring that financial packages (microfinancing) are available to improve the access of these communities to such solutions;
- Ensuring that market mechanisms are in place to provide these solutions; and
- Formulating appropriate policy to facilitate the adoption of these solutions at the grassroots level.

Finally, global food security cannot be attained unless poverty among the world's rural population is eliminated. Innovative approaches to solving the energy problems of this segment of the human race are important not only because past efforts have largely failed, but also because alternative energy technologies are opening up exciting new opportunities in this area. ■

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A 2020 Vision for Food, Agriculture, and the Environment

2020 VISION

Appropriate Technology for Sustainable Food Security

Food Irradiation

Morton Satin

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Contaminated foods are one of the most widespread health problems in the world and are a major contributing factor to reduced economic productivity in developing countries. The illnesses contracted from contaminated food are generally caused by microorganisms such as bacteria, viruses, molds, and parasites and usually result in conditions such as diarrhea, gastrointestinal pain and discomfort, vomiting, and headache. In the most serious cases, they can result in death.

Food irradiation is a safe and cost-effective way of eliminating contaminants in foods. Although some developing countries are using this technology, misunderstandings about the risks and benefits of irradiation are preventing it from being used as widely as it should be in efforts to provide a safe food supply in the developing world.

THE MAGNITUDE AND COSTS OF FOOD-BORNE DISEASE

The magnitude of food-borne disease episodes is such that few countries have the ability to monitor their incidence. The Centers for Disease Control and Prevention in Atlanta estimates that the number of cases of food-borne diseases in the United States is now about 30 percent of the population per year; the rate of food poisoning in developing countries is likely to be considerably higher. The food-borne diseases prevalent in developing countries include cholera, typhoid, salmonellosis, campylobacteriosis, shigellosis, amoebiasis, and E. coli infections. Although the full magnitude of the problem has yet to be accurately quantified, the available statistics show an alarming upward trend.

The major cause of illness and death in infants and children in developing countries is diarrheal disease. Children under the age of five suffer two to three major episodes of diarrhea per year, and almost 70 percent of these episodes result from contaminated food. Chronic aftereffects reduce the nutritional status and compromise the immune systems of these children. The stark statistic is that more than 2 million children under the age of five die each year from ingestion of contaminated food.

The recent globalization of the world's food supply has the potential to contribute to the proliferation of food-borne disease. Food-borne disease organisms move together with traded goods, crossing international borders with impunity. Since these organisms travel with the tiniest particles of dust carried in the wind and are easily swept along international waterways, even the most rigorous quarantine procedures cannot prevent their movement between countries.

In addition to their effects on overall health, the economic and social consequences of food-borne diseases are extremely serious. When factors such as lost labor or income, medical or hospitalization expenses, and other associated costs are taken into account, the estimates run into billions of dollars. The cost of salmonellosis alone was conservatively estimated at more than US$1 billion in 1987 in the United States. Such estimates are only the tip of the iceberg. The value of lost opportunities, ruined futures, and grief due to illness and death are impossible to calculate.

THE DIFFICULTY OF PREVENTING CONTAMINATION

Ensuring the safety of foods requires preventing contamination, which is not as easy as it sounds. Almost all basic food materials originate from an open or exposed environment. Grain, legumes, fruits, vegetables, meat and dairy animals, poultry, and seafood are all produced and harvested in a fully exposed environment or in production complexes that are generally open to the ambient surroundings. As a result they are exposed to all the organisms, harmful and otherwise, that naturally exist in the environment.

Despite efforts to exercise good agricultural practices, raw foodstuffs may still become contaminated with pathogenic organisms, particularly in countries where food animals are not maintained in sanitary conditions and where untreated waste and wastewater is used for fertilization and irrigation. The warm, humid environment of many developing countries is ideal for the growth and proliferation of pathogenic organisms. The poor methods used to handle foods down the food distribution chain further contribute to an increase in contamination.

HOW FOOD IRRADIATION CAN HELP

Food irradiation is a physical process that exposes foods to a highly penetrating form of energy—gamma rays or high-energy electrons. Gamma rays and high-energy electrons can uniformly inactivate the DNA of unwanted microorganisms without changing the basic nature of the treated food. Fresh irradiated foods are virtually indistinguishable from fresh untreated foods, except for the label and in many cases an improved appearance. The gamma rays and electrons used in the process are simply energy, just as heat, light, or microwaves are—they are not particles and therefore leave no residues. Food irradiation does not make foods radioactive.

While some people fear that food irradiation might allow manufacturers to dispense with good manufacturing practices, the contrary is true. Foods destined for further processing require greater attention to quality maintenance throughout the process to ensure that the subsequent value-addition will be realized. The more steps in the process, the greater the possibility for product rejection anywhere along the route. The same fears were originally voiced over the use of pasteurization, yet after almost a century of use, the on-farm quality of milk is higher than ever.

The choice of which irradiation system to employ depends largely on the type of product to be processed, the expected cost, and public concerns. Cobalt-based gamma irradiators have much greater penetration than electron-beam irradiators and are the choice for larger products or pallets. Because cobalt emits gamma rays continually, it has a limited half-life and must be replaced regularly, whether or not it is being used to irradiate foods. Cobalt-based irradiators are therefore most cost-efficient when they are used to irradiate a constant stream of food products on a 24-hour basis.

Electron-beam machines can only penetrate fairly restricted depths (10 centimeters), so they are suited to products that can be conveyed in layers of limited thickness. They can, however, be switched on at will, so they are not as sensitive to throughput considerations as are cobalt irradiators.

Public concern over potential environmental problems is another important issue. Because cobalt is not water soluble, the actual environmental risks associated with operating gamma irradiators are infinitesimally small and the irradiators have an outstanding safety record. Because electron-beam irradiators can be turned on and off like a light bulb, they are currently more acceptable to most communities. In the future, x-ray irradiators will combine the advantages of high penetration and on-off switching.

Food irradiation is a safe process that has been approved by all the international and national health authorities and medical associations and is highly recommended by public health officials all over the world. Purchasing irradiated foods is listed as one of World Health Organization's 10 Golden Rules of Food Safety. It can be used on most fruits and vegetables, meat, poultry, fish, seafood, spices, potatoes, grains, and a host of other commodities. Currently, it is used on spices, certain fruits and vegetables, poultry, and beef in the United States.

Irradiation facilities are not complex and exist in many developing countries throughout Asia and Latin America. As long as there is an infrastructure capable of keeping a plant supplied with sufficient raw materials and services, the operation of irradiation facilities is likely to be financially viable. Depending on the food product and treatment in question, the cost of food irradiation varies between 2 and 6 cents per kilogram—a low price considering the hygienic and health benefits it provides.

OVERCOMING MYTHS ABOUT IRRADIATION

If food irradiation holds such benefits for the consumer, why is it not used more commonly? Semantics has played a major role in the public confusion surrounding the subject of food irradiation. Ever since the first atomic bomb was dropped, we have had a great fear of the word "radiation." The accidents at Three Mile Island and Chernobyl have only heightened this fear.

But while misguided fear may have had some influence with the public in the past, the endorsement of food irradiation by all medical and public health authorities has had an even greater impact. All of the most recent studies carried out by universities and national polling organizations show that current consumer fears of food-borne diseases far exceed any lingering fears of food irradiation. Consumers will purchase irradiated foods, particularly when they are made aware of the improved hygienic quality of the food. The basic lesson is simple—consumers are unlikely to accept any new technology unless they understand the personal advantages it holds.

Food-borne diseases are a serious problem the world over. Strategies to control them that are based on political ideals or "myth-information" will not be effective. To the extent that centralized processing can be carried out on hazardous commodities, food irradiation should be promoted actively wherever possible. Getting rid of pathogens requires killing them before they kill people, and food irradiation is one of the safest and most effective ways to do this. ■

For further information see M. Satin, *Food Irradiation* and *Food Irradiation*, 2d ed. (Lancaster, Pa., USA: Technomic Publishing, 1996); M. Satin, *Food Alert! The Ultimate Sourcebook for Food Safety* (New York: Facts on File, 1999); and M. Satin, *La Irradiacion de los*

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